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Women in STEM Ambassador

BARRIERS TO PARTICIPATION IN ENGINEERING AND THE VALUE OF INTERVENTIONS TO IMPROVE DIVERSITY

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A report prepared for the
Engineering for Australia Taskforce

CONTENTS

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EXECUTIVE SUMMARY

> *Getting more girls and women into STEM education and careers requires holistic and integrated responses that reach across sectors and that engage girls and women in identifying solutions to persistent challenges. This requires political will, strengthened capacity and investments to spark girls' interest and cultivate their aspirations to pursue further STEM studies, and ultimately STEM careers… System-level changes are needed to improve the quality of STEM education to take account of the specific learning needs of girls. Engaging girls in STEM from an early age and ensuring that their overall education experience – the teaching and learning process, contents and environment – are gender-responsive and free from gender discrimination and stereotypes, are also important.* (UNESCO, 2017, p72)

Despite considerable effort, there is still much to be done to improve girls' participation in STEM education and careers. The Engineering for Australia Taskforce (the Taskforce) has appreciated the need to act based on four issues they have identified:

- Engineering enrolments do not reflect the diversity of the Australian population, particularly gender diversity.
- Engineering has a low visibility in schools (and in society generally).
- Despite numerous outreach and engagement programs and initiatives, gender parity in undergraduate enrolments has not been achieved.
- Much of the engineering industry values diversity because it increases innovation and improves financial performance.

The Taskforce contracted Education Futures to review the international research literature that not only focused on barriers to girls' participation in engineering, but more importantly focused on the value of interventions to improve diverse participation in engineering. The intention was to provide an evidence base for the Taskforce to select three actions that would influence the choices of young people (particularly females) to study engineering; and that actions would be scaled at a national, system level response.

While much of the literature refers to, at best, STEM – that is, an integrated approach to the individual STEM disciplines – there is also more literature around mathematics and science. Wherever possible, access to information about engineering and broad-based technology has been sought rather than technology solely focusing on digital technology, although this has also been included. It is not surprising that engineering education research literature is scant as it is only just becoming a more explicit part of the curriculum, mainly in the US. Engineering is included in the technology curriculum in the rest of the world, which in itself is a relatively recent addition in many countries.

Methods

We used systematic review methods for identification of literature pertaining to ***intervention programs*** addressing recruitment and engagement of girls in STEM. We used multiple search terms encompassing STEM areas, including an enhanced focus on engineering. Scopus and ProQuest databases were used to systematically collect peer reviewed sources and grey literature reports, supplemented by a targeted website search. An initial 6,591 references were reviewed and excluded on the following criteria (in order of exclusion): not pertaining to STEM education; not within the educational level scope (early years through secondary schooling); gender focus absent; assessment or reporting did not fall within the scope of girls' STEM engagement. Additionally, any articles that did not meet minimum quality standards for analysis were excluded. The search resulted in the consideration of 245 peer reviewed articles and 49 grey literature sources.

In this report, we discuss factors influencing girls' engagement in STEM (section 2), key considerations for developing intervention programs (section 3) and we provide a breakdown of the existing peer reviewed literature of STEM intervention programs for girls, highlighting significant knowledge gaps (section 4). These findings draw on 115 peer reviewed evaluations of STEM interventions.

Findings

From this review of factors that influence girls' engagement in STEM, we have proposed a socio-ecological model of girls' engagement, which recognises that the individual learner exists in interaction with both her immediate learning community (teachers, peers, family, community, learning environments and tools), as well as broader contextual factors.

At the first level or individual level, four important factors to consider are: attitudes and interest of the individual learner; their self-efficacy or, as Bandura (1997) describes it, the belief in your own capabilities; development of a positive STEM identity; and appropriate skill development. At the second level, factors of teachers and pedagogy (or teaching and learning approaches); the learning environment and learning tools; peer influence; and family and community were central considerations. In the third level of broad contexts, the socio-cultural, socio-political and socio-economic contexts were the three identified factors influencing girls' engagement in STEM.

When considering the development of interventions, research highlighted the importance of considering: the arena of intervention (whether the intervention is school-based or out of school); the notion of achievement, and what it means to achieve; the needs of the population you are working with; the target audience; the pedagogical approach; the promotion of a growth mindset; knowledge of engineer and/or design technology; mentoring; effective training of teachers and mentors; and the role of careers counsellors (an important resource that is often overlooked).

As a result of the review, we identify criteria for what might constitute gold standard interventions. At the same time, we acknowledge that there is little longitudinal data on the impacts of these interventions and those reviewed (based on the established criteria set out in Appendices A.1 and A.2) may not capture the great diversity of STEM interventions or best practice. The literature refers to STEM rather than engineering as the pathways to engineering (as a study option or as a career) are not apparent. When in the lifecycle does engineering need to become explicit? Another identified gap is the decision-making process around what population to target in respect to intervention and whether interventions should be short, medium or long-term. For sustained change, there is evidence of the need for long-term interventions (at least twelve weeks).

Possible actions

As a result of this review, three actions have been proposed:

- Action 1: Evaluate available engineering (STEM) interventions to map the landscape and build the evidence base of impact
- Action 2: Develop an inclusive vision for STEM and engineering
- Action 3: Work with education faculties to create a STEM and engineering identity in schools

The reviewed literature revealed a number of ideas, frameworks and evaluative tools that can be used in interventions. The real opportunities for making a difference come from the collaborative opportunities of implementing actions. The actions proposed not only address specific issues, such as providing access to high quality positive educational experiences, but also address the broader perspectives of the persistence of stereotypes and career possibilities.

1 BACKGROUND

In May 2019 the Engineering for Australia Taskforce (the Taskforce) identified the following issues in relation to engineering in Australia:

- Engineering enrolments do not reflect the diversity of the Australian population, particularly gender diversity.
- Engineering has a low visibility in schools (and in society generally).
- Despite numerous outreach and engagement programs and initiatives, gender parity in undergraduate enrolments has not been achieved.
- Much of the engineering industry values diversity because it increases innovation and improves financial performance.

In seeking to understand these issues better, the Taskforce contracted Education Futures to review the international body of research on barriers to participation in engineering, with a focus on identifying the value of various interventions to improve diversity.

The aim was to have an evidence base for the Taskforce to select three actions to implement based on:

- potential to influence young peoples' choices to study engineering, particularly females
- capacity for actions to be scaled to national, system-wide solutions

Why is it important that diverse populations, particularly girls, study STEM?

> *Ensuring girls and women have equal access to STEM education and ultimately STEM careers is an imperative from the human rights, scientific, and development perspectives. From a human rights perspective, all people are equal and should have equal opportunities...From a scientific perspective, the inclusion of women promotes scientific excellence and boosts the quality of STEM outcomes, as diverse perspectives aggregate creativity, reduce potential biases, and promote more robust knowledge and solutions…From a development perspective…gender equality in STEM will ensure that boys and girls, men and women will be able to acquire skills and opportunities to contribute to and benefit equally from the benefits and assets associated with STEM.* (UNESCO, 2017, p 15)

There is universal agreement that a STEM workforce is important for the future of countries in the twenty-first century, but there has been little change to the participation of girls and women in STEM careers. Australia is no different, as pointed out in numerous documents such as Australia's STEM Workforce (OCS, 2016) and the Women in STEM Decadal Plan (AAoS, 2019).

However, there are many facets to this issue. For example, the Women in STEM Decadal Plan has focussed on the STEM pipeline and, in particular, on keeping women in the STEM workforce. Australia's STEM Workforce focuses on this same pipeline but broadens it by including the study choices of upper secondary students and the pipeline of both the technical and professional STEM workers.

In this report, we have examined the large body of research literature that considers the barriers to girls' participation in STEM education and it is, consequently, much more focussed on the school sector of the pipeline. This attention is deliberate as **there is much evidence to suggest that the issue of a 'leaky pipeline' in STEM occurs at the earliest ages and continues throughout the career lifecycle**. Although the barriers are well documented in the literature, there has been less attention paid to the interventions that aim to retain and promote girls' participation in STEM. This review of literature is different, with a deliberate focus on interventions. This review is deliberately international in scope, including Australia, as it important to gauge how widespread these barriers are and how successful the interventions to address such barriers have been.

In considering interventions to address barriers to girls' participation in STEM, it is also important to look at the existing policy environment and the actions or interventions supported by this environment. To this end we have also examined three key policy documents, the Women in STEM Decadal Plan (AAoS, 2019), Cracking the Code: Girls' and women's education in science, technology, engineering and mathematics (STEM) (UNESCO, 2017) and the UN Sustainable Development Goals (SDGs) (UN, 2019) with updates on these goals as of September 2019, just prior to the UN summit on SDGs (New York, September, 24-25, 2019). Table 1 compares the actions and interventions proposed in these three policy documents.

We have classified the actions proposed in these three policy documents around three contexts: socio-cultural, socio-political and socio-economic, as this classification helps to delineate where the major focus of such actions is located. Such classification is also in line with the socio-ecological model that was developed as a result of this systematic review of the literature (see section 2).

While the inclusion of the SDGs may appear to be of a global scale, they do provide multiple contexts in which many actions or interventions can be located as they not only consider global issues, but also very local ones, as well as clearly engage education in the process of action embedded in these goals. The intention then is not always to consider

SDGs' context at the global scale, but also to consider how very local attention can contribute to SDGs. In this sense they provide extensive opportunities to embedded STEM education in social, cultural and political contexts and through more collaborative and team-based approaches to learning.

Table 1. Contextual comparison between actions and interventions of SDGs, UNESCO Cracking the Code and the Women in STEM Decadal Plan

Context	SDGs: 2019 Update on actions	UNESCO Cracking the Code: Interventions	Decadal Plan: Actions
Socio-cultural	***Goal 4: Quality education –*** *2019 update: Considerable progress has been made on access and participation, however not enough.* Rapid technological changes present opportunities and challenges, but the learning environment, the capacities of teachers and the quality of education have not kept pace. Refocused efforts are needed to improve learning outcomes for the full life cycle, especially for women, girls and marginalized people in vulnerable settings ***Goal 5: Gender equity*** 2019 update - Insufficient progress on structural issues at the root of gender inequality, such as legal discrimination, unfair social norms and attitudes, decision-making on sexual and reproductive issues and low levels of political participation, are undermining the ability to achieve Sustainable Development Goal 5. ***Goal 10: Reduced inequality*** 2019 Update - Inequality within and among nations continues to be a significant concern despite progress in and efforts at narrowing disparities of opportunity, income and power. Greater emphasis will need to be placed on reducing inequalities in income as well as those based on other factors.	**Learner**: • Early engagement to build girls' linguistic, number and spatial skills • Strengthening girls' self-confidence and self-efficacy • Improving girls' motivation • Providing appropriate role models • Provide support to develop positive STEM identities **Families and peers:** • Parent-child dialogue in early education experiences to increase linguistic, number and spatial skills e.g. block play • Reinforce positive encouragement of STEM identities through informal and experiential learning together in STEM – outreach, discovery centres, conversation etc. (Parents are fundamental in debunking persistent "male" stereotypes in STEM) • Provide opportunities to practice and experience STEM within families and with peers – practice can improve perception of confidence and self-identity in STEM.	**Education**: Strengthening the education system to support teaching and learning on a national scale will enable and encourage all girls and women at all levels to study STEM courses and equip them with the skills and knowledge to participate in diverse STEM careers. 5.1 STEM-skilled teachers teach STEM courses 5.2 Strengthen STEM teaching pedagogy, practices and resources to enable girls and women to engage with contemporary STEM content **Visibility:** Seeing women in diverse STEM careers, and equally represented in the media, in public events, and in other forums like boardrooms and classrooms will provide role models for girls and women and inspire a nation. 4.1 Utilise policy and other levers to facilitate participation of women in STEM conferences and events as well as require gender equity on panels and programs of STEM-related conferences and events 4.2 Establish mechanisms for media agencies to identify and represent diversity in reporting 4.3 Establish mechanisms for representing diversity in social media 4.4 Make concerted, coordinated and sustained efforts to celebrate the depth and breadth of STEM and the diversity within it 4.5 Position STEM in Australia as a viable and vibrant career option for girls and women
Socio-political	***Goals 3: Good health and wellbeing for all at all ages.*** Update 2019 - Concerted efforts are required to achieve universal health coverage and sustainable financing for health, to address the growing burden of non-communicable diseases, including mental health, and to tackle antimicrobial resistance and determinants of health such as air pollution and inadequate water and sanitation. ***Goal 6: Clean water and sanitation*** Update 2019 - More efficient use and management of water are critical to addressing the growing demand for water, threats to water security and the increasing frequency and severity of droughts and floods resulting from climate change. ***Goal 7: Affordable and clean energy*** Update 2019 - If Sustainable Development Goals 7, 13 and related Goals are to be met, much higher levels of ambition are required with regard to renewable energy, including transportation and heating. ***Goal 11: Sustainable cities and communities.*** Update 2019 - Urgent action is needed to reverse the current situation of the vast majority of urban residents breathing poor-quality air and having limited access to transport and open public spaces. With the areas occupied by cities growing faster than their populations, there are profound repercussions for sustainability. ***Goal 13: Climate Action*** Update 2019 - With rising greenhouse gas emissions, climate change is occurring at rates much faster than anticipated. Far more ambitious plans and accelerated action are needed on mitigation and adaptation. Access to finance and strengthened capacities need to be scaled up at a much faster rate, particularly for least developed countries and small island developing States.	**School:** • Prioritise professional learning for teachers that enhances gender-responsive STEM pedagogies (e.g. context-based; inquiry/problem/project-based; ICT-enriched; collaborative learning and use of extra-curricular activities). **Society:** • Prioritise the recruitment of female (and male) STEM teachers, particularly in rural areas. • Review of curriculum in STEM that is gender neutral, provides a strong conceptual framework, is contextualised (in social and scientific issues), is relevant to real life and has time for and encourages learning where students are encouraged to take risks, have a range of experiences and are allowed to make mistakes, which forces the brain to grow by thinking about what went wrong. • Legislation, quotas, financial incentives and other policies can play a significant role in increasing girls' and women's participation in STEM education and careers	**Evaluation:** Establishing a national evaluation framework will guide decision making and drive investment and effort into measures that work. 2.1 By 2022, establish a consistent national evaluation framework that guides evaluation efforts across all existing and future gender equity initiatives in STEM in Australia 2.2 Organisations who fund STEM gender equity initiatives support evaluation and evidence-based approaches by requiring evaluation as a condition of funding 2.3 Improve awareness of existing programs and their efficacy

	Goal 14; Life below water Update 2019 - As billions of people depend on oceans for their livelihood and food source and on the transboundary nature of oceans, increased efforts and interventions are needed to conserve and sustainably use ocean resources at all levels. ***Goal 15: Life on land*** Update 2019 - There are some encouraging global trends in protecting terrestrial ecosystems and biodiversity. Forest loss is slowing down, more key biodiversity areas are protected and more financial assistance is flowing towards biodiversity protection. Yet, the 2020 targets of Sustainable Development Goal 15 are unlikely to be met. ***Goal 16: Peace, justice and strong institutions*** Update 2019- Advances in ending violence, promoting the rule of law, strengthening institutions and increasing access to justice are uneven and continue to deprive millions of their security, rights and opportunities and undermine the delivery of public services and broader economic development. Attacks on civil society are also holding back development progress. Renewed efforts are essential. ***Goal 17: Partnerships for the goals*** Update 2019 - Significant challenges remain: Development Aid is declining, private investment flows are not well aligned with sustainable development, there continues to be a significant digital divide and there are ongoing trade tensions. Enhanced international cooperation is needed.		
Socio-economic	***Goal 1: No poverty*** Update 2019 - People who continue to live in extreme poverty face deep, entrenched deprivation often exacerbated by violent conflicts and vulnerability to disasters. Strong social protection systems and government spending on key services often help those left behind get back on their feet and escape poverty, but these services need to be brought to scale ***Goal 2: No hunger*** Update 2019 - Hunger is on the rise again. Public investment in agriculture globally is declining, small scale food producers and family farmers require much greater support and increased investment in infrastructure and technology for sustainable agriculture is urgently needed. ***Goal 8: Decent work and economic growth*** Update 2019 - More progress is needed to increase employment opportunities, particularly for young people, reduce informal employment and the gender pay gap and promote safe and secure working environments to create decent work for all. Note: In 2018, one fifth of the world's youth were not in education, employment or training. Young women were more than twice as likely as young men to be unemployed or outside the labour force and not in education or training. ***Goal 9: Industry, innovation and infrastructure*** Update 2019 - Aspects of the prevailing global economic environment have not been conducive to rapid progress on Sustainable Development Goal 9. Countries that are lagging behind, such as least developed countries, face serious challenges in doubling the manufacturing industry's share of GDP by 2030, and investment in scientific research and innovation remains below the global average. ***Goal 12: Responsible consumption and production*** Update 2019 - Urgent action is needed to ensure that current material needs do not lead to the over-extraction of resources or to the degradation of environmental resources, and should include policies that improve resource efficiency, reduce waste and mainstream sustainability practices across all sectors of the economy.	**School** • Expand access to mentoring, apprenticeship and career counselling to improve orientation on STEM studies and careers **Society** • Expand access to mentoring, apprenticeship and career counselling to improve orientation on STEM studies and careers Build partnerships across sectors and advocacy can direct attention to gaps in engaging girls in STEM, and to labour market needs for STEM e.g. WISE in the UK • Mainstream gender equality in public policies and programs across sectors, including education, social, labour.	**Leadership and Cohesion:** Stronger cohesion and leadership across the Australian STEM ecosystem will amplify and strengthen diversity outcomes. 1.1 Incentivise and promote accountability amongst leaders 1.2 Rollout the SAGE pilot nationally to facilitate the involvement of all higher education and research institutions in Australia and provide a pathway towards Gold Athena SWAN accreditation 1.3 Address diversity in government funding and procurement 1.4 Government as a key employer of STEM professionals adopt best practice in gender equity as outlined across this decadal plan 1.5 Develop and adopt national guidelines on best practice in all selection processes 1.6 Develop national standards to require accreditation bodies to meet national benchmarks 1.7 Leaders across all STEM professions and organisations adopt and adapt learnings from proven measures such as those developed by MCC, CEW and the 30% Club **Workplace Culture**: A significant cultural shift in workplaces is necessary to create gender equity for women in STEM. A culture that is inclusive and respectful, challenges traditional stereotypes, is free of discrimination and bias, enables flexibility and accommodates career interruptions and changes will maximise women's participation in the workforce. 3.1 Make each STEM organisation responsible and accountable for establishing a non-discriminatory workplace culture that does not tolerate harassment and bullying 3.2 Develop a system-level approach to retain and retrain women in STEM careers 3.3 Develop best practice guidelines for mentoring and leadership programs across the STEM ecosystem and support initiatives that work **Industry Action:** Establishing a national framework that guides and provides tools to address gender equity amongst SMEs will impact the vast majority of businesses not reached by existing programs. 6.1 Develop a framework and toolkits to help SMEs recognise and address gender imbalance 6.2 Government provides incentives for SMEs to address gender equity via funding and procurement requirements 6.3 Larger companies and universities using SME products and services provide incentives via procurement requirements

What is evident from this comparison is that the Women in STEM Decadal Plan focuses largely on post-school actions, which, while adding to the overall plan needs to increase girls' participation in STEM, is far too late for maintaining or increasing girls' participation in STEM. The education focus within this document needs far more detail if it is to address developing girls' STEM identity and self-efficacy. The UNESCO Cracking the Code report provides an 'across-the-contexts' approach; however, it should also be noted that many of their examples are from developing countries, where STEM is a positive driver of social mobility. This is not the case in developed countries such as Australia where there are multiple drivers of social mobility (e.g. commerce and health) and where STEM is often seen as undesirable.

The review of literature provides an opportunity to look at what has been attempted, what has worked and what needs to be attended to when looking for interventions to improve girls' participation in STEM. In conducting this review, we have found (as indeed have other bodies such as UNESCO) that there is limited literature outside of the US, hence we have deliberately accessed whenever possible findings from other countries. However, the US dominance of the research literature means that findings are not from diverse cultural backgrounds. Additionally, we have had to limit the review to literature written in English. Some of the literature we have accessed has provided insights from more diverse cultures.

Methods

We used systematic review methods to identify literature pertaining to ***intervention programs*** addressing recruitment and engagement of girls in STEM. We used multiple search terms encompassing STEM areas, including an enhanced focus on engineering (Appendix A.1, search terms). We used Scopus and ProQuest databases to systematically collect peer reviewed sources. We also included grey literature reports, as retrieved by the databases, and supplemented by a targeted website search (Appendix A.2, search methods). Initial references retrieved from the search were imported into the online systematic review system, Rayyan, and reviewed by a team of four analysts, led by Dr Aikens. An initial 6,591 references were reviewed, and excluded on the following criteria (in order of exclusion): not pertaining to STEM education; not within the educational level scope (early years through secondary schooling); gender focus absent; assessment or reporting did not fall within the scope of girls' STEM engagement. Additionally, any articles that did not meet minimum quality standards for analysis were excluded.

We provide an additional, comprehensive analysis of existing peer reviewed literature evaluating existing intervention programs.

Findings from the systematic review

In this report, we discuss factors influencing girls' engagement in STEM (section 2) and key considerations for developing intervention programs (section 3). These findings were developed from all literature retrieved from the search process, including 245 peer reviewed articles and 49 grey literature sources.

We then provide a breakdown of the existing peer reviewed literature of STEM intervention programs for girls highlighting significant knowledge gaps (section 4). These findings draw on 115 peer reviewed evaluations of STEM interventions.

2 FACTORS INFLUENCING GIRLS' ENGAGEMENT IN STEM

First, we discuss our conceptual model of factors influencing girls' engagement in STEM, developed through this literature and adapted in part from UNESCO's 2017 Cracking the Code report on girls in STEM. Figure 1 below is a socio-ecological model of girls' engagement, which recognises that the individual learner exists in interaction with both her immediate learning community (teachers, peers, family, community, learning environments and tools), and broader contextual factors. We have also heeded calls from STEM education researchers and equity advocates to avoid essentialism and deficit thinking; i.e. that relatively low female participation in STEM and engineering is related to relatively fixed deficits in girls' attitudes, skills, and behaviours (Boaler, 2002).

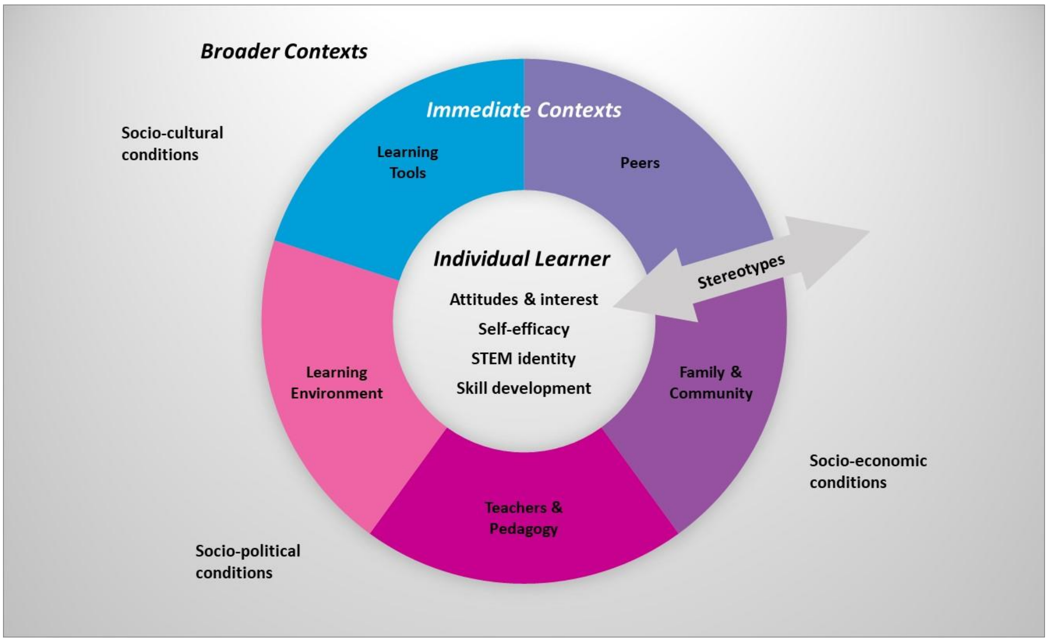

Figure 1. A socio-ecological model of influences on girls' engagement in STEM

In the following discussion of factors influencing girls' engagement in STEM, we will proceed through each level of the model, from Individual Learner, to Immediate Contexts, to Broader Contexts. Stereotypes are a cross-cutting influence that are discussed at each level of the model. We recognise that these levels do not operate in isolation, and therefore draw connections and conclusions across levels. This discussion provides the basis for section 3, Considering Interventions, where we outline considerations for effective interventions, provide a gap analysis of the peer reviewed literature, and offer three sets of tools to support intervention development (principles, guiding questions, and evaluation measures). Section 4 provides a brief analysis of gaps in the literature on interventions addressing girls' engagement in STEM.

LEVEL 1: INDIVIDUAL LEARNER

ATTITUDES AND INTEREST

There is widespread, cross-national evidence that girls experience lower levels of STEM confidence and higher levels of anxiety with respect to STEM (Bryant et al., 2013; Cusso-Calabruig et al., 2017; Else-Quest et al., 2010). In a systematic review of interest, motivation, and attitudes of K-12 students toward science and technology subjects, authors reported few aggregate differences between boys and girls, but significant gaps favouring boys in subjects of physics and technology (Potvin & Hasni, 2014). In their analysis of TIMSS (Trends in International Mathematics and Science Study) and PISA (Programme for International Student Assessment) data, Else-Quest and colleagues (2010) report relatively consistent gender gaps favouring boys in attitudes toward STEM. Research at the national and subnational level is largely consistent with these findings (Cusso-Calabruig et al., 2017; Britner & Pajares, 2006; Frenzel et al., 2007), as is research on student perceptions of barriers to STEM persistence (Fouad et al., 2010).

Some research suggests that girls' confidence decreases prior to decreased STEM achievement, but both decrease through middle school (AAUW, 1995; Baker, 2013; Barmby et al., 2008; Sanders & Nelson, 2004). This may be associated with Haladyna and Thomas' (1979) findings that showed students' attitudes toward school in general, as well as toward key academic domains such as mathematics and science, decrease as children get older. Specifically, early adolescence often seems to mark the beginning of a downward spiral in school-related behaviors and motivation, even leading to academic failure and dropping-out of school for many students (Eccles, Wigfield, Midgley, Reuman, MacIver, & Feldlaufer, 1993). As Bandura (1986) suggests, academic achievements and perceived ability are reciprocally related. High achievement boosts students' perceived ability and the resulting greater confidence in turn supports striving for and maintaining higher achievement. Conversely, if confidence is low, the achievement is likely to decrease.

In relation to mathematics, 40 per cent of the variation in mathematics performance can be explained by students' attitudes and beliefs (Lokan et al., 2001). Eccles et al. (1993) also found that often middle school (early secondary) mathematics teachers control their students more and provide less self-efficacious decision-making opportunities compared to sixth grade teachers. Hence, students' perceived value of mathematics could be related to the perceived level of teacher support. High level of support meant no change, whereas not receiving a high level of support resulted in declined value for mathematics by students.

Such issues seem worse for girls than boys. Girls as less likely to retain any early affection for mathematics and science (Orenstein, 1994; Else-Quest et al., 2010) even though there appears to be no achievement difference between boys and girls at age nine, minimal difference at age thirteen, but large difference by age seventeen (Sanders & Nelson, 2004). Coupled with such findings is that of Mujtaba and Reiss (2013) who found that girls are less likely than boys to receive specific encouragement to continue with physics and mathematics post-16 years. It is therefore important to build resilience among girls and women to help maintain their science aspirations (Carlone & Johnson, 2007).

Importantly, these issues can be addressed through the provision of positive educational experiences. As highlighted in Cracking the Code:

> *Research on biological factors, including brain structure and development, genetics, neuroscience and hormones, shows that the gender gap in STEM is not the result of sex differences in these factors or in innate ability. Rather, findings suggest that learning is underpinned by neuroplasticity, the capacity of the brain to expand and form new connections, and that education performance, including in STEM subjects, is influenced by experience and can be improved through targeted interventions. Spatial and language skills, especially written language, are positively correlated with performance in mathematics and can be improved with practice, irrespective of sex, especially during the earlier years of life.* (UNESCO, 2017, p.11)

SELF-EFFICACY

Self-efficacy (Bandura, 1997) is an important socio-cultural factor, in addition to STEM identity and decision-making with regard to careers, as it is a critical factor for predicting female and other under-represented students' engagement and persistence in the STEM pipeline (Chemers et al., 2011; Grossman & Porche, 2014). Self-efficacy is defined as 'beliefs in one's capabilities to organize and execute the courses of action required to produce given attainments … [it] may entail regulating one's own motivation, thought processes, and affective states and actions, or it may involve changing environmental conditions' (Bandura, 1997, p. 3).

Additionally, decision making with regard to careers is also important and is more complex and restrictive for women than men (and needs to specifically address career development for women). Gushue et al., (2006) identify decision making self-efficacy is an important variable in career development of high school students and is defined as the degree to which individuals feel confident in their ability to successfully engage in tasks associated with making a career choice and with commitment to a career (Taylor & Betz, 1983).

Most interventions in career self-efficacy fail to incorporate four sources of self-efficacy information (prior performance accomplishments, emotional arousal, vicarious learning and verbal persuasion), as identified by Bandura (1997).

STEM IDENTITY

Children are developing attitudes and ideas about technology and engineering in the early elementary years and these ideas are co-constructed with their expanding ideas about gender (Sullivan & Bers, 2014). There is a stereotypical belief that science is a boys' domain rather than a girls' and this impacts on the educational experience for girls in particular (Archer, 2012; Greenfield,1996). Similar findings have been reported for mathematics and IT (Norton, 2014; Lang et al., 2015). A combination of negative experiences may lead to stereotype threat, where anxiety about performance, provoked through specific, negative stereotype association, decreases performance. For example, if girls are prompted by the negative stereotype 'boys do better at (mathematics) tests' prior to taking a test, they will often perform less well than control groups without the negative stereotype prompt (Steel, 1997; Spence et al., 1999). Additionally, compared to boys, girls often perceive science as difficult, uninteresting, and leading to an unattractive career lifestyle (Huffman et al., 1997; Jones et al., 2000; Miller et al., 2006; Palmer 2009).

Rather than challenging dominant stereotypes about science as hard and scientists as 'brainy' for some students, the experiences they encountered may have unwittingly reinforced or promoted a perception of science as hard and for the 'brainy'. For example, the ASPIRES project national surveys of over 9000 Year 6 and over 5600 Year 8 students found that on both surveys over 80 per cent of young people agree that scientists are 'brainy' (Archer et al., 2013).

Therefore, fostering a positive STEM identity – a sense of who they are and wish to be in relation to the communities in which they develop knowledge, competence, and meaning from social interactions (Aschbacher et al., 2010) – early on can be pivotal to fostering girls' interest in STEM. Children's stereotypes of scientists and those who work in science are more nuanced than traditional 'geeky' or 'nerdy' stereotypes. Rather, perceptions of scientists are deeply intertwined with notions of 'otherness' and 'cleverness'. Consequently, combating stereotypical perceptions requires a more complex and subtle approach – more so than simply providing positive images of 'not geeky' (or 'cool') scientists (Archer et al., 2010, 2012). Perceptions of STEM as masculine are persistent, and girls that develop strong STEM identities may position themselves as less 'girly' than their peers (Archer et al., 2012; Carlone et al., 2015). These interactions are highly nuanced, however, as other researchers report that non-traditional STEM role models support stereotype reduction and remove participation barriers (Dahya et al., 2017).

A broader understanding of where science can lead is important knowledge in forming a young person's 'science capital (Archer et al., 2012) which is associated with higher science aspirations and a greater likelihood of intending to study science further (Archer et al., 2012; Mujtaba & Reiss, 2013). Mentoring plays an important role in creating such a broader understanding. Provision of role models with similar backgrounds as students helped to provide the belief that 'anything is possible' (Nazir et al., 2014) as did personal contact with a significant person in the field.

Ideas about science, and the notion of science as 'interesting but not for me', are formed in primary school. Consequently, there is a strong case to be made for the value and importance of providing STEM careers awareness and support to younger children (Woolley et al., 2013).

SKILL DEVELOPMENT

There is little evidence to support an innate skill deficiency as a main factor in girls' STEM engagement (Hill et al., 2010; UNESCO, 2017). Nevertheless, decreases in girls' STEM attitudes, self-efficacy, and identity are observed throughout the schooling trajectory. Findings from science research have found boys get more attention, are called upon and allowed to answer more questions and are provided with more feedback on their work (Jones & Wheatley, 1990; Kahle, Parker, Rennie, & Riley, 1993; Sadker & Sadker, 1994). Over time, these barriers to participation may result in less development of STEM skills, often through loss of hands-on opportunities. Teachers exert strong influences on girls' STEM skill and identity development, which supports the potential effectiveness of interventions to improve STEM teaching and reduce teacher bias.

LEVEL 2: IMMEDIATE LEARNING CONTEXTS

TEACHERS AND PEDAGOGY

Teachers are consistently reported as a significant source of support, as well as a barrier to girls' engagement in STEM (Fouad et al., 2010; Hill et al., 2010; UNESCO, 2017). The UPMAP study (Understanding Participation rates in post-16 Mathematics and Physics), which included more than 5,000 students from the UK, found that receiving specific encouragement from a science teacher is one of the most powerful predictors of a student's intention to continue with physics post-16 (Mujtaba and Reiss, 2013).

Teachers can exhibit forms of gender bias, including expectations for higher STEM ability and performance from boys (Espinoza et al., 2014; Hand et al., 2017; Murphy & Whitelegg, 2016; UNESCO, 2017), As discussed above, teachers may also unintentionally favour boys in classroom participation. Issues of teacher bias may be exacerbated by intersecting factors related to race, class, or ability (Calabrese-Barton et al., 2013; Pringle et al., 2012). Science teaching is often conducted in ways that 'focus on achieving established answers in uniform ways (Allen & Eisenhart, 2017, p. 410), which precludes more creative activities and forecloses opportunities for under-represented students (Brickhouse et al., 2000; Calabrese Barton et al., 2013).

Research into the influence of teacher gender on student STEM beliefs produced inconsistent results, with some studies reporting no effect of teacher gender (Carrington et al., 2008), and some reporting that female STEM teachers reduce STEM bias in their students (Sansone, 2019).

Girls are more likely to attach value to the social context of learning (Leong & Hawamdeh, 1999; Murphy & Whitelegg, 2006). Learning approaches or courses that are embedded in social contexts appear to have a positive benefit on overall performance and on girls' performance over boys (Murphy & Whitelegg, 2006) as well as narrow gender attitude differences (Raes et al., 2014). The lack of relevance in most science and technology curricula, which is often not socially context-based, is one barrier to good learning and interest in science content (Sjoberg & Schreiner, 2010). The point here is that it is not any context that makes a difference, but those with a social context. Hence there are opportunities for the use of the Sustainable Development Goals (SDGs) as social contexts for girls learning in STEM.

Inquiry-based approaches[1] have mixed results but can maintain student positive attitudes to science over time (Baker 2013; Brickhouse et al., 2000; Fadigan and Hammrich 2004; Jovanivich and King 1998; Kahle and Damnjanovic 1994; Mattern and Schau 2002; Palmer 2009; Stake and Mares 2001), increase students science-related interests, confidence in science, persistence in science (Fouad and Smith 1996; Lent et al., 1986), and improve science achievement (Cuevas et al., 2005; Lent et al., 1986; Mattern and Schau 2002; Steinkamp and Maehr 1984). Some studies provide evidence that inquiry-based laboratory experiences may, in fact, be beneficial for both boys' and girls' science achievement but results here are also mixed.

Integrated projects improve understanding of science concepts and increase interest in science (Sadler, Chambers & Zeidler, 2004), although there is little evidence on the impact of problem-based learning in school settings. Team-based and/or collaborative approaches are also important approaches. For example, teams of students, along with their teacher, engaged in a particular project-based instruction type (instruction was provided by mentors with similar backgrounds to student participants) positioned teachers as co-learners or collaborators with the students and provided

[1] Inquiry-based learning is a student-centred learning approach in which students are stimulated to work together and get involved in a social, active, engaged, and constructive learning process, as opposed to more traditional approaches, that emphasize the memorizing of factual information.

some of the conditions for the sustained change in students attitudes to science, mathematics and technology (Naizir et al., 2014).

LEARNING ENVIRONMENTS AND LEARNING TOOLS

Classrooms and other learning environments can be constructed in ways that promote greater inclusivity, as well as develop feelings of belonging for girls (Cheryan et al., 2009, 2011). Cheryan and colleagues propose that the physical learning environment includes ambient identity clues that can either reinforce inclusion or communicate stereotypes about who belongs in that space.

In terms of technology-enhanced learning, numerous studies suggest that Web-based inquiry-orientated science instruction can be effective in producing positive student attitudes towards science and science instruction (Lee & Erdgan, 2007; Slotta & Linn, 2009).

Girls enjoy the social aspects of computers where they can communicate with others, for example email, (Leong & Hawamdeh, 1999). In face-to-face situations, the Web provides scope, flexibility and access to pursue questions of personal interest and to compare ideas, analyse evidence for students' own ideas and help to distinguish among ideas – important processes of science (Linn & Eylon, 2011; Slotta & Linn, 2000; Wallace et al., 2000).

Web-based collaborative inquiries provide students with more autonomy and situates teachers as facilitators, with no apparent differences between girls and boys in this context. This may be important to overcome the tendency of teachers to hold the conception that higher order cognitive abilities are only suitable for certain students, such as those in identified science tracks as opposed to general tracks (Chan & Lee, 2007). If technology, e.g. sensor technology, is used effectively as a tool for creative work, students can be more autonomous, collaborative, and reflective than in classrooms where the technology is not present (NCES 2012a, 2012b).

Learning science and engineering processes

Students need to engage in practices that are a clear representation of what scientists and engineers do as they engage in the scientific inquiry process (Quinn et al., 2013), allowing students to ask questions, develop and use models, plan and carry out investigations, analyze and interpret data using mathematics and computational thinking, construct explanations (science) and design solutions (engineering), engage in arguments using evidence, and evaluate and communicate information.

Engineering is often absent from school curriculum and rarely taught explicitly. If it is taught, this curriculum is often more tailored to boys than girls, and on who is doing the teaching – males, females, mixed. For example, the notion of 'build' as part of the engineering process needs to be broadly conceived to include building in socially relevant ways. Similarly, 'figuring things out' should not just be about building. In developing a positive STEM identity, it is important that broader notions of building, 'solving it', etc. of the engineering process include more socially embedded interpretations of these processes. Curriculum needs to be inclusive as does the delivery of such curriculum.

An additional curriculum problem is that engineering often states that science and mathematics are foundational to engineering. Such a statement may be true but, from a school perspective, it could be taken to suggest that if we attend to science and mathematics, then engineering will take care of itself. Hence, it is important to engage students in practices that are clear representations of what scientists and engineers do to highlight the differences and the similarities. One example of engineering being embedded in curriculum can be found at Engineering is Elementary (eie.org), a US curriculum website for years one to five. To some extent STILE (stileeducation.com) includes some engineering in units, although it appears to be added on, rather than embedded, and the focus is clearly on science.

PEER INFLUENCES

There is significant evidence that peers impact girls' STEM interest, identity, self-efficacy, and, ultimately, their career trajectories (Archer et al., 2012; Aschbacher et al., 2010; Bandura et al., 2001; Calabrese-Barton et al., 2013; Denner, 2011; Fouad et al., 2010; Raabe et al., 2019; Webb-Williams, 2018). Peer influences may vary across contexts and educational stages. For example, in their survey of more than 900 students, Fouad et al., (2010) found that middle school students reported negative peer pressure as a significant barrier to STEM engagement, while secondary school girls described peers as a source of positive support. In a recent large-scale analysis of Swedish adolescents, Raabe and colleagues (2019) report that girls tended to adjust their STEM preferences to those of their friends, and in contexts where peers enjoyed STEM, also reported higher levels of STEM engagement.

Male students may engage in policing behaviours with respect to STEM belonging. Female students report more experiences of negative bias from male than female peers (Leaper & Brown, 2008; Robnett, 2016; Stake & Nickens, 2005), although female peers may also display negative bias (Leaper & Brown, 2008). This underscores the need to develop an overall inclusive approach to STEM and engineering education, rather than simply target more girls and women for recruitment.

Dasgupta and colleagues (Dasgupta, 2011; Stout et al., 2011) proposed that peer experts (high-achieving, near age female students) could provide inoculatory effects against negative STEM bias. Their experimental work in university students provides compelling evidence of this inoculatory effect (Stout et al., 2011). Specifically, they demonstrated that female students who worked with an advanced female peer demonstrated more positive maths attitudes and identity, and showed increased performance effort, compared to students who worked with an advanced male peer.

FAMILY AND COMMUNITY

Parents and families exert a broad range of influences on their children's STEM self-efficacy, identity, attitudes, and participation (Aschbacher et al., 2010; Bandura et al., 2001; Jacobs & Bleeker, 2004). Parents may hold explicitly stereotyped views about girls' STEM ability and suitability for STEM careers (Aschbacher et al., 2010; Bhanot & Jovanovic, 2009; Gudyunga et al., 2016; Tenebaum & Leaper, 2003; Sansone, 2019). Furthermore, parents may actually underestimate their daughters' interest in STEM (Ford et al., 2006; Jacobs & Bleeker, 2004). In some contexts, girls reported less parental encouragement to pursue post-secondary careers in general, and STEM careers specifically (Aschbacher et al., 2010). In a large-scale, longitudinal analysis of US school children, Jacobs and Bleeker (2004) reported that parents were more likely to purchase maths and science items for their sons than their daughters, resulting in greater opportunities for boys to practice STEM skills at home. However, their research also found evidence that parents invest more time in maths and science activities with their daughters.

Families may also unwittingly introduce anti-STEM bias into interactions with their children by gendered activity choices (Lubienski et al., 2013). Lubienski and colleagues (2013) report that, despite parental assertions of egalitarian beliefs, parents influenced highly gender-segregated after school activities for their children, especially in higher socio-economic status families.

There is little research into direct impacts of local communities on girls' STEM engagement. This may be related to large bias toward publication of Eurocentric[2] contexts in the English language literature. Reporting on student career aspirations, Archer et al., (2014) cite the influence of family, friends and neighbours on students' intended career choices. They describe how forms of social and cultural capital are reproduced in 'socially advantaged' circles which provide students with career access beyond information provision (p.70).

LEVEL 3: BROADER CONTEXTS

SOCIO-CULTURAL CONTEXTS

Different cultural norms may impact whether, and what form of, STEM is emphasized as an appropriate career trajectory for young women (Archer et al., 2013; Aschbacher et al., 2010). Archer and colleagues (2013) note that disidentification with STEM may be 'exacerbated by social inequalities, which render science aspirations potentially less thinkable for working-class girls' (p.178). Parents and students alike cite traditional and social media as significant influences on student perceptions of STEM and scientists, as well as personal career aspirations (Archer et al., 2013, 2014; Tan & Jocz, 2017: UNESCO, 2017).

SOCIO-ECONOMIC CONTEXTS

Socio-economic contexts, including the type of STEM career available within the local region, influences whether girls more easily see themselves as taking up a STEM trajectory. Some researchers have pointed toward structural issues in rural communities, such as lower socio-economic conditions and an absence of diverse career options, as barriers to educational attainment across disciplines (Adedokun & Balschweid, 2008).

SOCIO-POLITICAL CONTEXTS

In a meta-analysis of two large datasets (TIMSS and PISA), Else-Quest et al., (2010) found that factors related to gender equity, such as school enrolment, proportion of female parliamentarians, and representation of women in research positions, were the largest predictors of cross-national differences in girls' relative performance in mathematics. This suggests that more equitable socio-political contexts encourage more inclusive STEM learning environments, benefitting girls. The researchers noted an interesting relationship between mathematics performance and attitudes. Although performance and attitude are positively correlated at the student level, that is, students who perform well in maths also report more positive maths attitudes, at the country level, this correlation is negative. In other words, students in countries with high overall mathematics performance tend to report more negative attitudes than those in lower-performing contexts. This may be related to diminished enjoyment and/or higher anxiety in more performance-oriented mathematics contexts, such as Australia.

In summary, the influences on girls' engagement in STEM education are complex, interacting through a socio-ecological model. Even with extensive resourcing, a single intervention is unlikely to be able to adequately address the multitude of factors affecting girls' STEM attitudes, identity, self-efficacy, and ultimately, recruitment into engineering post-secondary

[2] There is no widespread agreement on which term best encapsulates the dominant influence of Eurocentric research; i.e. research emanating from Europe and colonized territories, in particular, the United States, Australia, Canada, New Zealand.

and career trajectories. In the following section, we build on the socio-ecological context of girls' engagement in STEM and outline key considerations for the development of STEM intervention programs.

3 CONSIDERING INTERVENTIONS

> *Too often well-intentioned individuals embark upon intervention programs without a clear understanding of what 'the problem' is for which the intervention is the solution. At best, such endeavours could be ineffective; at worst such 'interventions' could end up doing more harm than good if they are reinforcing damaging gender assumptions.* (Trauth, 2012, p. 53)

This section provides some critical considerations of the development of STEM interventions to increase representation of girls in engineering and other STEM disciplines. These considerations were developed from extensive literature review into influences on girls' engagement in STEM, as well as the systematic review of intervention programs.

KEY CONSIDERATIONS FOR DEVELOPING INTERVENTIONS:

- **The arena of intervention.** Both school-based, and out-of-school intervention programs have been demonstrated as effective in increasing girls' STEM self-efficacy, overall STEM enjoyment, and recruitment into STEM post-secondary programs (Habig et al., 2018; Kitchen et al., 2012; Patrick et al., 2009; Ward et al., 2015; Watermeyer et al., 2012). Some programs work effectively with schools to supply break-time and after school initiatives that take place at participants' schools (Jenson et al., 2011; Pinkard et al., 2011; Solberg 2018). There is evidence that shifts in mindset can be achieved through both arenas.

- **The notion of achievement.** What does it mean to achieve? Is it knowledge and skills acquisition; the application of knowledge; capability, performance and competence; or something else? The role of standardised testing and its influence in determining what is seen as achievement is important. There is increasing evidence that STEM achievement has little to do with girls' under-representation in STEM, including engineering (Hill, 2010; Wang & Degol, 2017). In a 2010 report for the American Association for University Women, Hill and colleagues note that gender gaps in STEM achievement are closing and that the engineering workforce is not populated by the highest STEM achievers. Rather, participation in engineering and other STEM disciplines appears to relate primarily to interest.

  In a recent analysis of the overall gender gap in STEM, Wang and Degol (2017) note that high-achieving girls and women tend to achieve well across multiple academic domains, which provide them with many avenues for post-secondary and career attainment. They hypothesize that, rather than opting out of STEM, many women and girls are simply choosing alternatives, and suggest increasing girls' interest in STEM through an emphasis on applied, altruistic forms of STEM education. This is supported by a wide literature base within this review (Puttick & Tucker-Raymond, 2018; Solis et al., 2019; Svarovsky, 2011).

- **Understanding the needs of the population.** Related to the notion of achievement is understanding the population. Many studies were based on high/low achievement (which returns to the question of what is achievement), gender, race, high or low socio-economic status, rural and remote or urban. Whatever interventions occur, there are different impacts for different groups within society. Therefore, knowing your target audience, and developing a program based around their needs, is critical. Middle class families often access more structured forms of STEM learning for their children (Archer et al., 2010) and, as such programs often serve as recruitment pipelines for STEM post-secondary, this results in under-representation of girls in lower socio-economic status families. Similar access issues exist for rural versus urban girls (Bystydzienski et al., 2015).

  Building in program mentorship which includes relatable cultural and socio-economic status mentors is one effective method of addressing these challenges. Other considerations include addressing barriers for program attendance, by not only considering program costs, but also the opportunity costs of taking part in a program. For example, in their summer program Rural Girls in Science, Ginorio and colleagues (2012) describe providing participants with compensation for lost wages, as the girls involved in the program would normally be completing summer jobs as a financial necessity for themselves and their families.

- **Target age.** Ideally, students should have access to excellent, inclusive STEM education, including out-of-school opportunities throughout their entire education trajectory. The middle years (ten to fourteen) have been identified as a critical age for intervention, as overall student interest in school begins to decline during this age and the STEM gap between boys and girls widens (Kerr & Kerpius, 2004). This does not mean that all intervention programs should necessarily target the middle years – different intervention programs have different goals. Students with multiple, intersecting, minority identities, for example, Indigenous girls in rural Australian schools, may be forced out of the STEM pipeline earlier than others. Making engineering and design-based learning explicit early in students' primary school experience may provide inoculatory effects that offset later negative experiences (see Aschbacher et al., 2010; Schumacher et al., 2012 for evidence of such persistent effects).

- **The pedagogical approach.** Any intervention will be dependent on who is the target population. However, it also needs to include a range of approaches such an inquiry, project-based, problem-based, collaborative and/or co-

constructive (where teachers are also learners in the experience). What is essential from the literature is that the educational experience needs to be a positive and inclusive one, where all participants feel that they can succeed. There is a widespread perception among students that STEM education, as practiced in schools, is divorced from real-world contexts and is therefore not ‘real science’ (Archer et al., 2010, 2012). Increased integration of applied and problem-solving approaches has been demonstrated to increase students’ STEM interests. Additionally, girls report enjoying collaborative problem-solving approaches in STEM (Asterhan et al., 2012; Stoeger et al., 2017). Collaborative work can also supply the benefits of strong, STEM-interested peer networks, which is an important influence on girls’ interest and engagement in STEM (Fouad et al., 2010; Habig et al., 2018).

Promoting a growth mindset. This consideration applies across all potential intervention target groups: students, teachers and other school staff, and families. As Wang & Degol (2017) summarise, ‘individuals with a fixed mindset believe that intelligence is a static trait or an innate ability, while individuals with a growth mindset believe that intelligence is malleable and that effort, practice, and persistence can enhance ability over time’ (p.126). The belief that scientific and mathematical abilities are innate and fixed is widespread and especially detrimental to girls and other under-represented groups (Hill et al., 2010; Perez-Faulkner et al., 2017; Wang & Degol, 2017). There is compelling evidence that a growth mindset counters stereotype threat, and promotes persistence and achievement in STEM (Dweck, 2006; Good et al., 2003). Promoting a growth mindset needs to begin in early years and continue throughout the educational process (Dweck, 2006; Good et al., 2003). Consideration of the intersection between neuroplasticity and engineering may be a useful meta-cognitive approach; that is, teaching about the biological capacity for growth and change whilst reinforcing connections to girls’ personal STEM trajectories.

- **Knowledge.** There is an imperative to make engineering explicit in the curriculum, regardless of other important considerations such as role models, interest, context and integration into different knowledge domains. If it is being addressed currently, students need to know that ‘this is what engineering is’ (as opposed to more general or allied design technology). Engineering has an image problem in schools. How engineering relates to social agendas is also important and the SDGs may be useful to connect engineering to more socially embedded activities that girls are interested in.
- **Mentoring.** Effective mentoring can increase girls’ confidence and competence, in addition to providing emotional support (Reid & Roberts, 2006; Stout et al., 2011). Mentoring can take many different forms, and the model adopted within a given intervention should be linked to the target audience, as well as to program purpose. Mentors should be relatable to program participants, sharing similar gender and/or racial backgrounds. Near-age mentors have been consistently demonstrated as effective, in particular because they represent attainable role models. Research into specific STEM interventions emphasises the importance of diverse representation of mentors in reducing student STEM stereotypes and bias (Dahya et al., 2017; Pinkard et al., 2017).

  Mentoring can take place in physical, face-to-face, environments, through online platforms, or in hybrid models. An example of online mentoring is provided by Stoeger et al. (2017), who demonstrated the effectiveness of online, group mentoring approaches. It is apparent from the literature that mentoring needs to be sustained over a significant period of time (at least twelve weeks but more likely at least a year). Habig et al. (2018) report on the effects of a long-term STEM mentoring program, including encouraging persistence in post-secondary education.
- **Effective training for teachers and mentors.** All program educators need to have effective training, not only in STEM teaching, but also in pedagogies responsive to program participants’ backgrounds. Many out-of-school STEM programs rely on educators and mentors without formal training in STEM education, which renders program success reliant on the charisma and ad-hoc teaching ability of individual mentors. Conversely, undertraining of teachers in STEM content areas and teaching methods is a challenge exacerbated for the discipline of engineering, as few teachers have undertaken post-secondary engineering courses. Collaborations between faculties of education and engineering could enhance both pedagogical and engineering STEM capabilities.
- **Career counsellors as an overlooked resource.** Several programs reported in the literature included career counsellors as part of their intervention program (Bystydzienski et al., 2015; Kelly et al., 2013). Given the potential for school counsellors to serve as gateway facilitators or barriers for STEM extracurricular programs, post-secondary programs, and financial aid (Falco, 2017), there is relatively little research reporting on programs primarily addressing school counsellors (Falco, 2017; Falco et al., 2010). Effective interventions targeting school counsellors to reduce biases, and provide effective, sustained support of non-traditional STEM students, are needed (Aschbacher et al., 2010; Falco, 2017).

EVALUATION OF PEER REVIEWED INTERVENTIONS

After reviewing a large number of intervention studies, there are some salient points that underpin the criteria for what constitutes a ‘gold standard’ intervention. However, it is important to note here that systematic reviews of evidence conducted by Slavin (2009a, 2009b) argue that twelve weeks constitutes a usual minimum intervention time for generating impact and change in the classroom and that it needs to be embedded in normal classroom activities so that it is not seen as ‘other’ and compartmentalized. Archer and colleagues (2014) provided similar conclusions in their analysis of a UK STEM program, noting that extended program length provides opportunity for ‘consolidation and reflection’ (p.52).

In this analysis, we include a total of 115 peer reviewed articles reporting on 116 STEM intervention programs either developed explicitly to increase girls' engagement and recruitment into STEM fields, or with unusually positive findings with respect to girls' engagement. We included only programs that exceeded a single activity or day-long event. We categorized programs into short term (one month or less), medium-term (~five to eleven weeks), and long-term interventions (twelve or more weeks), meeting Slavin's time requirement for effective interventions.

As indicated in figure 2, nearly half of the reported interventions (47 per cent, 55 total) were long-term, lasting from twelve weeks to a maximum of seven years in length. A smaller number (18 per cent, 21 total) were medium-term interventions, while 35 per cent (40 total) were short term interventions. The majority of reported short-term interventions were summer camps taking place over one to two weeks.

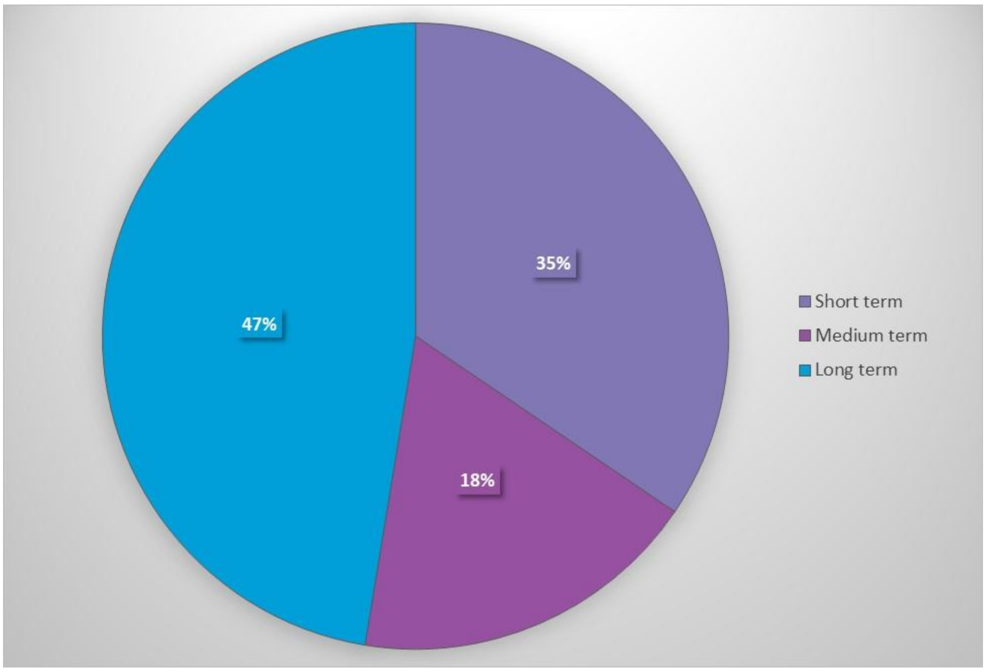

Figure 2. Interventions reported in the peer reviewed literature

There was little longitudinal analysis of program impacts; however, for recent exemplars, see the work of Bystydziendski and colleagues (2015), and Habig and colleagues (2018).

Concerningly, the overwhelming majority (70 per cent) of peer reviewed research reported on US-developed and implemented STEM intervention programs for girls. Other countries represented include Germany (eight articles), Canada (five articles), and Australia (four articles). In total, only sixteen countries are represented within this dataset, with particularly strong regional under-representation of Latin America (one article from Ecuador), and Africa (three articles, one each from Kenya, Nigeria and South Africa). Figure 3 presents the regional representation of STEM intervention evaluations, across North American, Europe, Asia-Pacific, Africa, and Latin American and the Caribbean.

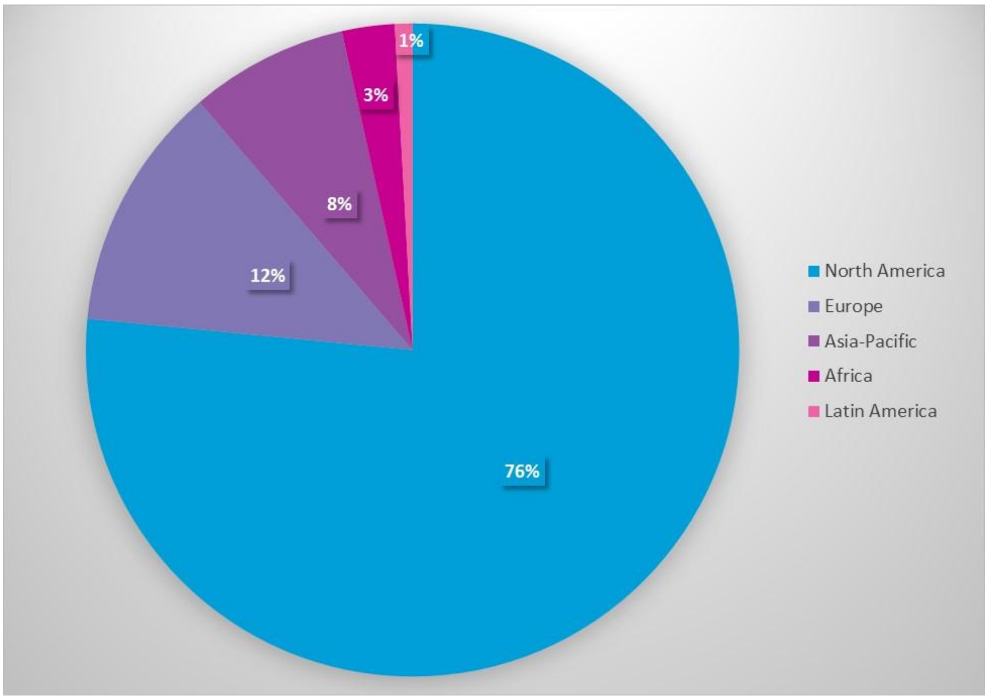

Figure 3. Regional representation across peer reviewed evaluations of STEM interventions targeting girls' engagement

Given that we know there is considerable cross-national variation in STEM achievement, attitudes, and interests, as well as influences of different national and subnational education systems and school environments, family and community influences, extracurricular and out-of-school opportunities and structures, cultural, racial, gender, class, and ability-based intersections, we can conclude that we have evaluated very little of the diverse potential STEM and engineering engagement programs for girls. We make this statement with the caveat that it is likely that this review has excluded some peer reviewed results published in languages other than English. Nevertheless, it is crucial that STEM intervention programs developed and administered in other national contexts receive peer reviewed attention. Directing resources toward research translation of identified bodies of STEM education literature published in other languages, for example Mandarin or Spanish, could uncover more diverse literature sources.

FOCUSING ON ENGINEERING INTERVENTIONS

Of the 115 articles included, twenty-five (21.7 per cent) included engineering as a substantial focus. There were only four articles evaluating engineering-focused interventions outside the US (one study from each of Australia, the UK, Israel, and Italy). This indicates a significant gap in peer reviewed program evaluation of intervention programs focused specifically on girls and engineering.

In terms of target age, just over half of reported interventions (52 per cent, 13 total) addressed the middle years (equivalent to years six to eight), while the remainder were split between primary and secondary education (eight and seven interventions, respectively). Interventions undertaken with primary school students (early years through year five) were mainly programs embedded into the primary curriculum, while interventions undertaken with middle school and secondary school students were generally stand-alone programs that took place out of school, including after school and/or through summer camps.

DEVELOPINGING GOLD STANDARD STEM INTERVENTIONS

As a result of this systematic review, we propose that the following seven questions serve as guiding criteria for developing a "gold standard" STEM intervention:

1. What ***type of intervention*** is it – in school or outreach?
2. What is the ***target population*** and size? Why?
3. What is the ***purpose/rationale*** of the intervention? What is it actually addressing?
4. ***Who needs to be involved*** through each stage of development, implementation, and evaluation? Are there any stakeholders not currently at the table that need to be invited?
5. ***How long*** will the program run? Are there follow-up or maintenance components that can be included?

6. How will we ***measure*** the impact (intended, actual, long-term) of the intervention? Do we have adequate resources for a long-term evaluation?
7. What are the opportunities for scalability and/or sustainability?

MEASUREMENT TOOLS FOR EVALUATING IMPACT OF INTERVENTIONS

Our review of the literature identified some common tools used for evaluating impact, including scaled instruments, which we have listed below.

Primary school

- Patrick et al., (2009) used the Puppet Interview Scales of Competence in and Enjoyment of Science (PISCES), which is intended for use with young children.

Middle school

- Kim et al., (2016) used the Attitudes Toward Science Survey (ATSS), which they developed based on Gibson & Chase's (2002) Science Opinion Survey. The ATSS covered cultural stereotypes, interest in science, student confidence/desire to do science, and attitudes toward scientists and science-related careers.
- Heddy & Sinatra (2017) used the Transformation Experience Scale (TES), developed and validated by Pugh and colleagues (2010). The TES consists of three components: motivated use, expansion of perception, and experiential value.
- Norton (2006) used a modified version of the Test of Science-Related Attitudes (TOSRA) developed by Fraser (1981). He adapted it specifically for maths.
- Schumacher et al., (2009, 2012) used a modified Attitudes Toward Science Scale (Fennema & Sherman, 1996; Doepken et al., 2001), an Occupational Stereotypes scale (White et al., 1989), an Educational Self-Efficacy for Science Occupations scale (Betz & Hackette, 1997), an Efficacy for Completing Science Course Work scale (Lent et al., 1984) and a Self-Esteem Scale (Rosenberg, 1965).
- Todd & Zvoch (2019) used the interest scale from the Colorado Learning about Science Survey, the Self Efficacy scale from Eccles (1984), the Attitudes Toward Science in School Assessment (Germann, 1988), as well as a Science Identity Survey (Todd, 2015).
- Holmes et al., (2012) used a measure tool, Attitudes Toward the Mentoring Experience, adapted from Allen & Eby (2002), as well as the Fennema-Sherman Attitude Towards Science Scale.

Secondary school

- Falco & Summers (2019) modified Fouad's Middle School Self-Efficacy Scale for use with secondary students (and completed a pilot to establish its reliability) to assesses the effect of intervention programs designed to promote career decision-making and maths and science career awareness.
- Raes et al., (2014) used the Interest in Science Scale from PISA 2015.
- Archer et al., (2014) used a scale from the ASPIRE project, which focused on science aspiration and attitudes, as well as participation and parental attitudes.

4 IDENTIFIED GAPS IN THE LITERATURE

There is limited longitudinal data in the review of literature pertaining to interventions addressing the issues surrounding participation in STEM. Therefore, is it difficult to judge the long-term impact, or the persistence of the impact, of such interventions; hence, the need for more formal and ongoing evaluation processes.

The literature review examined existing interventions, which do not necessarily represent best practice. For example, the literature details the need for interventions of an ongoing nature (at least twelve weeks or longer) and the need to embed such interventions into the culture of STEM, and engineering in particular.

Much of the literature refers to STEM rather than specifically engineering, with the pathways to engineering not apparent. While STEM may be appropriate in the early and primary years of schooling, when does the pathway to engineering need to become explicit – is this in secondary school or earlier or later.

In terms of target populations, there does not appear to be clear decision-making processes around what population to target: high achieving girls, low achieving disadvantaged girls, rural and regional girls, girls from under-represented racial groups, and so on. The identification of population needs consideration. For example, high achieving girls may need different interventions if they are already following a STEM pathway than those high achieving girls who do not intend to do so. Similar arguments for other groups also exist.

5 POSSIBLE ACTIONS

In addressing the need for action, and based on our systematic review, we are proposing the following three actions. We have listed them in a suggested order of priority.

ACTION 1 – EVALUATION OF AVAILABLE ENGINEERING (STEM) INTERVENTIONS TO MAP THE LANDSCAPE AND BUILD THE EVIDENCE BASE OF IMPACT

Given the limited longitudinal data pertaining to interventions and, therefore, the lack of knowledge around the long-term impact or persistence of impact of interventions, it is important that formal and ongoing evaluation of interventions take place. While establishing a national evaluation framework is part of the Women in STEM Decadal Plan, it will be important that evaluations take account of interventions across the life span – from early childhood, through school and the multiple pathways after the compulsory years of schooling. Additionally, the evaluation framework needs to include significant stakeholders other than children and students, such as parents, teachers, education leaders and community members. While study choice is one important factor, it is by no means the most important factor to be measured. This literature review has highlighted the multiple factors that need to be considered when developing an evaluation framework.

In building a national evaluation framework, the seven questions that frame what could be considered gold standard criteria for interventions will become important to ensure the target audience has been identified; the purpose of the intervention is clear; it addresses identified needs; and the impacts on the audience can be assessed. Additionally, evaluations of impact will need to include attitudinal change, development of a STEM identity, building of self-efficacy in STEM, challenging the notion of STEM as ‘other’ for the majority of the population, changing perceptions of what it means to achieve as well as the strengths, weaknesses, opportunities and threats identified in such interventions. For this reason, a number of existing measurement tools for evaluation of impact of interventions have been included to begin building the necessary longitudinal data.

The evaluation framework also needs to take into account the context in which the intervention takes place, whether it be at the level of the individual learner, the immediate context of schools, family and peers or the broader socio-cultural, socio-political or socio-economic context.

Ultimately, the evaluation framework should provide the data needed to map the engineering and STEM intervention space, as well as provide evidence on its impact across the country. Such a map will also provide evidence of what populations are or are not targeted and assist in the decision-making process to fund a comprehensive intervention system.

From the literature, it is evident that interventions need to be specifically based around the individual learner with early interventions (based on neuroplasticity studies) to build girls’ linguistic, number and spatial skills, strengthen girls’ self-confidence and self-efficacy and improve girls’ behavioural, cognitive and emotional engagement (Shernoff et al., 2016). At the immediate learning contexts of schools and community, interventions need to focus on the provision of appropriate role models and mentors that closely identify with intervention participants to support the development of positive STEM identities to engage families and peers in STEM experiences and dialogue from the earliest ages through to adulthood. At the broader context level interventions could address many of the actions necessary to progress SDG goals 4 – quality education; 5- gender equality; and 10 – reduced inequality.

ACTION 2 – INCLUSIVE VISION FOR STEM AND ENGINEERING

This action is to address the significant issue of the persistent stereotypes of STEM and engineering through communication, curriculum, work practices and mentoring. Messaging around engineering remains relatively silent and traditional views of engineering persist in the general population. While the visibility action from the Women in STEM Decadal Plan contributes to this action, it is only a beginning. To create an inclusive vision for STEM and engineering, it will be crucial that messaging, work practices and mentoring are inclusive and go beyond providing positive role models. One of the successful strategies in other professions (medicine, health, nursing and education) has been the identification of the non-academic qualities required in these professions as well as the academic qualities. Selection of students into programs in these fields includes non-academic qualities through different mechanisms (UMAT/GAMSAT in medicine, Situational Judgement Tests such as CasPer in education). Qualities such as interpersonal skills, empathy, and so on have become essential components of what is needed to work in these fields.

Current models of engagement for students (cognitive, affective and behavioural) operate on a deficit model (what is negative for girls and boys). Boys have a ‘policing the boundaries role’ about who belongs (as they belong in engineering), so there is an active need to create a gender inclusive vision for STEM and engineering. While the ‘male champion’ strategy attempts to address this issue to some extent, again, the message around having male champions is also a defining strategy about the gendered nature of engineering and particularly work practices. There are many groups identified in this review that do not identify with engineering and STEM (for example girls, rural and remote, differing ethnic groups and so on). These excluded groups need to see engineering and STEM as real possibilities. This will only occur when they see they are invited and welcomed and do not identify engineering and STEM as ‘other’.

Rather than present a negative view of STEM and engineering, we need to turn this into a positive vision that includes everyone, both girls and boys. Communication of an inclusive vision of STEM and engineering is crucial and needs to be more socially embedded. This inclusive vision would also be present in curricula across the entire education sector (school and higher education). This action would also need to develop mentoring interventions that create positive STEM identities and STEM career decision-making self-efficacy.

This action would include:

- Identified leaders in engineering to be challenged to present an inclusive vision of engineering that can form the basis of a strong marketing campaign. Such a vision would need to be mindful of the attributes of the successful workers (technical and professional) in STEM and engineering.
- Analysis of curriculum (K-12 and tertiary) and of work practices (STEM industries, including education) for their representation of an inclusive vision for engineering. Such an analysis would need to consider academic and non-academic qualities as well as inclusive STEM and engineering practices that are embedded in broad contexts (socio-cultural, socio-political and socio-economic). Again, the SDGs provide examples of such broad contexts.
- Development of mentoring inventions to develop positive STEM identities and STEM career decision-making self-efficacy. As identified in the review, for sustained change, interventions would need to be at least twelve weeks and usually more sustained for at least one year. Different types of mentors are needed and real connections are essential. Successful mentoring relationship often develop when there are similar connections such as girls from rural backgrounds, a similar age bracket (ideally no more than five years apart), similar passions, such as making a difference to the environment, and so on. Mentoring also needs to be from across the technical and professional working sector. Far too often the focus is only on the professional and pathways to STEM and engineering careers become invisible.

The achievement of an inclusive vision for STEM and Engineering will be evident when the public perceptions of Engineers and STEM workers will be an inclusive one and not seen or stereotyped by such a large proportion of the population as “other” or more specifically a male occupation.

ACTION 3 – WORKING WITH EDUCATION TO CREATE A STEM AND ENGINEERING IDENTITY IN SCHOOLS

Engineering has an identity problem in schools – structurally, personally and pedagogically. There is a need to provide instances where engineering is front and centre. Stating that engineering relies on strong foundational knowledge of science and maths just reinforces the idea that if teachers attend to science and maths, then engineering will look after itself. Engineering needs to be explicit when it is experienced within the school curriculum; it needs to be personally relevant and pedagogies (collaborative, inquiry-, project- problem-based, contextually embedded) need to be inclusive and have broad social appeal. Again, the SDGs provide opportunities here as they also address broader views of what it means to ‘fix’, ‘build’ and ‘solve’. There need to be positive educational experiences where engineering is the focus. Given the findings around neuroplasticity, the need to provide exciting, creative and high quality, positive educational experiences from an early age is crucial.

Engineering faculties and industries need to work collaboratively with education faculties to build strong STEM and engineering practices within both the initial teacher education sector and the teaching profession. Opportunities for teachers across the early years and compulsory years of schooling to engage in professional learning programs that are authentically focused on developing STEM and engineering capabilities within the future and current teaching profession are fundamental to building STEM identities and self-efficacy in students. It is important to acknowledge the collaborative nature of this action between engineering and education: interventions cannot be just about producing more knowledge, but must be about how to access and embed existing knowledge within the current educational structures of early learning and schools. This is fundamental as neither STEM or engineering are explicit within the current Australian curriculum, and education faculties are playing a major role in helping schools meet these structural challenges.

An example of such collaboration has been between the faculties of engineering and education at Monash University. The Faculty of Education has an extensive STEM suite of programs available to pre-service and in-service teachers that includes:

- A series of four ‘STEMinars’ across the year where academics, professionals from industry, and school teachers share positive and high quality STEM learning, teaching and programs. These are free and act as an invitation into this space.
- A suite of professional learning courses where notions of STEM are explored and then specific programs such as Making Engineering Explicit in STEM Education are available. These are fee-based short courses.
- An award course in STEM, the Graduate Certificate in STEM Education, will provide deeper educational dives into the knowledge base and contemporary practices within the STEM sector and the building of educational practices around this knowledge base and practices. This course is fee-based and needs significant support for teachers to participate (for example, through the provision of scholarships).

- Future additions to this suite of programs would also need to focus on career teachers and on extending the reach to a wider range of authentic settings that include industry-based technical and professional work. Additionally, how to provide more access to a wider audience for the whole suite of programs is important even though these are currently offered in virtual classroom modes.

Working with education with respect to careers teachers is equally important in making the multiple pathways into STEM and engineering careers explicit. Careers teachers have traditionally undertaken a university-based pathway to teaching, so there is significant work to be done in their professional learning to broaden their experiences about technical as well as professional pathways and the general world of work.

The development of a STEM and engineering identity in schools will be evident when not only are there enough STEM teachers across the education sectors, but when students see the possibilities of engaging in STEM and engineering and follow multiple pathways into these fields. It will also be evident when all students see the social value in STEM and engineering as they engage in their adult lives.

6 FINAL COMMENTS

There are a number of ideas, frameworks and evaluative tools that can be used in interventions from within the reviewed literature. The real opportunities for making a difference come from the collaborative opportunities of implementing actions. The actions proposed above address specific issues, such as providing access to high quality positive educational experiences, and also address the broader perspectives of persistence of stereotypes and career possibilities. We would like to thank the Engineering for Australia Taskforce for the opportunity to engage in this process of reviewing an evidence base that will allow them to move forward in addressing their passion for an inclusive pathway for all into STEM and Engineering.

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APPENDICES

APPENDIX 1: SEARCH TERMS

1st set of search terms (STEM education)

STEM AND educat* OR teach* OR learn* OR pedagog*
AND
gender OR female* OR girl* OR women
AND
barrier* OR bias* OR gap* OR success* OR engagement* OR inclusion* OR intervention*
AND
school* OR "early years" OR preschool* OR kindergarten*

2nd set of search terms (Engineering education)

Engineering AND educat* OR teach* OR learn* OR pedagog*
AND
gender OR female* OR girl* OR women
AND
barrier* OR bias* OR gap* OR success* OR engagement* OR inclusion* OR intervention*
AND
school OR "early years" OR preschool* OR kindergarten*

3rd set of search terms (Science, technology, mathematics education)

"science education" OR "technology education" OR "mathematics education"
AND
gender OR female* OR girl* OR women
AND
barrier* OR bias* OR gap* OR success* OR engagement* OR inclusion OR intervention*
AND
school* OR "early years" OR preschool* OR kindergarten*

4th set of search terms (Informal education programs)

STEM AND ("informal education" OR outreach* OR program*)
AND
gender OR female* OR girl* OR women
AND
barrier* OR bias* OR gap* OR success* OR engagement* OR inclusion* OR intervention*

APPENDIX 2: SEARCH METHODS

We included literature that addressed both formal and informal schooling (e.g. outreach programs, after school clubs) in early years, primary, and secondary education levels. We recognised that significant contributions to girls' STEM education existed within grey literature, such as government reports and white papers, and other institutional and non-profit organization reports. Therefore, we included both these forms of grey literature, as well as peer reviewed literature. While database searches are generally adequate for surveying peer reviewed literature, they may have incomplete coverage of grey literature. We developed a multi-step search process in order to comprehensively capture both peer reviewed and (specified) grey literature. In step 1, we searched ProQuest and Scopus databases; in step 2 we surveyed governmental and international organizations and select national organizational websites. Step 3 included forward and backward reference searching.

We developed sets of keywords for each database search in order to adequately capture different facets of STEM education, as well as both formal and informal schooling. These included combinations of STEM education terms, gender terms, terms addressing biases, barriers, and interventions, and terms addressing schooling levels. Appendix A.1 provides exact terminology and search combinations. This approach was developed through trial and error of different approaches; for example, we found that broad combinations of 'science' and various pedagogical terms yielded over 10,000 results, while searches that excluded levels of schooling returned mainly higher education results. The terms chosen here represent a balance between exhaustive searching and efficiency.

We developed a decision chart to guide review of documents for inclusion (figure 4, below) and to track the number of exclusions at each step of the process. Our initial combined database searches returned 6,591 unique references. After initial review of the literature returned, we made the following post-hoc exclusion decisions:

- Exclude documents published prior to 2000
- Exclude the following grey literature types: dissertations, conference proceedings

These exclusions were retained within the initial database so that we could return to them, if necessary, to verify findings with respect to gaps in the literature. After the above exclusions, we were left with 4052 documents.

All inclusion/exclusion decisions were documented through the online systematic review platform, Rayyan. Rayyan permits tracking of researcher decisions for each document, and includes 'blinded' and 'unblinded' review options. There were three analysts involved in document review, with a fourth providing guidance and oversight. In order to ensure consistency in inclusion/exclusion decisions, all four analysts reviewed approximately ten per cent of the database together, and discussed areas of confusion and conflict. We also completed a blinded review of subset of articles (102) with the three main analysts, documenting only nine conflicts (91 per cent of the decisions were unanimous). These nine conflicting articles were reviewed by all four analysts until a consensus on inclusion/exclusion was reached. Throughout the process, any uncertainties were flagged by individual researchers with a 'maybe' decision and were reviewed by an additional researcher. Where necessary, we completed full-text review to resolve all maybe decisions.

All articles for inclusion were then sorted into three main categories, based on the specific components of girls' engagement in STEM education:

a) Assessment of **barriers** to girls' engagement in STEM
b) Assessment of **cognitive, affective, and/or behavioural aspects** of girls' engagement in STEM
c) Assessment and reporting of **intervention programs** addressing barriers and/or girls' engagement

We completed full-text analysis of 115 peer reviewed articles reporting on intervention projects.

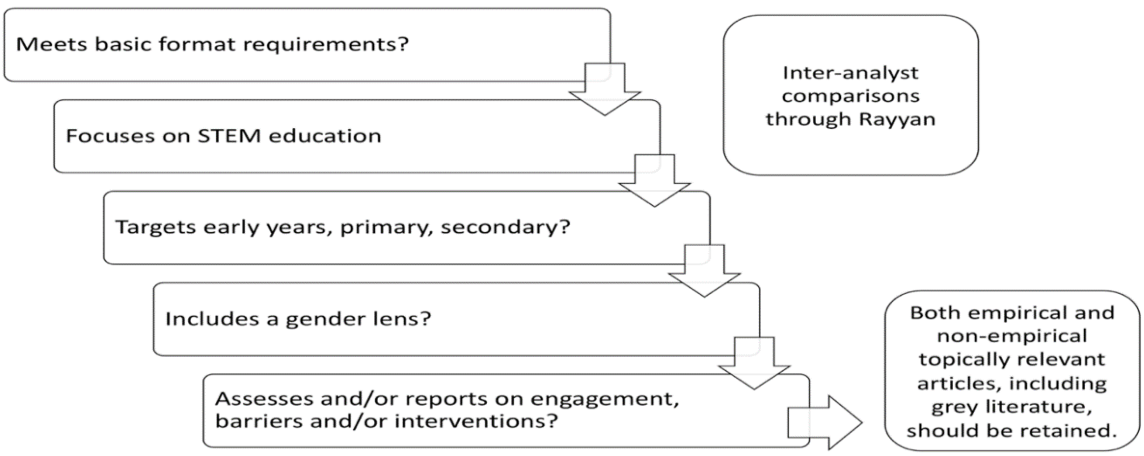

Figure 4. Decision tree guiding exclusion decisions for literature pertaining to girls' engagement in STEM

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