GIRLS' FUTURE – OUR FUTURE

The Invergowrie Foundation STEM Report

AUTHORS:

Linda Hobbs, Cheryl Jakab, Victoria Millar, Vaughan Prain, Christine Redman, Chris Speldewinde, Russell Tytler, Jan van Driel

This report was developed for the Invergowrie Foundation by Linda Hobbs, Cheryl Jakab, Victoria Millar, Vaughan Prain, Christine Redman, Chris Speldewinde, Russell Tytler and Jan van Driel from the University of Melbourne and Deakin University.

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CONTENTS

List of figures

The Invergowrie Foundation Council

Back row (L-R):
Dr Anne Sarros
Dr Heather Schnagl AM
Dr Susan Stevens
Ms Meg Hansen

Front row (L-R):
Ms Judith Potter
Ms Wendy Lewis
Ms Lisa Ronald

FOREWORD

On behalf of the Invergowrie Council I am delighted to present
GIRLS' FUTURE – OUR FUTURE: The Invergowrie Foundation STEM Report.

Just over two years ago the Invergowrie Council embarked on a journey to realign the Foundation's grant-making process to focus on a specific area of interest that supported the Foundation's mission of advancing the education of girls and women in Victoria.

The Council decided that girls and STEM (Science, Technology, Engineering and Maths) was a high priority. The number of girls undertaking these subjects at school has been declining at an alarming rate, significantly contributing to an under representation of women in careers in these areas.

The Council sought advice and undertook a review of the current issues in STEM education for girls to identify what opportunities might exist for the Foundation to make a contribution in this area.

It was agreed that research was required to provide an overview of what was being undertaken in Australia and globally in the area of STEM and to identify ways to redress the declining numbers of girls undertaking these subjects at school. Following a tender process, a joint proposal from Deakin University and The University of Melbourne was selected to undertake this research project.

The finding of this research is a call to action for anyone who is concerned about this issue. Not only are girls not taking these subjects at school (and therefore not choosing a career in STEM areas) they are not receiving a balanced education.

It has been estimated that 75% of the fastest growing occupations, including those in the creative industries and humanities, will require STEM related skills and knowledge. Critical thinking and problem-solving, analytic capabilities, curiosity and imagination have all been identified as critical 'survival skills' in the workplace of the future.

The implications for not addressing this issue now will have major ramifications going forward. These include a lack of gender balance to align with real world experience, the absence of equal opportunity for all people and a decline in the economic empowerment of women The area of economic empowerment of women is of growing concern in Australia today with many women unable to support themselves in their later years. If girls and women are not encouraged to engage with STEM now they will be at greater risk of becoming excluded from a substantial part of the workforce of the future.

We would like to thank Professor Jan van Driel and the team from Deakin University and The University of Melbourne for all their work on this project. We have also been impressed with the collaborative approach used to combine the talents of two universities to achieve this outcome.

In addition, we would like to thank Marylou Verberne, who has assisted the Foundation in managing this project and Kim Bartlett, the CEO of the Invergowrie Foundation, for her behind the scenes support.

The Council is delighted to commend this report and hope that you find it of value. We also encourage you to join with us to address the issue of girls and women in STEM which, in turn, will lead to a better future for all of us.

Wendy Lewis

Wendy Lewis
On behalf of the Council of the Invergowrie Foundation
10 October 2017


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EXECUTIVE SUMMARY

The retention of girls and women in Science, Technology, Engineering and Mathematics (STEM) is important for both equity and economic reasons. Focusing on girls, from birth until the age they leave school, this report provides an up-to-date look at the reasons why many girls do not pursue STEM subjects in school and STEM careers. Next, the report outlines the most promising ways to address this critical problem. The report is based on a comprehensive review of the international literature, combined with interviews with stakeholders, and followed by two rounds of consultations among representatives from education, governments, and industries.

The study found that the participation rates of girls in STEM education, particularly in physics and advanced mathematics have remained unchanged or declined since the mid-1990s. This trend is similar in many Western countries, but particularly prominent in Australia. The stagnation hints at a problem that is complex. Deeply embedded cultural expectations and traditions are, either overtly or unintentionally, gender-biased and impact on girls' perceptions of, engagement with, and subsequent participation in STEM education. In this study, the following factors were identified as being of critical importance:

- Aspects of home and community, where gendered stereotypes are established and maintained from an early age, with particular pertinence for those in low SES environments.
- Broad public and associated personal perceptions, where media and institutional structures shape both boys' and girls' views of appropriate behaviours and life-paths.
- Teaching and learning environments where teacher expectations and perceptions, STEM curriculum structures, and assessment and selection regimes all act to shape girls', and boys', attitudes and aspirations with regard to STEM.

The present study identified the following interventions and initiatives with potential to improve girls' participation in STEM:

- A focus on early years and primary education to address unconscious biases and teacher lack of confidence and competence in teaching STEM for all, with programs for teachers, parents and carers to sensitise them to stereotyping of girls' interests and abilities in STEM subjects. This is important across the socio-economic spectrum.
- Working with teachers and schools on coordinated approaches to pedagogy and curriculum that encourage all learners, and girls in particular, to engage with STEM.
- Partnerships of schools with industries and local communities, to provide girls with authentic STEM opportunities, including mentoring and industry placement, and engagement with role models who are "everyday" STEM professionals.
- Quality career advice on the diversity of STEM-based career possibilities.

The report concludes that there are gaps in current provision of resources and expertise that need to be addressed through a coordinated and sustained call to action. It calls for more coordinated and sustained action and research on:

- Building strategic and long-term partnerships between schools, communities, industries, and universities.

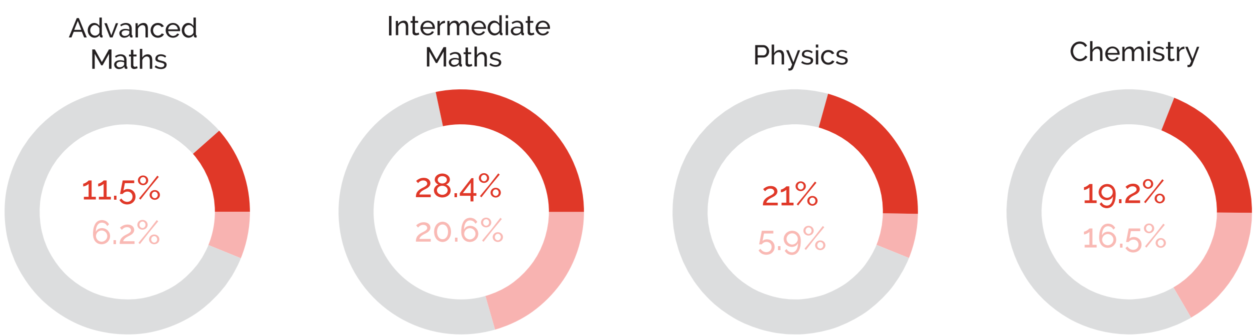
- Compensating the time of teachers (CRT relief) and experts from industries and universities to work together to develop and implement an intervention, aimed to change curriculum content and pedagogies of STEM.
- Developing and enacting programs aimed at young children and their parents, carers and teachers to address unconscious biases and stereotyping of girls' interests and abilities in STEM.
- Research the impact and keep track of specific interventions, finding out what works, how and why, and collating and disseminating these insights (e.g., through a clearing house) to inform stakeholders.
- Managing the organisational and logistical aspects of interventions, and to support special events such as information and career evenings, guest appearances, or special learning experiences.
- Brokering and supporting negotiations between representatives from education and industry and coordinate activities in a region.

1 INTRODUCTION

The importance of Science, Technology, Engineering and Mathematics (STEM) has been emphasised in a range of recent research and policy reports, both in Australia and abroad. STEM is seen as important in providing the knowledge and complex technologies required for a knowledge based society and economic growth. STEM education is seen to be instrumental in developing a set of skills that students need to be prepared for future jobs. There is, however, concern with Australia's performance in the STEM disciplines compared to other countries, both in research and development, and in education.

A recent report from Engineers Australia (Kaspura, 2017) indicated that Australia ranks poorly in global innovation indices. The 2016 reports of PISA (Programme for International Student Assessment) and TIMSS (Trends in International Mathematics and Science Study), showed a decline, or stagnation, in achievement in mathematics and science of Australian secondary school students, especially from lower Socioeconomic Status (SES) groups. In particular, the continued loss of females from some of the STEM disciplines across multiple stages of the education and career trajectory continues to be a major issue (Marginson, Tytler, Freeman & Roberts, 2013; Torok & Holper, 2017). At the school level, significant gender differences remain a persistent issue particularly in physics and (advanced) mathematics (Kennedy, Lyons & Quinn, 2014). From Year 7 onwards, physics and (advanced) mathematics become increasingly unpopular, in particular among girls, with many opting out of these subjects once they are no longer compulsory. The report from Engineers Australia revealed that currently only 6% of the girls in year 12 study physics or advanced mathematics (for boys, these percentages are 21 and 11.5, respectively). Worryingly, these percentages have dropped considerably, for both girls and boys, since the mid-1990s (Kennedy et al., 2014).

Fig 1: Percentage of students undertaking year 12 mathematics, physics and chemistry
Percentage of male (red) and female (light red) students in year 12 advanced and intermediate mathematics, physics and chemistry, 2015.
(copied from Kaspura, 2017, p.36, with permission from Engineers Australia).



Through the last two decades of the 20th century, gender issues in STEM at the school level received much research and policy attention. Recently however there has been a growing realization that the gender issue has slipped off the agenda, with data on girls and women's participation in many STEM areas showing regression in recent times (Marginson et al., 2013). Accordingly, there is renewed concern and policy attention to gender issues in STEM at the national level for education, and more broadly in professional STEM research and development bodies such as Engineers Australia.

The underrepresentation of women in STEM professions is problematic from equity and economic viewpoints. Moreover, a better gender balance is associated with more productive STEM workplaces, and higher quality STEM research (Marginson et al., 2013). Research shows that girls' and women's participation in STEM is influenced by a complex set of factors including gender stereotypes, culture, curriculum, policy, teachers, parents, carers, mentoring and career information (Archer, DeWitt, Osborne, Dillon, Willis & Wong, 2012). Many girls lose interest and motivation to pursue STEM from an early stage of education and this is particularly the case for students in rural or remote schools, students from lower SES backgrounds and indigenous students. Consequently, students from these groups are underrepresented in STEM pathways (Buckley, 2016; Eccles, 2016). The low numbers of girls in physics and (advanced) mathematics is particularly problematic because these are considered the enabling STEM subjects providing access to tertiary level science and engineering courses, and to job opportunities after graduating from such courses. Many initiatives have been instigated, in Australia and elsewhere, to counter these trends. Although some of these have been shown to be successful to different extents in different parts of the world, in most western countries, the under representation of women in certain areas of STEM persists, and the retention and promotion to senior levels of women who have entered the STEM workforce remains problematic (Marginson et al., 2013).

The Invergowrie Foundation is a public charitable trust whose mission is to advance the education of girls and women in Victoria. A recent review of their approach to funding highlighted the importance of a focus on STEM education for girls. Consequently, the Foundation is in the process of developing a STEM Strategy, the first stage of which is the production of a 'STEM Report' that provides a blueprint or roadmap for the most effective ways ahead in leveraging STEM education in Australia at all levels of education, and across all sectors, with a focus on the needs of girls and women. The University of Melbourne and Deakin University were contracted to prepare this report. The investigation was undertaken by a team of eight researchers from these two universities. The methodology was iterative and included a comprehensive literature review, interviews with a variety of stakeholders, and two rounds of consultative panels. The method is articulated more fully in the following section.

2 METHOD

The research team conducted a project consisting of the following steps. First, an overview was constructed of existing and recent initiatives and practices in STEM education particularly in relation to gender participation, in Australia and elsewhere, with attention to their impacts on schools, teachers, parents, carers, and, of course, students. For this purpose, a study of international literature was conducted. The examination of the literature involved a systematic collation of reports, reviews, journal articles and media reports relevant to STEM education, with a focus on gender-related issues. Key ideas emerging from this literature have been synthesized to extract the recommendations from each of these publications, and to identify recurrent themes.

Simultaneously, a select group of stakeholders was identified from a variety of sectors (education, government, industries, and entrepreneurs) with expertise in this field. Nearly all those selected and contacted made themselves available for interview in the timeline of the project. After ethics approval for the project was obtained on 9 February 2017 from Deakin University Human Ethics Advisory Group, team members conducted interviews with 23 individuals between February and April 2017. Except one expert from the UK (Professor Louise Archer), and one from New Zealand (Cathy Buntting), all interviewees were Australian. The interviews were designed to identify the experiences and opinions of experts on ‘what works and how we know’ for girls in STEM. Each interview was approximately of one hour duration and audio recorded. In the conduct of the interviews, each interviewee was encouraged, in their responses to the questions, to recount and expand on their experiences in STEM, STEM education in general and for, with and about girls and women in particular. The list of interviewees is included in Appendix 1; the set of interview questions is in Appendix 2. All interviewees were sent a Plain Language Statement prior to the interview, and returned a signed consent form to the research team.

Based on the literature study and the interviews, a discussion paper was written in April 2017. This paper concluded with six sets of questions that served as input for a two-hour forum with a group of 14 stakeholders from several sectors (industries, universities, schools, government). Participants were emailed the discussion paper a week before the forum. Participants were selected on the basis of their experience with various aspects of STEM education and, in particular, with initiatives aimed to improve the engagement of girls with STEM. Most of them were based in Victoria; three were from interstate. This forum was conducted on 8 May 2017 in the Melbourne CBD. The intent of the forum was to sharpen thinking on the issue of girls in STEM at two levels: first as a broad issue calling for policy and practice recommendations, and secondly in terms of what specific initiatives might be productively supported for a foundation such as Invergowrie. To capitalize on the expertise of the participants, the forum consisted of two interactive activities. During the first hour, participants worked in small groups, and wrote responses to questions, drawn from the discussion paper (see Appendix 3). Next, they read each other’s responses and wrote reactions to these. This procedure (called Collaborative Interactive Discussion;

Redman & James, 2016), then served to start a whole group discussion around themes that emerged from the small group activity. The written forms were collected; notes were taken and audio recordings were made of the group discussions. All participants were sent a Plain Language Statement prior to the forum, and returned a signed consent form to the team.

The data collected during these steps were analysed by members of the team, usually working in pairs, and discussed during meetings of the whole team. Several themes emerged from these analyses. These themes formed the basis of a draft STEM Report (July 2017).

As a next step of the project, this draft report was disseminated and discussed with selected groups of stakeholders (n = 6-10) during workshops at three locations in Victoria (i.e., Geelong, Melbourne, Bendigo; August/September 2017). The workshops aimed to challenge, validate and extend the draft report, by discussing possible gaps in the report, looking for opportunities to strengthen or prioritise issues in the report, or adding recommendations. These discussions were analysed and incorporated in the final version of the report.

3 ANALYSIS OF FACTORS THAT IMPACT ON STEM ENGAGEMENT

The present study identifies a variety of factors that impact for students, generally and for girls in particular, on their perceptions of, engagement with, and subsequent participation in STEM education. These factors range across aspects of home and community, broad public and associated personal perceptions, teaching and learning environments and school culture, and systemic factors shaping interests and choices. Both the literature and the participants in this study highlighted how deeply embedded cultural expectations and traditions within STEM education are, either overtly or unintentionally, gender biased. This bias continues to impact negatively on the formation of girls' attitudes, identity, and self-efficacy beliefs with respect to STEM, particularly the physical sciences, and mathematics.

Similarly, the literature dealing with interventions targeted at increasing participation and engagement in STEM education is diverse. It ranges from a focus on system wide public awareness, through education curriculum policy change and national projects, to targeted context-sensitive interventions in teacher learning, curriculum development, or special initiatives such as mentoring and industry-related experiences. The factors influencing take up of STEM have different impacts and profiles at different points along a life trajectory. Thus, even the same type of intervention will look different for different age groups, and can lead to different outcomes.

In this chapter, we will first address the compounded nature of the problem, by unpacking the ways in which different factors impact on engagement with and participation in STEM. Following this, in chapter 4, we will discuss interventions and initiatives that have demonstrated potential to increase participation and engagement. First, however, we comment briefly on the notion of STEM education.

In recent years, across Australia and worldwide, the exposure of students to STEM experiences and encouragement to pursue STEM careers is considered an educational priority. The strong policy message consistently permeating the media and policy statements is that more STEM graduates are needed for a competitive future. The creation of the notion of STEM (Science, Technology, Engineering and Mathematics) in the late 1990s represents an approach that could, and sought to, connect science and mathematics disciplines with the more entrepreneurial design and product-oriented fields of engineering and technology. It appears that currently there is not, and perhaps there cannot be, a single definition of neither STEM, nor STEM education. Any consideration of engagement with STEM pathways must therefore include separate consideration of the different school subjects, disciplines and professions within the STEM policy framing.

The leaky pipeline metaphor has dominated policy talk and public debates on the supply of a STEM workforce. This metaphor presents a picture of a continually decreasing supply in STEM related fields: at various stages of their educational careers, but also during their working life, individuals choose, for a variety of reasons, to discontinue their participation in STEM. This drop out occurs for both males and females, however, the leaky pipeline is often used specifically to describe the low participation rates of females in male dominated fields, particularly in engineering, IT, mathematics and physics. The leaky pipeline metaphor has also been used to describe the low representation of women in leadership positions, including in STEM related occupations. In Australia, and worldwide: women who do pursue a career in STEM related fields are more likely to leave the field than their male counterparts and are less likely to rise to higher and executive levels within STEM fields. There have, however, been criticisms of the metaphor in that pathways through STEM subjects and jobs can be complex rather than linear, with multiple entry and exit points (Mendick, Berge & Danielsson, 2017; Tytler, R., Osborne, Williams, Tytler, K. & Cripps Clark, 2008).

"Children as young as six have been shown to associate science with males"

There is a significant gender disparity in participation in STEM studies and professions in Australia, however, there are substantial differences in this disparity between STEM disciplines. The representation of women in areas such as mathematics, statistics, engineering, computer and physical sciences is low when compared with male representation, and continues to be of particular concern (Forgasz, Leder, & Tan, 2014). However, in health and life sciences, such as biology and in medicine, females continue to outnumber males.

3.1 Society and culture

There is a broad consensus in the literature and among the participants in this study that while girls perform equally well as boys in maths and science, a complex range of factors contribute to the decline of girls' participation in school science and mathematics in senior secondary education. In the literature and in our interviews and consultations, social and cultural influences were seen to be major influences on girls' attitudes and self-efficacy, leading to their underrepresentation in subjects such as (advanced) mathematics, physics and computer science.

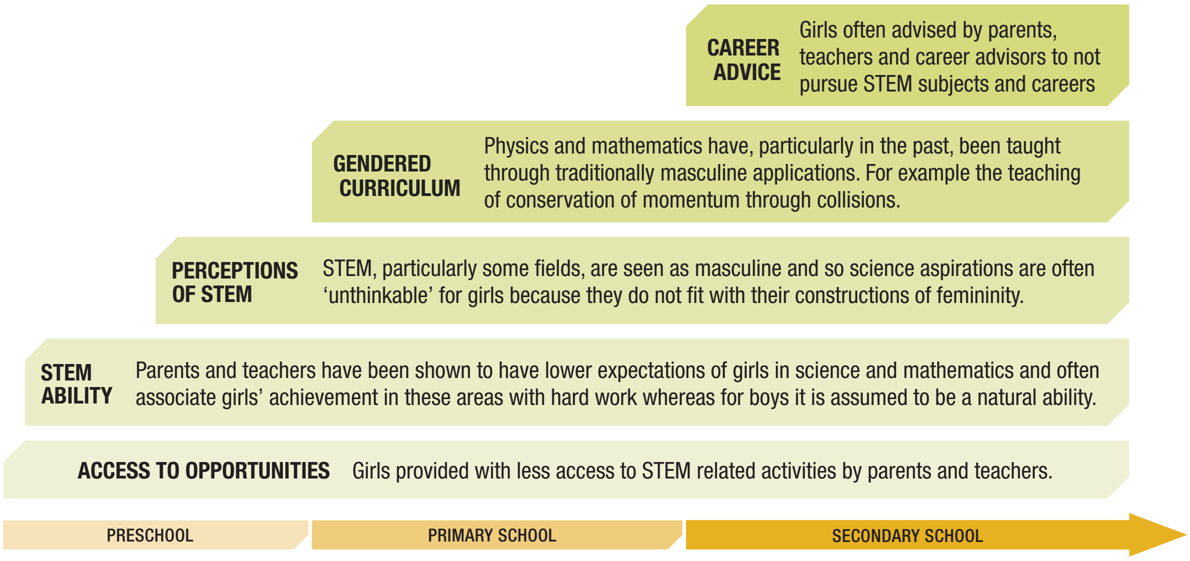
"Girls and boys at pre-school age as well as primary and secondary school are exposed to different gendered experiences by their parents, carers, and teachers"

The nature versus nurture debate continues to play a role in discussions about gender participation in the STEM fields. It is present in both explanations of gender disparity and solutions to disparity. What we know is that research has repeatedly shown that the development of children and the sex differences we see in social roles and occupation are "constructed from the complex and dynamic interaction" between the environment in which a person grows up and is exposed to (social and cultural influences included) and their biology (Fine, 2015, p. 1738). Neuropsychology has identified that the construction of gender, as opposed to biological sex, is influenced by social stereotypes and norms and becomes "part of our cerebral biology" (Kaiser, Haller, Schmitz, & Nitsch, 2009, p. 57). A study by Cvencek, Meltzoff and Greenwald (2011) investigated the way gendered self-concept developed in young children and became associated with 'girls don't do maths' stereotypes prior to ages at which there are actual differences in maths achievement. These studies align with views that have long been argued in feminist theorisations of identity that gender is performative (e.g., Butler Kahle, 1990; 1993) and socially constructed. Girls learn to act in certain ways that are socially acceptable. The social world to which girls are exposed from a very young age plays an important role in forming their identity, their views of what it means to be a girl, as well as their aspirations (Baxter, 2017).

Children as young as two have been shown to develop an awareness of gender identity and "play an active role in their own gender development" (Fine 2015, p. 1741). For STEM, this has important consequences. Many STEM areas continue to be male dominated and research over a long period of time has shown that many of the STEM fields where women remain underrepresented are viewed as masculine. Indeed, children as young as six have been shown to associate science with males (Hughes, 2001). This pervasive alignment of STEM (particularly the physical sciences, engineering, and mathematics) with masculinity, through the myriad cultural practices of sciences in society, creates an identity gap that prevents many girls — particularly those from ethnic minorities and lower SES backgrounds—from identifying with science (Tan, Calabrese Barton, Kang & O'Neill, 2013). The lower likelihood of girls and women pursuing STEM related careers can be associated with, and appears to be influenced by, lifelong traditional gender stereotyping. What it is to be 'a girl' and how girls are encouraged to be 'in the world' is constrained and directed by cultural stereotyping in experiences from an early age. In this world being a girl and a woman is often depicted in opposition to being 'good at maths' or 'science-interested'. Many girls express science aspirations as 'not for me' (Archer, DeWitt, Osborne, Dillon, Willis & Wong, 2013). Identity researchers claim that science aspirations are largely 'unthinkable' for girls because they do not fit with either

Fig 2: The negative influences of sociocultural norms and gender bias on girls' STEM participation

Taken up by students, parents, teachers, career advisors and society more broadly, sociocultural norms and gender bias impacts negatively on the formation of girls' attitudes, identity, and self-efficacy beliefs with respect to STEM, particularly the physical sciences, and mathematics.



their constructions of desirable/intelligible femininity nor with their sense of themselves as learners/students. Science careers are seen through a set of male/female dichotomies such as 'clever' or 'brainy' against 'nurturing' and 'geeky'. These dichotomies contrast girls' self-identifications as 'normal', 'girly', 'caring' or 'active'.

Girls and boys grow up in a world where social stereotypes and norms effect the experiences they are exposed to. These experiences are often based on assumptions about girls' interests and abilities (Polavieja & Platt, 2012). Research shows that parents, carers and teachers have different expectations of boys and girls, of biologically based gender differences in learning styles, and in relation to profession choices (Bamberger, 2014). This leads to boys and girls at pre-school as well as primary and secondary school being exposed to different gendered experiences by their parents, carers, and teachers (Alexander, Johnson & Kelley, 2012; Archer et al., 2012). The parental environment, arguably the most important setting outside of school in shaping student identity and beliefs, is seen as reinforcing of gender stereotypes and norms (Adamuti-Trache & Andres, 2008; Wang & Degol, 2013). Parents have been shown to expose boys to more science related toys and outings and tend to overestimate boys' maths ability and underestimate that of girls (Eccles, 2016). Also, if girls achieve less well, this is often associated with 'being a girl'. These results are similar to those within the school environment where the presence of teacher unconscious bias and gender stereotyping has also been identified (Butler, 2016). To be treated as successful in the school and in the workplace, girls and women typically need to achieve better than males (Spearman & Watt, 2013; Wennerås & Wold, 1997).

Collectively, the literature and the participants in the present study, show the deeply-ingrained take-up of socially and culturally-shaped identities by children, parents, carers and teachers, and how these have constricting effects on female career aspirations and subject choices around STEM. Pulling apart and addressing the complex range of influences on girls' identity formation and their science aspirations, therefore, requires a deep consideration of the assumptions society makes about girls from a very young age and the kinds of differentiated experiences that are provided for girls and boys from early childhood through to adulthood.

3.2 Curriculum and pedagogy

The research literature presents two main reasons for promoting STEM education, for all, and for women in particular, by distinguishing between 'pre-professional training for some' and 'scientific literacy for all' (Millar, 2006), which are labelled as Vision I and Vision II by Roberts and Bybee (2014). In other words, to encourage students, both male and female, to pursue STEM must be seen as a duality: it serves the need to open up career opportunities and training for STEM professions, and also the need for citizens to develop the STEM skills and knowledge needed in so many non-STEM occupations or in dealing with decisions in personal life. In many countries, a balance is sought between a focus on STEM literacy for all students, for disadvantaged groups, and for elite students (Marginson et al., 2013). Vision II is aimed at influencing the broader population including low SES and other disadvantaged groups. It is argued that there are many STEM pathways that can be associated with non-elite curriculum purposes.

"At primary and secondary school, test scores in science show girls having equal or greater success rates compared with boys [however] girls express feelings of being less capable than boys and tend to under-participate in science classrooms."

Schooling experiences have been shown to play a key role in the development of students' interest and self-concept in science (Pintrich, 2003) and in mathematics (Walkerdine, 1998). Self-concept can be seen as a "person's self-perceptions that are formed through experience with and interpretations of one's environment" (Marsh & Martin, 2011, p. 61). This relates to students' subjective belief about their own ability in an area. Vincent-Ruiz and Shunn (2017) claim girls' competency beliefs are an essential foundation for science content learning during middle school and how these effects of competency beliefs are mediated by in-school and out-of-school factors.

For many decades, researchers have broadly recognized that science curricula, particularly the physical sciences, and mathematics curricula reflect their masculine disciplinary origins, and have struggled to interest or be valued by many girls (Baker & Leary, 1995; Calabrese Barton & Brickhouse, 2006; Calabrese Barton, Tan, & Rivet, 2008; Haussler & Hoffmann, 2002). The masculine origins of these subjects are evident in a focus on agentic power, competition in the history of breakthroughs and in the character of explanatory theories about nature (Haraway, 2013). This cultural history of fixed gendered identities expressed through disciplinary boundaries plays out in 'exemplary' curricular topics in science and mathematics. For example, force and motion were for a long time presented only through traditionally masculine examples. On the other hand, a wider range of learners, inclusing many girls, are perceived to be drawn to 'caring' versions of the curriculum, rather than technical aspects, such as the social purposes of science, and discussion of ethical aspects (Schreiner, 2006). Lengthy histories of 'hard' and 'soft' subjects reinforce gendered accounts of the curriculum, and the gendered attributes claimed as necessary for success in different subjects. Such assumptions about what draws individuals and groups of different genders into various STEM areas may in fact be reinforcing gender stereotypes associated with particular aspects of the sciences, technology, engineering and mathematics.

Pedagogical factors refer to how STEM subjects are taught. Typically, the experience of girls differs from those of boys. This includes both the opportunities provided by teachers and the assumptions teachers make about student interest and ability. Teachers often unwittingly dissuade girls from engaging with science, reinforcing gender stereotypes (Kelly, 1985), communicating both explicit and implicit lower expectations for girls, and failing to recognize girls' science and mathematics competence and expertise (Carlone, 2004; Tan et al., 2013; Warrington & Younger, 2000). On the other hand, girls and boys appear to perform better in STEM subjects when teaching strategies address the learning needs of individuals, and when teachers express high expectations regardless of gender. It appears that many teachers have a lack of knowledge about, or lack the skills to apply more supportive pedagogies and approaches that are likely to engage students' diverse interests and needs, such as those involving more nuanced discursive resources. This lack of expertise, which was confirmed by participants in this study, in practice, leads to the application of default pedagogies that may be less sensitive to the needs of individual learners, girls as well as boys. Teachers also tend to place greater emphasis on performance mastery, reflected in assessment regimes that typically favour an 'only one answer is correct'

approach to STEM subjects. This approach seems to be discouraging, especially so for many girls. Also, it conflicts with STEM reality where genuine problems are usually ill-defined, and allow for multiple solutions, of which the pros and cons need to be considered before an eventual decision about practical solutions can be made. Allied to this need for teachers to be helped in developing pedagogical strengths for individualised learning, participants in the study emphasised the need to support teachers in developing strong content knowledge in STEM.

Teachers have been shown to provide boys with more science-related activities in the classroom (Alexander, Johnson & Kelley 2012). This results in boys achieving a greater understanding of science topics, more praise from teachers, and a higher overall self-concept (Reis & Park, 2001). Girls on the other hand, oftentimes have less exposure to science activities and report a weaker self-concept, even in those who achieve equally well as boys. Teachers have also been shown to be more likely to attribute girls' success in the physical sciences and mathematics to hard work whereas for boys, they perceive achievement as being due to natural talent (Carlone, 2003; Tytler et al., 2008). There is also evidence of gender bias in different forms of assessment, with some evidence that assessment by formal examination favours boys over girls (Stobart, Elwood & Quinlan, 1992).

In the context of gender–math stereotype threat, traditional oppositions align masculinity with natural ability, real understanding, rationality and reason, and femininity with hard work, rote learning, irrationality and emotion (Mendick, 2005). For example, the idea that 'girls are not good at maths' identifies maths as a male pursuit. However, this idea is now challenged since girls are achieving in school mathematics as well as boys. Nevertheless a stereotypical 'masculine' view of maths as being more important for boys is still in evidence (Clark Blickenstaff, 2005; Forgasz et al., 2014).

In this context, it is important to note the overwhelming evidence that differences in participation rates and attitudes towards science and mathematics do not result from biological factors (Ceci, Williams & Barnett, 2009). Recent studies provide clear statistical evidence of significant gains having been achieved in female's early academic success in STEM fields, however there continues to be "a clear disconnect between girls' science achievement and their desire to pursue

STEM careers" (Tan et al., 2013, p. 1144). In the primary and secondary school levels test scores in science show girls having equal or greater success rates, when compared with boys, but this achievement is not associated with an accompanying identification with the subject, with girls expressing feelings of being less capable than boys and tending to under-participate in science classrooms (Spearman & Watt, 2013). Similarly, girls with high scores in high level mathematics are less likely than boys with lower scores to be encouraged to take highest level maths. Girls, statistically, do not see themselves going on with (physical) sciences, even those with successes in test scores (Archer et al., 2013). A particular concern in the research literature and in the interviews and forum discussions is that females continue to express and enact lower self-efficacy in STEM subjects than indicated by their achievement levels in tests, in comparison with male counterparts, who tend to overestimate their abilities. There is evidence that boys are also more likely than girls to be encouraged by teachers, parents, carers, and career advisors, to go on with STEM related subjects, particularly the higher level mathematics subjects and physics, even in high achieving groups.

3.3 Partnerships

A key to engaging girls in STEM is making connections between school and their lives beyond school. Positioning STEM as being integral to their general lives and their world of work is critical if young people are to appreciate the need to engage with STEM subjects in school, or if they are to consider following STEM pathways into Vocational Education and Training (VET) and higher education avenues. Connections can be made in multiple ways between the usefulness of the curriculum delivered through STEM subjects and this 'future world of life and work' beyond school: by teachers using contexts taken from students' current and future lives and from industry, by special programs that make these direct links through industry links with schools, and through externally delivered experiences that expose students to a range of practices, industries and role models.

Underpinning these proposed experiences is the desire to make schooling relevant. Darby-Hobbs (2013) stated that "[A] relevance imperative arises out of a push to reframe curriculum and pedagogy in ways that ensure that students' experiences at school are relevant to their lives and perceived needs" (p. 78). Newton (1988, as described by Darby-Hobbs, 2013) described several aims associated with relevance, all of which are pertinent to understanding the purposes of connecting students with STEM practitioners from industry and the community. These aims set the tone for a variety of experiences that can emerge through partnerships around school-industry/community links, as indicated in the following:

- Moral aims are concerned with empowering people in their choices, so exposing students to STEM careers and possibilities potentially empowers girls to make informed choices in their current and future lives. Exposing students, teachers and parents/carers to different career options involving science and mathematics, and different role models from industry and the community, can underpin experiences that are focused on empowering students.
- Contextual aims are concerned with placing STEM in broader contexts so that students see the applicability of what they are learning in schools to life beyond school. Industry-based problems or industry scenarios can provide interesting contexts for learning, especially when industry and community representatives are part of the learning experience and the learning outcomes are linked to the curriculum.
- Philosophical and epistemological aims are concerned with highlighting STEM practices in order to present an appropriate image of the nature of STEM-related ways of knowing, inquiring and applying to practice. A focus on twenty-first century technology is critical here. Exposing students to the work of both male and female scientists, mathematicians and engineers, or giving teachers industry-based placements can serve to highlight the nature and purposes of the work and types of knowledges and skills and attitudinal orientations needed.
- Psychological aim**s** are concerned with experiences that are considered relevant to students themselves and which offers motivational value. Re-engagement of students in school through STEM is often mentioned by schools as a rationale for engaging with industry partners or contemporising the curriculum. In relation to girls in STEM there are strong identity implications of exposure to role models of female STEM practitioners.

Interview data highlighted the many benefits associated with engaging with industry. Industry can, for example, provide passionate people who believe in what they are doing, activities and project briefs that can be aligned with the curriculum and access to technology and equipment. This provides students with exposure to a variety of role models, types of work and jobs, and applications of school knowledge. However, interview data emphasised that there is currently no coherent or coordinated approach to the outreach and STEM programs that are offered by various groups. Alongside this, short term initiatives can lead to disconnection and often results in initiatives having no systemic impact beyond the project period. As pointed out by participants in the forum and workshops in this study, schools and industries are different worlds, each with their own purposes and cultures. Taking students into workplaces has its own challenges, including restrictions to the number of students who can be taken into workplaces, and consideration of legal barriers for people under 18 to engage with workplace experiences.

However, while there may be challenges associated with these types of experiences, they can provide a range of potential benefits, including increased general levels of STEM literacy. Across the board, there is a need to provide role models to students, both male and female, and engage them in practices that introduce them to the prospects associated with being part of the next generation of STEM professionals.

3.4 Career aspirations

Gendered aspirations and career interests develop early. By the time career education occurs in schooling, most children have already constrained their thinking towards what they see as possible in their lives. Children's career aspirations are closely linked to their SES grouping. A study of Rural Youth Aspirations (Redman, Anderson, Cooper and Bottrell, 2014) conducted across school communities in country Victoria showed that contact with members of professions was influential in directing children's interests early in life. Notable in this study is that these primary school students voice early consideration of what careers they might want to aspire to and work towards. The knowledge they express is based on local knowledge and the extent of their contact in the wider community, and with a range of other people who may have been involved in that career path. Increasing aspirations in STEM in primary education, or even earlier, is vital as career aspirations appear to become rather fixed during the middle school years (Archer, Moote, Francis, DeWitt, & Yeomans, 2017).

How girls relate to a potential career in STEM also affects their participation in and choice of subjects at school. Many girls do not see career paths for themselves in science (Archer et al., 2012). Stereotypes of what exactly a career in STEM might entail and who scientists, engineers and other STEM professionals actually are, create significant disincentives for girls to become interested in and pursue study and careers in STEM fields. STEM fields tend to be perceived by students as masculine. This is revealed in the 'Draw a scientist test' that is often used to investigate students' understandings and images of science, identifying several key stereotypical characteristics that students have learnt to associate with scientists (Chambers, 1983). As noted by Butler (2016), current models of career guidance exacerbate the problem by ignoring gender, and thus discrimination is, often implicitly, inherent in much career advice.

Students have also been shown to be influenced by what they believe are typical teacher characteristics of a particular subject. These perceptions do not play a role on learning outcomes so much as on student attitudes towards that subject (Kessels & Taconis, 2011). For many students, their science and mathematics teachers are the closest link they have to someone who is working in a STEM profession. While of course there are many differences between working in a STEM industry and as a STEM educator, one study undertaken in the Netherlands and Germany found that most students thought of a man when describing a physics or mathematics teacher. Also, these students believed a teacher of the physical sciences to be more intelligent and motivated, however, a science teacher was also considered to be less attractive, socially competent and creative than a typical language teacher (Kessels & Taconis, 2011). Students who perceived themselves as having similar characteristics as a typical physics or mathematics teacher were more likely to pursue study in these areas. Interestingly, however, there is little evidence to suggest that the gender of a teacher influences girls' or boys' decisions to pursue study in that area (Kessels & Taconis, 2011; Martin & Marsh, 2005).

Despite significant gains, gender stereotyping and perceptions about subjects and career options 'suitable' for young women are often still reinforced in schools and families. Nationally in Australia, and internationally, cultures of many STEM-related professions show traditional differences in employment patterns for men and women. There is substantial evidence about barriers in the workplace that constrict women's careers, and sometimes even cause them to leave their profession. For instance, male dominated workplaces in IT or engineering are often not very welcoming or supportive for women (Barnett & Rivers, 2017). These patterns can impact negatively on the career choices of young women and result in barriers that are increasingly shown to be impacting on young women's participation in STEM and non-traditional occupations (Butler, 2016). Arguably these workplace gender issues inevitably feed back into girls' choices through word of mouth, or experience of the nature of workplaces.

3.5 Taken together

The combined impact of the factors discussed above is relatively predictable. Girls show less positive attitudes to the physical sciences and mathematics from early primary school years onwards, and they tend to consider these subjects as being for boys even though girls achieve equally well (Scantlebury & Baker, 2007; Scantlebury, 2014; Schreiner, 2006). In particular, boys demonstrate a more positive attitude and greater confidence in these subjects than do girls (Ceci, Williams & Barnett, 2009). Therefore, long before the age when students can opt-out of science and mathematics subjects, in late secondary school, girls are reporting negative feelings towards science, as being not for them and as alienating for them (Adamuti-Trache & Andres, 2008).

Attitudes towards science and mathematics are an important concern in considering the under-representation of girls in STEM because they have been shown to be a strong predictor of career choices (Eccles 2005; Watt, Eccles & Durik, 2006). Studies in secondary Australian education have found that student attitudes and career aspirations, in particular, in the early secondary years are critical in determining engagement in tertiary level science courses. This research showed that girls are less positive about STEM study and that there appears to be a connection between early attitudes and the propensity to pursue study and careers in these fields. The formation of attitudes towards science and mathematics are strongly linked to students' self-concept and interest (Taskinen, 2013). The link between interest and having a positive attitude toward a particular subject area, typically leads to motivation and enjoyment for that area, and its pursuit in the post compulsory years. However, the research evidence demonstrates that girls and women, in particular those from minority groups and disadvantaged backgrounds, are confronted with multiple barriers throughout their life course, from lack of encouragement by parents, unconscious biases from teachers, to inequitable practices in workplaces.

4 AN OVERVIEW OF PROMISING DIRECTIONS

Researchers over the last two decades have identified the need to change what and how girls experience learning in science, technology, engineering and mathematics. Several intervention strategies claim to effectively increase female participation in these subjects. These strategies are discussed below, according to how interventions may target different aspects of the problem.

4.1 Identity work

Cleaves (2005), in exploring student choices using an identity framework, showed that the self-perceptions of students' ability combined with their life aspirations, drive their decision making in opting into or out of STEM related subjects. Identity is sometimes taken as fixed or intrinsic. However, according to Mendick "identity work sees people's identities, not as intrinsic and essential but as active accomplishments, neither fixed nor singular but multiple and fractured, and as coming into being through talk, actions and relationships" (2005, p. 165). Calabrese Barton, Kang, Tan, O'Neill, Bautista-Guerra and Brecklin (2013) argue that "girls view possible future selves in science when their identity work is recognized, supported, and leveraged toward expanded opportunities for engagement in science" (p.37). Reconfiguring meaningful participation in science, according to that study, involves doing this identity work through the life-course, and notably from an early age.

This message is consistent with a major finding from the interviews, workshop and forum discussions in this current project. The main storylines identified in the current study highlight the need to start early with tackling the pervasive unconscious biases in the ways that girls are experiencing their STEM learning and supporting greater variety of identities and how 'girls' can be in the world. Strong messages of 'girls can' and 'need for a safe place to try' were voiced in interviews, workshops and forum discussions in this study. From early years, all children need encouragement to consider a diverse range fields, rather than being restricted by socio-cultural stereotyping. In an experimental study in the United States, Master and Meltzoff investigated the effects of an intervention aimed at providing girls with positive experiences in STEM by changing the physical classroom environment. They demonstrated that this intervention "can increase and equalize motivation and engagement in STEM for both boys and girls" (Master & Meltzoff, 2016, p. 215). In another study, they found that first grade girls who were given an experience with programming a robot reported increased interest and self-efficacy in technology (Master, Cheryan, Moscatelli & Meltzoff, 2017). Strategies to help parents and carers be aware of gendered assumptions and unconscious biases in their treatments of their children, both girls and boys, can help to expand the range of options for each individual child. Expanding from gendered expectations and aspirations can be particularly problematic in disadvantaged and isolated communities. When the home language fits with STEM ways of thinking the identity work towards taking on a more positive STEM attitude is made easier.

As discussed in the previous chapter, ideas about STEM develop at early ages, and unconscious bias of, and gendered stereotyping by teachers and parents/carers, impact importantly on children's self-concept and identity formation (Chapman & Vivian, 2016). However, children's patterns of identity formation and self-efficacy over time show differences between science and mathematics, with many students seeing themselves as 'not good at' mathematics in the early primary school years. In science, the identity is more positive in early and primary years, with a sharp drop in attitudes across the middle secondary school years. Therefore, experiences through the early to middle secondary years can be crucial in maintaining interest and confidence with sciences, leading to points of choice of direction at ages 15-16 (Tytler, 2014). There is also evidence in the literature, and from the participants in this study, that for a girl, or any student, to maintain an interest in and commitment to STEM across the secondary school years, each individual needs to have ongoing positive experiences and measures of success that will reinforce and develop their identities in relation to STEM futures. According to Cleaves (2005), whose study focused on years 9-11, the early secondary years and the transition into senior years with subject choices influenced by a range of factors, are key points of influence.

"Participants in this study proposed moving away from presenting STEM through delivery of abstracted concepts towards STEM as involving problem solving and real-life issues as a way to engage students."

Strategies to increase aspirations must include all stakeholders, particularly parents, carers, teachers and children themselves (Bamberger, 2014). The tight link between girl and 'feminine' human attributes and boy and 'masculine' human attributes, needs to be challenged and modified in interventions to reflect a continuum of possibilities, encouraging all children to develop skills in areas of interest. Learning how to participate fully, develop interests and be positively motivated towards the wide range of human skills, attributes and activities is necessary for individuals to do their own 'identity work' and develop positive self-concepts. Working on influencing and breaking down traditional stereotypes, that is, nurturing diverse identities is recommended. Central in these endeavours is supporting girls to see the benefits of STEM in expanding their possibilities.

4.2 Educational opportunities

Historically the school science curriculum has been skewed to reflect boys' interests. While Marginson et al. (2013) highlight the need to develop content, pedagogy and resources suited to girls' preferred ways of learning, reflecting the identity needs of these students, attempts have been made to make curricula more gender-neutral and cater for what is perceived by some as girls' interest in more caring and contextualized forms of learning (for example, recent moves to make the Victorian Physics Curriculum more context-based). This comes with a risk of reinforcing stereotypes. Maybe we should reconsider researching these gender-based assumptions about how students learn and what they are interested in. Questions were asked in the workshops about whether girls and boys learn differently, or whether this generalization itself needs further study. As with stereotypes, such as race and other groupings, the variety within groups can be greater than between groups. Many of the desired changes in pedagogy and curriculum could benefit all students in individualising and personalising their learning opportunities. In any case, given the variety of student responses to STEM curricula and pedagogies, including gendered responses, there is a need to offer a range of topics activities, and pedagogical styles in any STEM subject,.

Participants in this study repeatedly pointed to the importance of teacher expertise. They advocated that teachers need ongoing support and time to develop their pedagogical repertoire and stay up to date with developments in the STEM disciplines. DeJarnette (2016) has stressed the need to change teacher education. STEM approaches such as scientific inquiry, problem-based learning, engineering design and technological activities should be part of every program for primary and secondary pre-service teacher education, thus increasing graduates' confidence in adapting existing curricula to incorporate pedagogies and activities that have been shown as interesting and relevant to diverse students, including both girls and boys.

Participants in this study proposed moving away from presenting STEM through delivery of abstracted concepts towards STEM as involving problem solving and real-life issues as a way to engage students. Research literature confirms that the attitudes towards STEM, of both girls and boys, are improved through more student centred, inquiry based pedagogies (Kim, Suh & Song, 2015). In a review study, Murphy and Whitelegg (2006) found "significant evidence that a context-based or humanistic curriculum increases students' motivation and enjoyment of physics, especially for girls" (p. 20), and emphasised the importance of the teacher-student relationship, particularly in physics "where girls' self-concept is less positive relative to boys" (p. 24). The participants in this study also suggested that STEM should be presented as a human endeavour, and

that more attention needs to be paid to relations with professions and other subjects (medicine, arts, new technologies and innovation). This would be consistent with the Australian curriculum. Also, there was a call for more space in the curriculum, time and resources for research and design activities, including data gathering and drawing conclusions, innovation and invention, to emphasise that problems in STEM typically have many possible solutions as compared to 'one right answer'. However, difficulties for teachers of senior secondary students, in balancing these novel approaches and student needs for high scores, creates problem that requires a response that supports teachers, parents, carers, and students. External demands of achievement in assessments (such as NAPLAN and ATAR scores) can act as a barrier to involvement in more motivating and real-world problem-solving approaches.

Chapman and Vivian (2016) also point to the value of promoting STEM engagement through providing real world experiences, with links to industry and extension programs such as mentorships. They claim that effective messaging can attract girls to consider STEM and help them envision themselves as STEM professionals. Effective messaging strategies from marketing through to role model interactions are proposed. Access to carefully selected female role models working in STEM, and mentoring, is a pervasive strategy that can break down gender stereotypes and support girls in STEM work, at many levels of schooling (Marginson et al., 2013). For example, Massachusetts Institute of Technology (MIT) achieved almost gender parity in undergraduate engineering by applying a mentoring strategy that led to a cultural shift "sparked by many small changes and the support of key allies on campus" (O'Leary, 2017).

There has been much research about whether single-sex learning environments better encourage girls to pursue STEM (Harker, 2000; Kessels & Taconis, 2011; Schoon, 2001; Thompson, 2003) with some research showing a positive effect (Archer, 2016; Haussler & Hoffman, 2002), while others report none (Rodrick & Tracy, 2001). The possible benefits of single sex schooling are often linked to reducing the different ways in which teachers interact with girls and boys, assessment bias and how content is presented, as discussed above. Additionally, negative interactions between boys and girls in a co-ed classroom environment are removed (Hattie, 2002). Chapman and Vivian (2016) claim that offering girls-only experiences and learning spaces provides

the opportunity for girls to be empowered and feel comfortable to question, experiment and lead in STEM. By structuring these safe environments, girls are more willing to try and experiment with STEM.

One study by Kessels and Taconis (2011) explored whether girls from single sex learning environments were more likely to have a positive self-concept and aspire to a career in science. This study found that girls in single-sex classes did have a better self-concept in physics and mathematics, both subjects currently perceived as masculine fields, due to gender-related self-knowledge being less prominent once the opposite sex is absent. This idea of engagement with subject being tied to gender identity is illustrated by studies of young women working in mathematics (Pronin, Steele & Ross, 2004) and physics (Archer et al., 2017), who disassociate themselves from feminine stereotypes. The teaching of single sex classes, however, is not recommended by other studies, without a deeper understanding of gender-equitable teaching behaviours (Rodrick & Tracy, 2001). There is also the possibility that single sex education may defer rather than counter problems of deep-seated cultural biases about gendered capabilities. Further, removing boys from the equation in girls' education, runs the risk of failing to address, and perhaps exacerbate, the other half of the cultural problem. Boys also need exposure to strong female role models in STEM. A study by Hughes, Nzekwe and Molyneaux (2013) found that it was not that one setting (single sex or co-educational) was more effective than the other, rather it was the type of pedagogy used that determined the results, againstressing the critical role of the teacher. Pedagogy must be part of the larger debate regarding the benefits and drawbacks to single sex and co-educational programs, particularly as it relates to adolescent girls' STEM identity (Hughes et al., 2013).

4.3 Partnerships and career aspirations

The *STEM Programme Index* (SPI) by Australia's Chief Scientist (2016) identified 266 programmes, 120 of which involve STEM industries, businesses or community groups. The follow up document *Strengthening school-industry STEM skills partnership* (Australian Industry Group, 2017) analysed the SPI and concluded that given the broad range of initiatives already on offer, the focus should be on upscaling the more successful models rather than introducing more. The document concluded that "it would be beneficial to focus on school-industry initiatives that are integrated into the school curriculum and have achieved some degree of systemic support" (p.21). Further, teacher professional development as a component of school-industry programs was identified as key to their success.

Several participants in the present study signalled the possible gains for girls, with industry seen as an 'untapped resource'. A growing number of initiatives that focus on programs specifically for girls involve STEM industries or companies. Many of these are aimed at girls in senior secondary school, when they face the choice of whether to continue with post-compulsory STEM subjects as part of their senior secondary certificate. Such initiatives may also influence girls' ideas about higher education and future careers. For example, Ash (2009) reported on an amply funded after school program in the United States involving the *Girl Game Company* where girls simulate a gaming company. Other examples of experiences involving industry partners tailored for girls include: tailored learning experiences (such as the Geelong based program *Girls Leading in Advanced Manufacturing*), camps (Hughes et al., 2013, Levine, Serio, Radaram, Chaudhuri & Talbert, 2015), clubs (Prives, 2015), and mentoring programs (Stoeger, Schirner, Obergriesser, Heilemann, Laemmle & Ziegler 2016; Watermeyer, 2012). In assessing the value of STEM camps for girls, Hughes et al. (2013) noted that the length of the camp, the diversity of participant scientists and engineers, and educational theories behind the activities were important to a camp's overall effectiveness.

The point has been made, in the literature and the interviews, that exposure to the human aspects of practice in STEM industry and Research and Development (R & D) through partnerships can engage and motivate both male and female students to consider studying and having a career in STEM. This is particularly pertinent to engaging girls with STEM through contact with strong female STEM practitioner role models. Three different categorisations of partnerships based on their form and nature, rationale for involvement, and their reach or scale could be used to inform a framework for considering applications for funding (see Appendix 4). Transformative partnerships, locally or regionally organised, seem most appropriate for in-depth and longer term approaches to engaging girls in STEM futures.

The success of many of these programs involving partnerships with industry, peak bodies and others, is usually documented through the collection of data on how many students go through such programs. Moving beyond numbers and evaluating 'what works, when and under what circumstances' is less common. The many available 'parachute in' interventions aimed at specific groups, can be and are reported to be helpful, providing support and motivation for individual students, teachers and schools. The idea of experts coming in to help 'fix' problems in schools or teachers, is less supported by the research than interventions aiming for co-ordinated ways of working with teachers and schools to address unconscious biases in current practices, and to support schoolwide or system wide professional learning.

Several suggestions on how to maximise the positive outcomes of school-industry partnerships emerged from interviews and workshops in the present study. Not all of these are specific to engaging girls with STEM. Initiatives aimed at enhancing school experiences may benefit from the following considerations:

- Success is more likely where a broker assists with translation of educational and industry outcomes in partnerships, and where more transformative partnerships are the focus, such as through co-development of curriculum to provide meaningful contexts for learning.
- Bursaries or scholarships for students or teachers, depending on the intended focus, support involvement in the program.
- Partnership success is often reliant on the commitment of school senior management approval and keen staff. Parents or carers, working in industries, can be instrumental in creating and sustaining partnerships.
- Collaborations need to have ongoing funding because without longevity, schools and teachers are unlikely to be involved and invest their time in changing the curriculum.
- There may be benefits in targeting developing networks of teachers, teacher associations and industry associations rather than companies. The transitory nature of working in companies means that employee attrition can lead to the end of a program due to the program not being more broadly embedded in the organisation or association.
- Academic leaders from universities can take on broker roles to coordinate multiple activities in a region, extend reach of initiatives, provide or support professional development for teachers, act as gatekeepers to industry associations, as well as provide a venue for STEM experiences involving local industries.

Initiatives that focus on providing workplace experience can influence students' ideas about studying and working in STEM. The following aspects may benefit such initiatives:

- Communities and spaces where students can meet role models, and engage in educative workplace experiences, can help to create realistic expectations of the work of STEM professionals. Experiences that provide a space where it is safe to trial and make mistakes have been shown to be successful, especially for girls.
- Universities and other further education institutions such as TAFEs can play an important role in tripartite relationships between schools, industry and universities. Staff from higher and further education institutes can mentor or supervise school students, for instance, when students work on STEM projects. Such interactions may encourage students to consider taking up a study in a STEM area. In this context, it is vital to address universities' entry requirements. There is evidence that students, girls in particular, avoid 'difficult' subjects, such as physics and advanced mathematics, in years 11-12 to maximize their ATAR scores. Students need to have an accurate understanding of what it takes to study STEM subjects, and institutions for further and higher education may want to reconsider their entry requirements, or how they communicate these.

5 A CALL TO ACTION: A ROADMAP FOR GIRLS IN STEM EDUCATION

None of the initiatives mentioned in the previous chapters are new as such. In fact, most of these have been recommended and implemented in the past decades, in Australia and elsewhere, to leverage interest, participation and success in STEM for all students, or for particular groups, such as girls. However, many initiatives have had a local scope, and the majority has been supported for a limited amount of time. Typically, they were met with limited or temporary success. Moreover, their implementation is usually met with significant systemic constraints, cutting across a range of deeply embedded cultural presumptions and practices. Focusing on Australia, the conclusion can be drawn that current initiatives have not led to sustainable improvement generally. In other words, the challenge, in particular, to increase female participation in STEM, seems to be greater than might have been anticipated.

In fact, while we have seen many initiatives implemented, there is difficulty in saying what has and has not been successful. This is due to a lack of formal evaluation or research. Participants in this study called for documentation, research and dissemination of the drivers, trends, trajectories, extrapolations, projections, and predictions. Research is needed to enhance our understanding of the impacts of specific programs and projects, and is vital to design co-ordinated and sustained approaches to better engaging girls with STEM. This implies the collection of data among stakeholders (students, teachers, but also parents/carers and industries) who are targeted by specific interventions. Investigating whether there is greater uptake among students in senior school STEM subjects and enrolments in STEM university programs and TAFE degrees would be relevant in many interventions. Also, student self-efficacy and attitudes could be monitored to establish trends. Data from the teachers involved could, for instance, focus on changes in pedagogical approaches and abilities to make links between the curriculum and STEM career opportunities for students. In addition to collecting and analysing data from current and new initiatives, it is recommended to build a repository or clearing house that brings together (international) research into initiatives aimed to increase STEM participation, in general and among girls in particular.

The issue of girls' participation in STEM is complex. As outlined in this report, there are several factors that contribute to girls' under-participation in STEM, and as such there is no single solution or quick fix to this multifaceted problem. Solutions that focus on one or two factors (e.g., curriculum, or teachers) are not likely to show improvement if other factors are ignored (e.g., parents or identity), since these factors interact with each other. Also, short term initiatives don't lead to sustained changes. The participants in this study called for a coordinated approach. Summarising and combining the most important messages from the literature, the interviews, workshops and the forum, the following elements need to be considered in relation to each other:

- **Start early (and follow through)**!

  Evidence shows that girls' self-efficacy and attitudes related to STEM are strongly influenced by their immediate family environment, especially parents (UNESCO, 2017). From an early age, unconscious biases in the different ways that girls and boys are supported to develop their identities need to be challenged. The forum emphasised the role of language in this context. It is important that parents, carers, teachers and career advisors have equal expectations of girls' and boys' ability in STEM and work together to broaden aspirations and skills, and to assist girls to create positive identities and

Fig 3: A call to action: A roadmap for girls in STEM education

self-concepts related to STEM subjects. Programs for teachers, parents/carers and career advisers are needed to sensitize them to potential biases and stereotyping of girls' interests and abilities in STEM subjects.

- **Create an encouraging culture of pedagogy and assessment**

  Primary and secondary teachers need support to better encourage female students to identify with STEM, thus enhancing access and opportunity to engage in STEM. Pedagogy and assessment approaches are needed that take into account a broad range of individual interests and abilities, and provide equal expectations and opportunities for girls and boys To implement these approaches, professional learning opportunities are needed, in particular for primary teachers who often lack competence and confidence in teaching STEM. School leaders need to support and actively contribute to this development to enable and sustain changes.

- **Provide supportive educational experiences, curricula and contexts**

  Curricula for STEM education, at early years, primary and secondary levels, need to be consistently constructed around topics and activities and forms of assessment that encourage all learners to engage with STEM. Participants in this study advocated a stronger focus on design and technology, and on the development of specific skills, such as critical and creative thinking. In general, an approach is needed that presents STEM as a human endeavour and that links

STEM content with real-life experiences, contexts and problems students can work on collaboratively. Partnerships with industries or local communities can enhance these experiences, and may involve industry placement, and mentoring of student projects.

- **Provide ongoing STEM career awareness orientation**

  Career awareness has an important role throughout the life course. Students need regular and engaging opportunities to stay current with the possibilities in STEM to diversify the range of options available to them. Students from lower SES groups are less likely to have access to good quality career advice, however, they are the ones that need it most! Accurate and detailed career information needs to be provided about the importance of STEM skills in employment and the value and diversity of STEM-based careers possibilities for girls. Such information needs to be connected to, or embedded in the teaching of STEM subjects throughout the life course.

- **Engage with carefully selected role models**

  Access to role models and mentors to increase and sustain engagement with STEM is important, particularly for groups underrepresented in STEM fields, including girls and lower SES groups. It is important to make an explicit connection between the activities of role models and mentors with STEM at school. Interaction with role models does not automatically inspire greater self-efficacy, or confidence among students. Careful selection of role models who can demonstrate success that will inspire the specific target group is important. Importantly, 'everyday' STEM professionals need to be represented to combat the myths that only extremely academically gifted people are suited to STEM (Codiroli McMaster, 2017).

What is needed are durable, concerted efforts that connect the above-mentioned elements in a purposeful way, and involve multiple stakeholders (parents, carers, teachers, career advisors, mentors or role models from industries). A central goal of such efforts should be the development of accurate, positive self-concepts of girls in relation to STEM capabilities and aspirations. This would allow them to make more informed decisions about pursuing STEM subjects in school, and later, in further or higher education, and about STEM career options. Crucially, these decisions should not be influenced by gender-biased expectations and views of adults or peers. This general goal can, of course, be achieved in a variety of ways, with different emphases, and aimed at specific target groups. Interventions focused on STEM engagement can range in terms of reach, that is, be local and deep, or be broad-scale singular events that have either a light touch (such as competitions), or intensive (boot camps), or be quite deep through incorporating multiple partners to deliver complex and comprehensive experiences. Broad scale initiatives may aim to influence public perceptions of girls and women in STEM, for instance, by promoting positive images of women in engineering.

> "What is needed are durable, concerted efforts that connect the [roadmap] elements in a purposeful way."

Local, intensive initiatives may target specific age groups (e.g., early years, or years 9-10, when decisions are made about subject choices that have important implications for future study and job opportunities), specific communities (e.g., with a high proportion of low SES and/or indigenous students), or focus on particular domains (e.g., physics, computing, mathematics). For instance, role models and mentors, in combination with the provision of workplace experiences, can be effective strategies for students from around age 10, before their aspirations become fixed. Where the focus is on under-privileged, disadvantaged or regionally-placed students, initiatives may be aimed at opening pathways, increasing awareness of importance and applicability of STEM. Alternatively, girls that already show a high ability in STEM may benefit from 'enrichment' opportunities, aimed to attract them into STEM careers. Findings from this study suggest that the advantaged students have had more attention in the past, and that interventions targeting less advantaged girls should now be prioritised. Teachers and parents need to be included to maximise the impact of such initiatives.

To effectively organise and support an intervention, a small number of schools could collaborate in a network to jointly develop and share STEM practices. The network would provide greater access to STEM opportunities and experiences for girls, both in school and extra-curricular, alongside their parents, carers, and teachers. Extracurricular activities, such as camps or projects with local industries may be integrated in these experiences. Girls of different ages could share experiences in peer groups, where older girls may act as mentors for younger girls. Obviously, changes will not happen overnight, and a sustained effort will be needed. The various elements or factors that influence girls' attitudes and engagement in STEM need to be addressed in a coordinated way. This implies a need for capacity building among teachers and school leaders of the participating schools in diverse areas such as STEM content (e.g., physics or engineering), understanding the cultural and identity aspects of gender, gender-sensitive pedagogies and assessment. Universities may contribute to a network in several ways. First, by providing expertise or targeted programs aimed at capacity building in these areas. Second, direct communication between university staff and school students (e.g., about entry requirements) may facilitate students' transitions to STEM programs. Finally, universities are well placed with expertise to add a strong research component to a network to generate evidence of its impact on cultures and practices, and, subsequently, on the knowledge and beliefs of teachers and parents/carers, and ultimately, the identities, attitudes and choices of students. By applying these principles over time, a network can become a centre of expertise in STEM to help overcome roadblocks for girls, schools and teachers.

STEM initiatives such as the ones outlined above, imply strategic and long-term partnerships between schools, communities, industries, and universities. Depending on priorities and specific purposes, successful initiatives may focus on:

- Developing and conducting a program aimed at young children, parents, carers, teachers and career advisors to address unconscious biases and stereotyping of girls' interests and abilities in STEM subjects.
- Supporting networks of teachers and schools that collaboratively investigate interventions aimed at changing curriculum content and pedagogies of STEM so that they engage all students and their diverse interests. This may include collaboration with experts from industries and universities. Such interventions could be targeted at particular groups and subjects such as primary mathematics in low SES schools, or years 9 and 10 curriculum and pedagogy interventions in rural schools.
- Investigating the impact and keep track of specific interventions: Finding out what works, how and why, and collating and disseminating these insights (e.g., through a clearing house), will help to inform the policies of governments, schools, universities and industries.
- Managing the organisational and logistical aspects of interventions, and to support special events such as information and career evenings, guest appearances, or special learning experiences.
- Brokering and supporting negotiations between education and industry representatives and to coordinate activities in a region.

The issue of gender particiption is complex and deeply embedded in cultural and schooling practices. Stagnating or declining participation numbers in STEM education indicates the entrenched nature of this problem that limits girls' access to life pathways that will become increasingly important in the coming decades. Interviewees in this study stressed that, whatever initiatives are undertaken, they need to be based on evidence, carefully conceived, and involve in-depth processes and monitoring.

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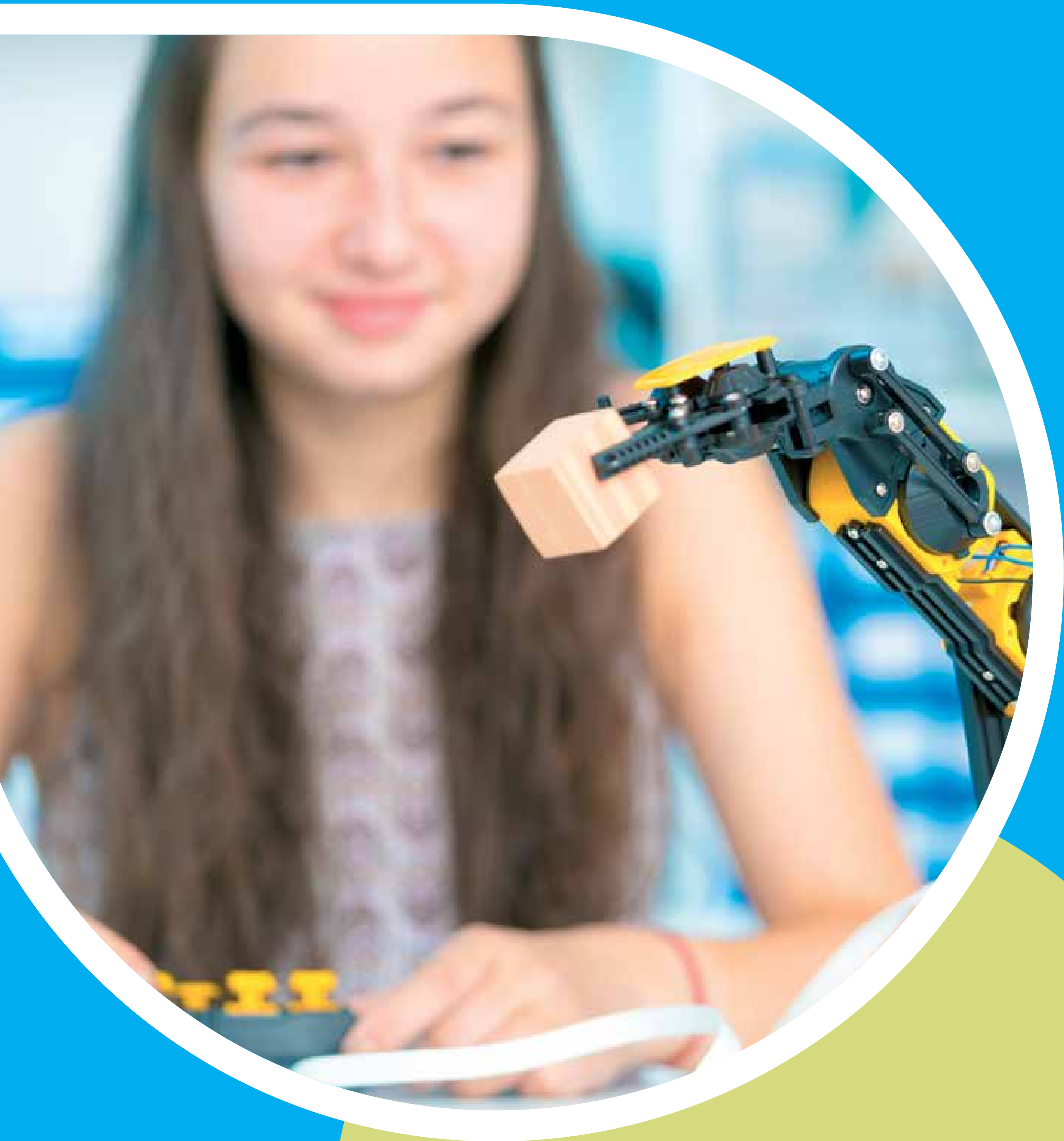

APPENDICES

Appendix 1: List of interviewees

Louise Archer
Cathy Buntting
Sarah Chapman
Kath Charlton
Leanne Collins
Merryn Dawborn-Gundlach
Jamie Evans
Marguerite Evans-Galea
Mark Glazebrook
Margaret Grove
Nalini Joshi
Edwina Kolomanski
Georgia McDonald
Janine MacIntosh
Victoria Millar
Christine Redman
Kathy Smith
Pennie Styoles
Rebecca Vivian
Leonie Walsh
Helen Watt
Emma Wilson
Lyn Yates

Appendix 2: List of interview questions

Using the following questions, we will be asking you to consider both the 'bigger picture' of STEM education and more specifically how you see gender and equity issues in relation to STEM and STEM education.

Firstly we ask if you would share your overall experience in STEM.

1. How did you come to be active in STEM? (at what level/s of education? what purposes? and with whom?
2. Which aspects of STEM do you focus in your work?
3. Now, would you describe if and/or how you see gender playing a role in STEM education and in what you focus on in your work?
4. What do you see are the biggest benefits likely to come from STEM ed ... and for girls in particular?
5. What do you see as the major existing problems that need to be addressed in the overall STEM area?
6. Females are underrepresented in STEM compared with population sizes. Based on your experience what do you believe are the central reason/s for this?

Next we would like you to discuss, in more detail, one or more example/s from your experience of developing or implementing STEM education initiatives.

7. What strategies have you used, or are you aware of?
8. What has been successful (what works) according to your experiences?
9. What indicators or criteria would you use to identify success?
10. What obstacles and challenges have you or those you work with experienced that discourage students continuing in STEM, and how could they be overcome? (eg set curriculum)
11. In relation to gender issues in STEM education, what are the major obstacles and challenges? (To be asked if none of the above questions were about this).

Now, in your view what would you like to see happen next to increase support for a) STEM education in general and b) females in STEM in particular.

12. What do you think might be done better to overcome barriers to females into STEM? At the school, university and work levels?
13. What role/s c ould different stakeholders play – government, philanthropic organizations, schools, universities, industries?

How might schools and industry better work together to deliver strong STEM education outcomes? How do/could schools work together better with these sectors, and or these sectors with schools? How might your organization/sector work to better support STEM education and girls in STEM?

14. What would you suggest as a next move for philanthropic organizations interested in encouraging/supporting females into STEM?
15. And if there was one thing you could change … what would it be?
16. Would you be willing to name or recommend other people we might talk with about the above ideas? Or people who might be interested in the report? Do you know of any critical references or policy documents or publications that you recommend we include in our review?

Appendix 3: Forum questions

1. At what age group(s) is intervention best targeted and how might strategies differ for different age groups?
2. Are there particular issues that differ for the different subjects, and issues concerning how best to target these? Is there a reason to focus on particular discipline pathways?
3. Are there particular groups that should be targeted specifically, such as – STEM talented students? Low SES students? Girls or both genders? Rural? Indigenous? If yes, for what reasons?
4. What are the relative advantages of targeting: curriculum framing, pedagogy, system conditions, public and teacher awareness, special projects? Is it an advantage to target all together? Are there particular strategies that we know are successful, that should be targeted? If yes, what are the criteria and evidence for success?
5. What types of project might best produce meaningful results: Local, contextual and sustained? Broad, focused on public awareness or policy leverage?
6. What balance should be struck between broader public awareness and policy-supporting initiatives, compared to devising and researching new interventions? Between research and advocacy? Between education and public awareness?

Appendix 4: Categorisation of partnerships and industry engagement

1. **Form and Nature:**

   (Jones, Hobbs, Kenny, Campbell, Chittleborough, Gilbert, Herbert & Redman, 2016; Upstart, 2017)

   Connective or transactional – short-term and provide a one-off service (such as guest speaker or industry visit, work experience opportunities) or product (such as provision of resources or equipment, sponsorship), and the outcomes are likely to have less profound effect on students;

Generative or cooperative – longer term or at least providing greater involvement of all partners, such as problem-based industry challenges;

Transformative – longer term or more embedded, such as co-creating learning opportunities, on-going relationships between schools and industries, mentoring for teachers and students.

2. **Rationales associated with involvement:**

   Relates to who and why industry gets involved in partnerships with education. The Victorian Government funded Tech School initiative engaged the NOUS group to support their engagement with local industry in developing the new Tech School curriculum. The NOUS Group (2017) identified a number of interests behind industry engagement with education; knowing these interests can assist educators, businesses, and funders in targeting the desired outcomes. The Platform Partner, usually larger employers such as Microsoft and Apple, has an interest in providing tools and services. The Innovator, often small to medium enterprises (SMEs, such as a local engineering firm, draws on student skills and insights or work with teachers to develop new curriculum to drive product and service innovation. The Champion, SMEs or larger employers, such as local energy provider or water board, see the bigger picture and want to give back to the community. Finally, The misrepresented, SMEs to larger employers, wish to address misconceptions about their industry, such as raising or correcting the image of the industry.

3. **Scale:**

   The Australian Industry Group (2017) reported on three partnership models, all of which have strengths and weaknesses as outlined in their report (p. 78). The three models and some key characteristics are outlined below:

- **Single school and single company:** Individual schools working with one company can be successful as the partnership can be localised, kept relevant to participants, extended over years rather than as a one-off and lack the complications of large partnerships in maintaining key stakeholder relationships.
- **Multiple schools and multiple companies:** Multiple partners mean broader reach, and a greater potential for development of teachers. Regional approaches involving tripartite school-university-industry relationships have particular benefits where a program operates as a 'hub' or network (Australian Industry Group, 2017).
- **Multiple organisations:** Multiple organisations enable a focus on a particular area, for example, using multiple technology companies to build teachers' digital technology skills. Broad reach can be achieved when multiple companies act as a collective in targeting teachers from multiple schools, which can lead to greater efficiencies and increase the chances of the initiative being ongoing. Such programs can use scientists, engineers and technologists from multiple companies, often as volunteers. The Scientist and Mathematicians in Schools program (CSIRO, 2016) is an example of this type of initiative.

Disclaimer

Ethics approval for the project was obtained on 9 February 2017 from Deakin University Human Ethics Advisory Group (HEAG), project number HAE-17-016, and on 20 April 2017 from the Melbourne Graduate School of Education - Human Ethics Advisory Group (HEAG), Ethics ID 1748876. If you have any complaints about any aspect of the project, the way it is being conducted or any questions about your rights as a research participant, then you may contact:

The Manager, Research Integrity, Deakin University
221 Burwood Highway, Burwood Victoria 3125
Telephone: 9251 7129, Facsimile: 9244 6581
research-ethics@deakin.edu.au.

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