Engaging Primary Girls in STEM

BEST PRACTICE IMPLEMENTATION, INNOVATIONS & GAPS IN VICTORIAN CLASSROOMS

ACKNOWLEDGMENTS

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EXECUTIVE SUMMARY

The case for increasing girls' and women's interest and uptake in STEM careers has been clearly outlined and resonated with educators, industry, and policy makers in Australia.

International research has found that girls have a natural interest in STEM related subjects and activities. However, girls' interest in STEM is found to diminish, or be abandoned, as girls age. This is partly due to cultural and gender-based stereotypes which manifest in media and popular culture portrayals of STEM, messaging about STEM from parents, and the way STEM is presented and taught in the education system.

It is recognised that primary school years are critical in harnessing and developing girls interests and enthusiasm for STEM activities and education. However, some primary school teachers lack the knowledge, capacity, and confidence to teach STEM, and that an overpopulated curriculum does not lend itself easily to integrating change and STEM approaches to teaching.

In 2015, the Office of the Chief Scientist for Australia released a position paper recognising that STEM teaching needs to start in primary school and that unique challenges and responses are required to strengthen girls' STEM engagement.
It acknowledged that pre-service teaching courses need more rigor and further emphasis on increasing pre-service teachers' knowledge of science, mathematics and technology. The paper also calls for the transformation of STEM teaching in primary schools. Recommendations include a national professional development program for teachers, facilitating principal leadership, and providing access to STEM specialists in schools (Prinsley & Johnston, 2015).

The Invergowrie Foundation is a public charitable trust dedicated to the advancement of education of girls and women in Victoria. The Foundation has funded a three-year project to enable Swinburne University to develop resources and tools to assist teachers and parents with engaging primary school girls in STEM. This report forms part of the project: summarising recommendations for best practice and guides further project efforts.

This report is based on a review of current literature. A limited amount of published academic literature could be located that specifically addresses the intersection of primary school aged girls (approximately 5-11 years old) and STEM engagement. We found that more attention was paid to this topic by grey literature, mostly in the form of consultancy reports and reviews which were commissioned by government or industry. Findings from this review are reported below, with a focus given to everyday classroom practices within the current educational context.

This report addresses one of our key project objectives: to curate and create free resources for use by teachers and parents within the current environment to assist *the now to the future state.*

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BACKGROUND CONTEXT

Automation, data analysis, artificial intelligence, and other emerging technologies are underpinning a new world of work (Pricewater House Cooper (PwC), 2020). These technologies require a specific set of skills that are reinforced by science, technology, engineering, and mathematics (STEM). In the last five years, STEM-related occupations in Australia have increased by 160% compared to the average rate of other non-STEM jobs. However, there is an identified shortage of qualified STEM workers to support this growing economic need (The Australian Industry Group, 2015). In educational terms, this shortage requires a shift in focus.

The number of students who are choosing to study STEM subjects in later years of their education is declining. This suggests that action needs to be taken to ensure there is a pipeline of STEM professionals with the right skills (Kennedy & Odell, 2014) to address future employment needs. This pipeline commences with students in primary school; early STEM learning experiences are predictors for uptake of STEM subjects in later years and subsequent STEM careers (Rosicka, 2016). Girls' interest in STEM is related to multiple indicators such as their perception of self-efficacy and performance, and their social context, including parental expectations, their peers, gendered stereotypes, and the media (UNESCO, 2017).

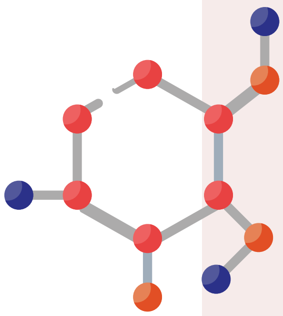
DEFINING STEM EDUCATION

The concept of STEM, originally known as SMET (Science, Mathematics, Engineering & Technology), was introduced in 2001 at the National Science Foundation in the United States by Dr Judith Ramaley. She rearranged the letters to STEM. In doing so, she emphasised Technology and Engineering as being integrated with Science and Mathematics (i.e. not considered inferior or secondary). The National Science Foundation did not define, precisely what STEM was, which left interpretation to the stakeholders, each with their own vested interest in STEM education and occupations.

The absence of a unifying definition and understanding of STEM continues to be acknowledged in Australia. Reviews of best practice suggest it may not be possible to have a unified definition (Hobbs et al., 2017). According to Hanover Research (2012, p. 9), "STEM education should include interdisciplinary and hands-on, experience-based pedagogical techniques" while acknowledging the lack of consensus regarding the method to this approach. Despite the popularity of the term STEM, its complex and multidimensional nature makes it difficult to produce a clear definition incorporating all important aspects.

The term STEM is often used as a shorthand to describe the four discrete fields of Science, Technology, Engineering and Maths. However, when used within the field of education, the meaning of STEM often extends beyond this. According to the Australian Education Council (2015, p. 5) the definition for STEM is:

> ...a term used to refer collectively to the teaching of the disciplines within its umbrella – science, technology, engineering and mathematics – and also to a cross-disciplinary approach to teaching that increases student interest in STEM-related fields and improves students' problem solving and critical analysis skills.



The Education Council's definition recognises STEM as both separate disciplines and as a cross disciplinary approach. STEM education definitions set STEM as a distinct integrated pedagogy larger than the sum of its parts.

The National STEM Education Resources Toolkit (Dandolopartners International, 2020) identified two common ways to refer to STEM education. Firstly, as individual subjects. Secondly, as an integrated entity.

An integrated approach to STEM promotes key skills such as problem-solving and creative thinking. Other researchers have also advocated an integrated approach to STEM (Breiner, Harkness, Johnson, & Koehler, 2012). The integrated approach removes the artificial silos of Science or Technology or Engineering or Mathematics. Rather, it takes the view: Science and Technology and Engineering and Mathematics.

Since real-life problems are interdisciplinary in nature, an integrated approach to STEM provides students with a context for engaging in authentic problem solving. The theoretical underpinnings for the integrated STEM approach to solving real world problems is provided by Dewey (Waks & English, 2017).

For the purpose of this report, STEM education is defined as an integrated teaching approach to Science, Technology, Engineering, and Mathematics disciplines and their relation to other disciplines in the curriculum. This approach is informed by experiential project-based and/or inquiry-led learning, with connections to real world situations and issues, and aims to enhance critical thinking and problem-solving skills.

DEFINING STEAM EDUCATION

STEAM is STEM with the additional integration of the Arts. The Arts include humanities, social sciences, language, arts, drama and visual arts and design. There is much debate surrounding the inclusion of the Arts. Some state that its inclusion is unnecessary, whilst others believe that the Arts are necessary for a fully integrated curriculum.

Those who argue for the inclusion of the Arts believe that the creative thinking approach can be applied to solving real-life problems. Whilst this approach seems sensible, it can be difficult to find teachers who are confident, and well credentialled, to teach STEAM. For this report, and to maintain consistency, we will focus on and use the acronym STEM.

The STEM Pipeline

Until recently, a 'leaky pipeline' has been used as a metaphor to illustrate the pathway along which girls progress through education and into STEM careers. 'Leaks' represent the barriers and challenges that girls' face in advancing along the pipeline, i.e., points at which girls drop out of the system. While the model is useful for identifying areas for improvement and for highlighting where efforts should focus in order to seal leaks, the model takes a deficit approach and looks backwards (Sammet & Kekelis, 2016).

In recent years, the model of a 'STEM pipeline', or ecosystem model, has emerged. It takes a broad view of the landscape in which girls can engage in STEM. It is forward oriented and focuses on opportunities rather than deficits. Furthermore, it considers connections and partnerships with and beyond the formal classroom setting (Chapman & Vivian, 2016; Sammet & Kekelis, 2016). The ecosystem model highlights the critical role of partnerships with community, and cultural and industry groups. Partnerships can provide opportunities and resources for implementing a STEM curriculum. The model further highlights the influence that family and communities have on young girls' ideas about and engagement with STEM. Partnering with families and communities can help 'build an understanding of the rigor of science education and helps parents develop an appreciation of the beauty and wonder of science to educate them' (Chiu, Price, & Ovrahim, 2015, p. 12).

Sammet and Kekelis (2016) advocate for industry role models. However, they also caution that just because a person may be actively involved in a STEM career, this doesn't necessarily mean that girls will identify with and/or look up to them (i.e. see them as role models).

In a report funded by the Australian Office for Women, Department of the Prime Minister and Cabinet, Chapman and Vivian (2016) apply their findings in best practice to engage girls in STEM to an Australian STEM ecosystem model. The ecosystem model is also used in The Australian Academy of Science 2019

Decadale Plan (2019, p. 4), which states "that cohesive and collective action is taken to maximise the attraction, participation and retention" to the STEM workforce, and uses the ecosystem model to frame their strategy and targets for 2030. The STEM ecosystem model integrates various best practice recommendations found in the current literature review and is a best fit as a conceptual model for integrating a STEM approach to primary school girls in Victoria, especially given its recommendation and use at the Australia-wide level.

Global Approaches to STEM Education

In 2017, the Irish Government (Brunton, 2017, p. 12) outlined their vision for STEM Education through their Policy Statement providing a roadmap to address areas of development:

> In line with our ambition to have the best education and training service in Europe by 2026, Ireland will be internationally recognised as providing the highest quality STEM education experience for learners that nurtures curiosity, inquiry, problem-solving, creativity, ethical behaviour, confidence, and persistence, along with the excitement of collaborative innovation.

Particularly for school settings, the Policy statement articulates their vision for schools, leaders, parents, teachers, and learners to have high awareness of the importance of STEM education. The Policy also identified the need for teachers to be engaged with professional learning opportunities and embed STEM into their teaching practice. It was suggested that teachers use a cross-disciplinary approach, incorporating pedagogical content knowledge and understanding, developed in and across the four disciplines of STEM.

The United States Report on STEM Education outlines the importance of transdisciplinary learning and STEM literacy as well as lifelong access to STEM education for people from all backgrounds, especially groups which are underrepresented in STEM disciplines (National Science and Technology Council, 2018). STEM workers in tomorrow's economy will benefit from transdisciplinary learning, STEM literacy, and the cultivation of a mindset that embraces innovation and entrepreneurship.

In the United Kingdom, the commitment to STEM was first expressed through the Science and Innovation Investment Framework 2004–2014 (HM Treasury, 2004), and further elaborated in the STEM strategy 2014–2024 (HM Treasury & Department for Business Innovation and Skills, 2014). In response to the demand of STEM jobs, the Department of Education recognised the need for promoting STEM and improving education from primary level. The initiative has been put into action: addressing teachers' support, running the STEM ambassador program, STEM clubs, STEM competitions, and organising and evaluating accelerator programs in STEM disciplines such as computer science, mathematics, and physics (Hoyle, 2016).

STEM IN PRIMARY SCHOOLS

Education plays a significant role in STEM engagement and for many children it can be the first time they experience STEM. Learning opportunities through curriculum, or supplemented and complemented by extension or co-curricular activities, provide real-life STEM experiences.

Research shows that self-confidence and self-perception of being successful starts decreasing from the age of 12 (González-Pérez, Mateos de Cabo, & Sáinz, 2020; Sáinz & Eccles, 2012). The primary years are formative in terms of students' self-belief as STEM learners. This is the time when they establish a 'sense of competence that students have in the foundations of mathematics and science and can kindle their interest in science related fields' (Ainley, Kos, & Nicholas, 2008, p. 3). Primary years are the years when life-long interests are being formed. It is therefore important to engage primary students in STEM learning, especially 'foundational numeracy and scientific proficiency' (Caplan, Baxendale, & Le Feuvre, 2016, p.8) since these skills are prerequisites to mastering other disciplines and to being successful when it comes to more complex, advanced learning in later school years.

Providing students with positive STEM experiences in their primary schooling years sets students up for later learning and possible career options. During this time, it is important that students are taught well and any gaps in their STEM knowledge are addressed (Rosicka, 2016).

Teaching STEM at the Primary School Level

In 2015, the Office of the Chief Scientist for Australia released a position paper titled *Transforming STEM Teaching in Australian Primary Schools: Everybody's Business*. The paper recognises that STEM teaching needs to start in primary school and that there are unique challenges and responses required to strengthen girls' STEM engagement.

Recommendations were made to transform STEM teaching in primary schools with provision of a national professional development program for teachers, support of principal leadership, and access to STEM specialists in schools (Prinsley & Johnston, 2015). Globally, other nations have also signalled their intent to raise the status of STEM in the P-12 context (Department of Education & Department of Employment and Learning, 2009; National Science and Technology Council, 2013).

It has been argued that curriculum that is authentic and 'hooks girls with real world scenarios provides context that allows them to see the value in the work and can make STEM more vibrant' (Sammet & Kekelis, 2016, p. 6). Additionally, student-centred and inquiry-based curriculum represent documented

strategies for improving girls' self-confidence in STEM (UNESCO, 2017). However, this approach is found to only work when teachers have subject expertise and can cultivate a constructive learning environment (UNESCO, 2017).

In their review of STEM practices at elementary and middle school levels in the USA, Chiu et al. (2015, p. 8) noted that the reviewed literature lacked:

> ...explicit examples of successful problem-based or inquiry-based learning content for teachers to use within the classroom. New standards have been adopted by many states and given to teachers to implement within the classroom, without full understanding of their structure or their purpose. Additionally, the literature suggests integrating STEM into the curricula, but does not give examples of specific curricula for schools to adopt that integrate STEM within the school.

Various government reports and research identify the need for: STEM literacy, providing long-term access to learning STEM disciplines, addressing diversity and inclusion aspects of STEM education, and focusing on integrated delivery of STEM subjects. However, these recommendations are too general as they lack specific guidelines, teaching materials and training support for teachers. Additionally, a lack of qualified STEM teachers is identified as one of the barriers of STEM education (Ejiwale, 2013).

Caplan et al. (2016) emphasised the importance of primary-level STEM education for Australia's future. One of their findings accentuated the previously established need for high-quality STEM focused professional development for all primary school teachers. The professional development is especially important for helping primary teachers to implement integrative approaches in teaching STEM subjects. This is because students have a higher chance of success if they are exposed to integrative STEM learning from primary school (Becker & Park, 2011; Sanders, 2009).

The Australian Curriculum and STEM

In the Australian Curriculum, STEM is identified through the learning areas of Science, Technologies, and Mathematics, and also through the general capabilities, specifically Numeracy, Information and Communication Technology (ICT) capability, and Critical and Creative Thinking.

There are two clear approaches to teaching STEM subjects. One is subject-centred, also referred to as discipline-based. Within this approach, teaching and learning are focusing on the knowledge and practices of the specific discipline (Dowden, 2012). It is a convenient, traditional approach based on how school (and higher education) curricula are presented to teaching staff and students. The other approach is student-centred curriculum (Ornstein, 1982, p.408). In this approach, teachers focus on engaging students in active participation.

Regardless of the approach taken, many primary school teachers tend to integrate STEM subjects one way or another. Integrated STEM education incorporates combining two or more STEM subject areas into one lesson, or project, to tackle real-life problems (Moore et al., 2014). Research shows that the integrated approach to teaching STEM is beneficial for students' learning experience, for developing their knowledge and skills, making them ready for the jobs of the future, and for maintaining their interest in the STEM fields of study. However, currently Australian Curriculum does not support interdisciplinary/integrated learning of STEM (Becker & Park, 2011; Fitzallen, 2015; Timms, Moyle, Weldon, & Mitchell, 2018). The curriculum and associated knowledge evaluating techniques are structured based on the assumption of traditional subject-centred teaching and learning (Venville, Sheffield, Rennie, & Wallace, 2008).

Since we live in an age of fast technological developments and innovations, it is necessary to keep updating curricula, providing learning materials and associated teaching guidelines (Ejiwale, 2013). More importantly, approaches to instruction delivery are evolving and these need to adapt to modern times. This calls for integrative teaching of STEM subjects aimed at giving students a more realistic view of the world, as well as skills to tackle problems using knowledge from related STEM fields (Barcelona, 2014).

Successful implementation of integrative STEM education is heavily dependent on the school environment, principals, teachers, and the classroom atmosphere (Venville et al., 2008). Teachers may have difficulty implementing integrative and student-centred approaches within subject-focused curriculum constraints.

Girls and STEM in Primary Schools

Girls show interest in STEM related topics and activities in preschool and early years of schooling (Baker, 2013; Sammet & Kekelis, 2016). However, this interest is often not reinforced or leveraged in primary schools. Whilst some reviews provide different chronological ages as to when girls lose interest in STEM, it can, however, be agreed that girls interest in STEM related activities starts declining around the ages 10-12. This is when their identity formation is heavily influenced by peer groups and social norms (Wall, 2016). According to Wall (2016, p. 29), "students lose interest by age 6; peer influence affects attitudes by age 12; they are bored in class by age 14; and their grades drop in STEM related subjects by age 15."

Perceptions that STEM subjects are difficult or boring are formed before students commence secondary school (Accenture, 2017). Gender stereotyping tends to align STEM disciplines with masculinity or geek and nerd culture. This may explain why some girls reject STEM and seek to disassociate themselves from these attributes. This has been particularly documented in the Computing industry, where the stereotypes of people attracted to this career are often male, frequently described as boring, socially isolated, lacking social skills (Vainionpää, Kinnula, Iivari, & Molin-Juustila, 2019), and involving tedious activities that have no relevance to everyday life (Vekiri, 2010).

Another large study from the United States highlighted that science achievement gaps begin very early in life and continue throughout the student's schooling. Children that did not have much exposure to the natural and physical sciences through informal learning opportunities prior to commencing primary school were identified with achievement gaps in science. As students progressed through their schooling, these gaps increased. Consequently students become disinterested in STEM or formed negative views towards science and other STEM subjects (Morgan, Farkas, Hillemeier, & Maczuga, 2016).

Women continue to be underrepresented in STEM careers. It has been identified that this is related to the quantity and quality of exposure to STEM that girls experience prior to starting school and to their school-related experiences. To alleviate negative perceptions of STEM at an early age (Timms et al., 2018), there is a need to enthuse girls about STEM prior to and throughout their schooling; intervention is essential.

HOW TO INSPIRE GIRLS FROM PRIMARY LEVEL?

It is widely documented that participation in STEM in schools is low for girls. This problem is further exacerbated as they grow up (Campbell et al., 2020). Part of the reason why girls move away from STEM subjects as they grow older is because they do not have clear conceptions of what a career in STEM could be or the breadth of STEM career options. They may also lack exposure to positive women role models who work in STEM.

Lack of inspiration was identified as one of the reasons students abandon the STEM stream of studies (Ejiwale, 2013). Project-based and inquiry-led learning that is grounded in an integrative approach to teaching STEM could address this shortcoming. The practical implementation should focus on connecting projects with real-life problems, as well as engaging students through excursions and incursions (Rosicka, 2016).

Also, stereotypes associated with STEM careers being limited to gifted men likely play a role in deterring girls from entering the STEM

field (Leslie, Cimpian, Meyer, & Freeland, 2015; Shin, Levy, & London, 2016). Exposing girls to role models through showcasing their biographies and exploring their academic journeys could have a positive impact on future study and career choices (Shin et al., 2016). It can also be beneficial to invite female STEM professionals into the classroom (Timms et al., 2018). Female teachers with expertise in STEM disciplines can also be role models. Teachers may facilitate activities that focus on famous female STEM role models, such as sharing readings or telling stories about STEM women pioneers such as Sally Ride, Marie Curie, or Bessie Smith.

Using Integrated, Cross Discipline Learning

Hands-on, experiential learning that is connected to real world issues may garner the most interest and engagement from girls. Activities and projects based around issues that are of general interest to girls, such as environmental concerns, animals, or helping other people, create stronger engagement. Project-based or inquiry-led learning also contributes to building important capabilities in the Victoria curriculum such as using scientific inquiry, critical thinking and problem solving. Project-based learning supports the teaching of STEM skills and capabilities.

However, according to Bryan, Moore, Johnson, and Roehrig (2015), STEM integration is not about teaching two disciplines of STEM together or using technologies as a tool to facilitate the other disciplines. They define integrated STEM through the lens of teaching and learning. They see it 'as the teaching and learning of the content and practices of disciplinary knowledge which include science and/or mathematics through the integration of the practices of engineering and engineering design of relevant technologies' (p. 24). Therefore, the teaching of STEM needs to be specific and intentional with respect to content and context when integrating STEM. Through this lens, there are three forms of integrating STEM:

1. Content integration has several STEM learning objectives.
2. Integration of supporting content concentrates on one focus area in support of the learning objectives of the main content.
3. Context integration is where the context from one discipline is used for the learning objectives from another.

The most common method used in schools is through supporting content integration, however there are shortcomings to this method of integrating STEM as it does not further the discipline of learning of the supporting content.

There are many things that teachers can do to spark interest and promote curiosity in STEM. These involve developing the skills and knowledge of their students to solve real-life and authentic problems. An example of a cross discipline project integrating reading with STEM content is presented below:

> During weeklong series of science investigation activities where elementary school children learn about owls and birds and have the opportunity to dissect owl pellets and discuss what they find, the children are also asked to read from both informational and narrative texts that focus on owls. Embedding the reading activities into the context of science investigation serves to generate situational interest and further curiosity. (Halpern et al., 2007, p. 24)

Another example can be found at Mentone Girls' Grammar School (Melbourne, Australia) of shared experiences of using STEM pedagogy in a play-based curriculum.

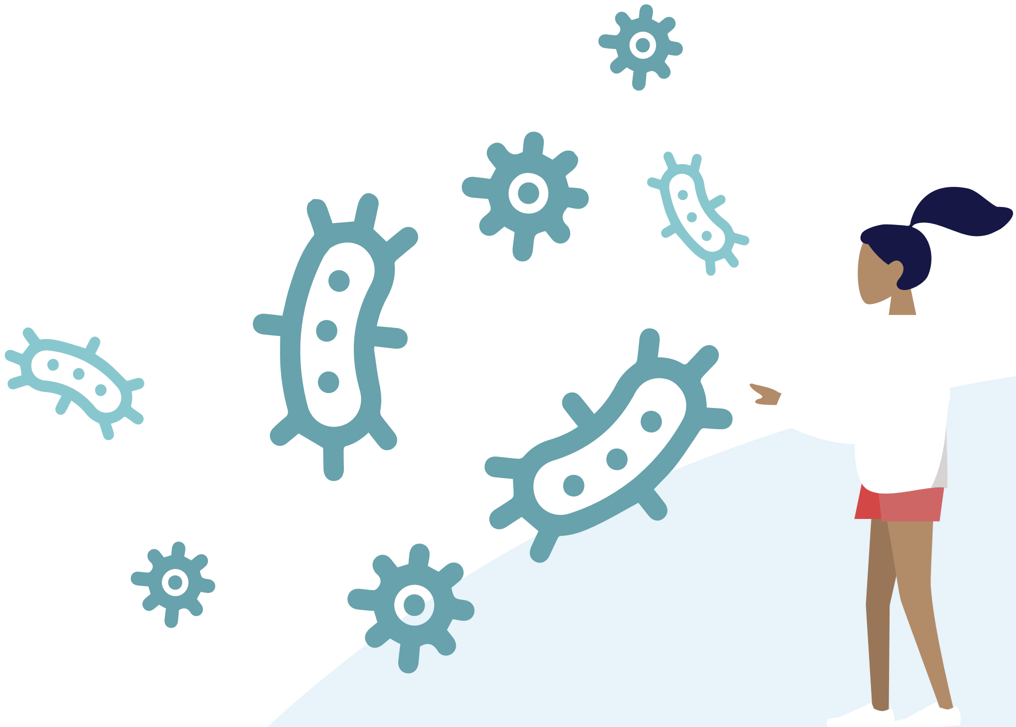
> When using yeast to make pizza during a cooking lesson, we talk about yeast chemical reactions in bread or pizza base and how they work. We plant daffodil bulbs to understand how plants grow and put the cut flowers in coloured water to watch the petals change colour to help students understand the essential functions of roots and stems in plant growth. Other such explorations might include playing with magnets to discover the concepts of magnetism and opposing forces (The Alliance of Girls Schools (Australasia), 2013, p. 10).

The National Science, Technology, Engineering and Mathematics (STEM) School Education Strategy 2016-2026, encourages STEM to be taught using a cross-disciplinary approach to increase student interest in STEM-related fields and improve students' problem solving and critical analysis skills development (Education Council Australia, 2019).

Experiences and Concepts Need to be Linked to Real World and Interests Relevant to Girls

Integrated STEM experiences provide students with the opportunity to see the natural connections between the disciplines and how they are applied in real-life. Open-ended authentic STEM problems not only engage students interests in STEM, but they also assist in the development of 21st century skills such as collaboration, communication, critical thinking, and creative thinking (Keane, Keane, & Blicblau, 2016). Providing students with the opportunity to select topics of interest, or different types of projects, encourages girls to follow their own curiosity to learn about topics they nominate, heightens engagement, and reinforces learning.

Teachers who can make the connections explicit to students between learning activities and the everyday reality of the students



can help in overcoming stereotypes that only boys do science or are better at math than girls. Making connections and seeing the relevance of STEM activities also helps girls to apply learning to their own lives and prepares them with skills for further education and eventual adulthood.

Engaging students in authentic, active, and meaningful learning experiences demonstrates to students the connection and importance of STEM. Science fairs, cybersecurity contests, robotics and invention challenges, and mathematical gaming are identified as providing further opportunities to engage students at all levels in real-world applied experiential learning. The main disadvantage with engaging in these activities is that they can be inaccessible for many students or schools due to the financial outlay for equipment or registration of individuals or teams (Committee on STEM Education & National Science & Technology Council, 2018). It is agreed, however, that to increase motivation, there needs to be a link to *real-world* STEM through informal learning opportunities. It is important for teachers to encourage STEM to be experienced and explored both formally and informally inside and outside the classroom. However, it must be noted that girls are significantly less interested in an activity that is distinctly aligned to a gender-interest stereotype compared to an activity with no stereotype (Master, Meltzoff, & Cheryan, 2021).

STEM Best Practices for Indigenous, Culturally Diverse, and Disadvantaged Girls

Girls from disadvantaged or rural communities are further behind in STEM achievement than girls in general. It has been observed that access and participation in STEM is highly socially structured (Lowrie, Downes, & Leonard, 2017). Factors such as low expectations of students, less access to STEM teaching resources, high teacher turnover in rural and disadvantaged areas, program sustainability issues particularly with respect to funding, and challenges in engaging with parents exacerbate the issues. In limited but critical research on how best to close gaps for these students, pedagogical practices targeted towards such students have demonstrated benefit for all students of all genders in the classroom (Hackling, Byrne, Gower, & Anderson, 2015; Tynan & Noon, 2017; Walker & Banks, 2021). It is reasonable and appropriate that recommended practice for these populations be standard teaching practice for all students from the start, rather than expecting teachers to alternate between a dominant pedagogy for mainstream (and mostly white students) and a separate pedagogy for Indigenous, rural, culturally diverse, and disadvantaged students.

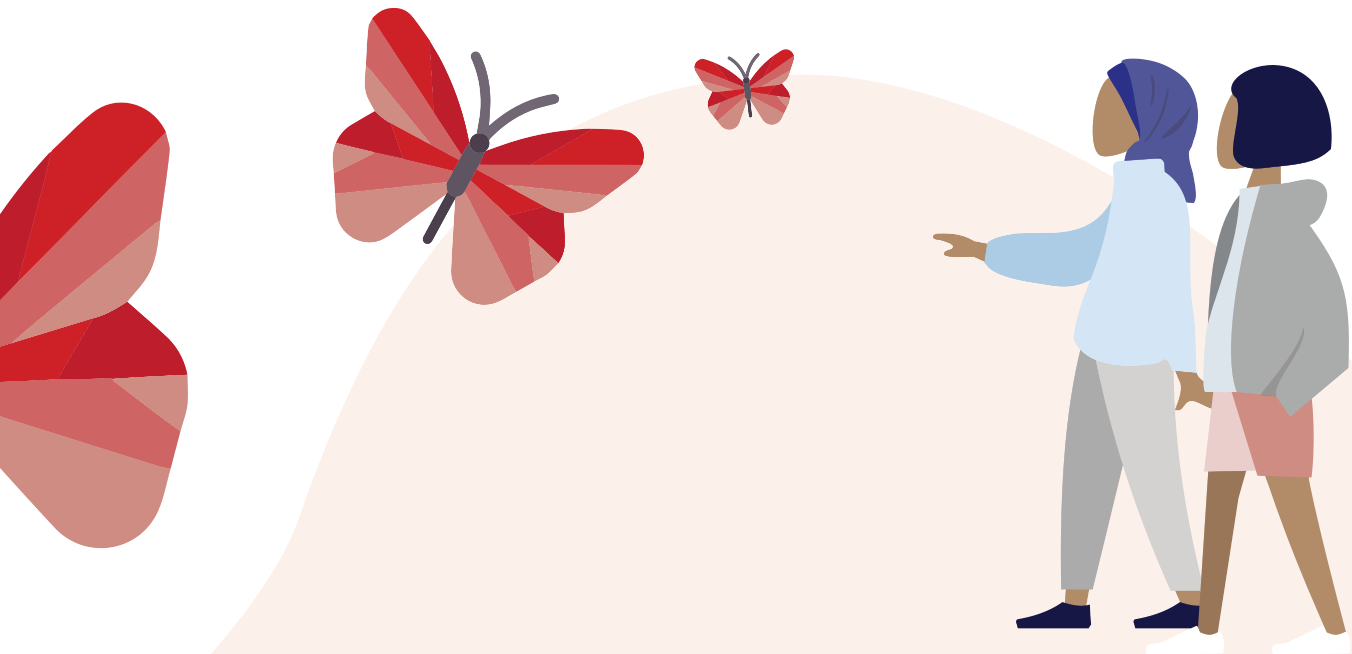
Tynan and Noon (2017, p. 20) in reviewing best practice for Indigenous and Torres Strait Islander students in STEM state:

> Aboriginal and Torres Strait Islander peoples… have been characterised as belonging to 'high-context' cultures where meaning is 'extracted' from the environment and situation. In contrast, mainstream Australian culture is characterised as a 'low-context' culture using a more linear, sequential building block approach to information processing in which meaning is constructed (YDM overview, 2014:25).

In high-context cultures, relationships are critically important to understanding meaning and less reliant on precise verbal communication. Pedagogical practices, developed by Perth-based SciTech, evolved from research into best practice to teach science to Aboriginal students. Relationship building is placed at the forefront of their recommended practices, as outlined in Table 1.

Table 1. Pedagogical practices for engaging Aboriginal students with science learning. Adapted from (Hackling et al., 2015, p. 36).

Engage Connections	**Use a collaborative and inclusive approach**	**Build relationships through cultural competency**	**Facilitate student ownership and agency in learning**
Engaging students through hands-on activities	Students have direct access to materials for hands-on activities	Give few and simple instructions communicated multimodally	Use low-key responses for behaviour management
Maximising engagement using interactive–dialogic communicative approach within a supportive classroom climate	Use a high proportion of open questions	Focus on vocabulary building	Use movement, gestural and sound cues along with speech
Making it relevant	Links made between science activities and familiar contexts and experiences		



In the United States context, Sammet and Kekelis (2016) also recommend taking the time to develop relationships as part of pedagogical practice in teaching STEM to girls from culturally diverse communities. They recommend practicing *cultural humility* and involve girls, their parents, and communities in designing STEM education experiences. This has correspondingly been recommended and is currently being practiced in several Aboriginal STEM programs in Australia, where Indigenous ways of knowing and understanding the natural world are integrated with western perspectives and knowledge of STEM subjects (Cherry, Banks, Mudhan, & McNeilly, 2019). This makes the learning material more relevant to the students and inclusive for the whole classroom. Students and parents should be asked often 'what is working?', 'why?' or 'why not?', and 'what can be better?' (Sammet & Kekelis, 2016). Teachers and school systems should recognise there may be barriers for girls from diverse and or disadvantaged backgrounds, such as access to time, money, transportation, or language understanding that can prevent families or students from participating in family-oriented STEM events, attending out of class experiences, or completing home projects that require access to materials (Sammet & Kekelis, 2016). Schools should work to redress or work around these barriers to maximise opportunity, access, and participation.

Allow for Experimentation and Failure without Judgement

Experimentation, just like failure, is an important part of learning. Girls should fail fast and fail often in a supportive environment in which the teacher encourages them to innovate, try new options, and understand what can be learned from what has not worked (Halpern et al., 2007). This is also known as a growth mindset where there is continual learning and improvement through a willingness to try, fail and inquire (Microsoft, 2018). Teachers should highlight the importance of effort for succeeding at difficult tasks. By attributing success to effort rather than to innate ability or intelligence, girls learn how they can become successful at STEM endeavours through effort and persistence. Praising girls on their efforts to work through failure also helps build emotional resilience to failure, enabling them to build self-efficacy and not give up or become demotivated when working on difficult tasks.

Using thinking skills, such as design thinking, encourages girls to create solutions to problems, prototype their solutions and learn from what does and does not work to improve the solution (Sammet & Kekelis, 2016). Other thinking skills that can also be used with students include computational thinking as a means to break down programming problems into manageable chunks to build solutions (Wing, 2008).

Best Practice Approaches and Themes

In 2015 a review of whole of school STEM practices at elementary and middle school levels in the USA, Chiu et al. (2015, p. 8) note that:

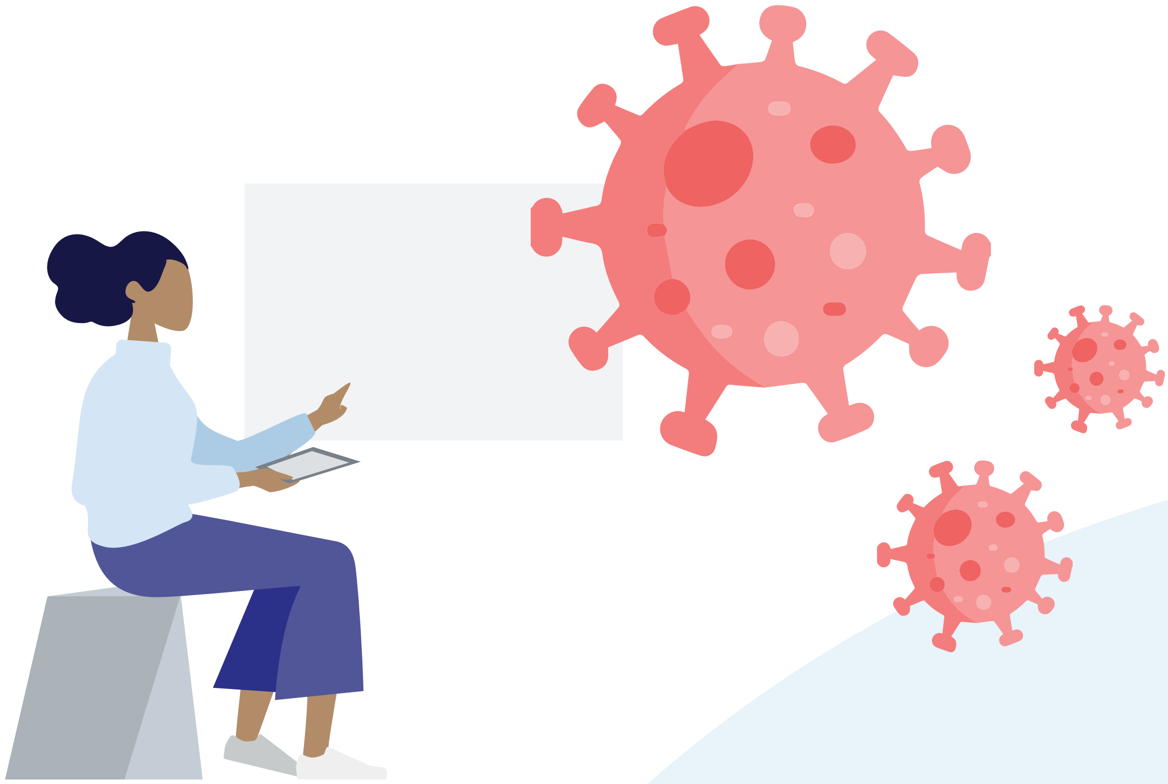
> The literature that we found lacks explicit examples of successful problem-based or inquiry-based learning content for teachers to use within the classroom. New standards have been adopted by many states and given to teachers to implement within the classroom, without full understanding of their structure or their purpose. Additionally, the literature suggests integrating STEM into the curricula, but does not give examples of specific curricula for schools to adopt that integrate STEM within the school... Much of the literature regarding curriculum and instruction offers broad suggestions and recommendations for schools to follow, but provides limited examples or ways for schools to move forward.

Similarly, a noticeable feature of the current reviewed literature was the extrapolation of evidence from specific studies in specific STEM or STEM-related disciplines and projects into conceptual statements of aspirational practice for teachers in the classroom. However, specific examples and instruction of how to make these practices tangible were difficult to find. Likewise, direct causal evidence linking STEM practices to outcomes is also unclear.

Writing in an Australian context, Tynan and Noon (2017, p. 17) called attention to the following:

> ...the importance of measuring these school level practices and STEM education characteristics as focusing solely on STEM education outcomes does not provide guidance about the instructional practices and conditions in individual schools necessary to achieve these outcomes. There are also limitations as to the breadth of what quantitative outcomes data (e.g., test results) actually measure; and there is often a time lag between change in practice and the outcomes being achieved.

Thus, in this report, we attempt to provide guidance to Victorian primary school teachers about classroom best practices, examples of such practices, and what is needed at the school/systemic level to enable teachers to engage in these practices. It is acknowledged within the STEM ecosystem and the education ecosystem that macrostructures and influences are critical for enabling practice at the teaching level. Issues of policy, legislation, funding, curriculum reform, and societal gender equity are well covered in the source literature reviewed and are beyond the scope of this report. The intentions of this review are focused on the direct interaction between teachers and students and the immediate school community, including families. The best practices outlined below are intended to assist teachers in present circumstances in their current classrooms.



DIRECT BEST PRACTICE IN AND OUT OF THE CLASSROOM: SPECIFIC ACTIONS

The learning environment plays a crucial role in encouraging girls to participate in STEM activities. The classroom environment needs to be inclusive and non-judgemental. It needs to address various issues, including how to deal with the gender stereotypes, provide hands-on opportunities to experiment and develop a variety of STEM-related skills. It is also imperative to actively involve parents in afterhours activities while guiding them on how to support and encourage their daughters in developing and fostering STEM interests. The following suggestions for teachers and parents are prepared to address the identified issues.

Alter your Language and Messaging to Girls about STEM Gender Stereotypes

Unwittingly, teachers and parents may reinforce gendered stereotypes about STEM careers and activities to girls through the phrases they use, the way they talk about STEM-related topics, or the role models they refer to. Unconscious bias (or implicit bias) is a term used to describe this (Dee & Gershenson, 2017). Teachers are at the coalface and spend large amounts of time with students over their development trajectories, therefore it is imperative that consideration is given to unconscious bias. STEM gender stereotypes also exist in media, film, television, and literature. Use of these materials in classrooms as part of lessons and activities should be reviewed beforehand for negative stereotypes and portrayals. Teachers can also use these materials to point out and challenge stereotypes in media and cultural entertainment, as well as to seek out more positive female role models and descriptions. Teachers can also provide parents with guidelines on how to speak about STEM roles and activities, and how to recognise and encourage positive STEM related behaviours at home (such as encouraging curiosity and questions about what makes baking work in an oven, interest in insect life in the yard, interest in plants and how the seasons change, interest in looking at stars at night and cloud movements in the day).

Create Cooperative Safe Spaces and Girls-Only Experiences

Girls have confidence gaps when comparing themselves to their peers. Girls may be more reticent or dominated by boys in group work and therefore not gain opportunities to participate as fully or in diverse roles. Creating opportunities for girls to work together will encourage experimentation with STEM activities, increase opportunities for mastery experiences, as well as create opportunities for peer modelling in which girls can observe other girls succeeding. Sammet and Kekelis (2016, p. 8) state:

> In a well-designed girls-only space, opportunities for girls will be amplified. For example, in a girls-only space, girls are empowered to fill every role in an engineering design team. Observing, hypothesizing, creating, asking questions, and testing results are skills everyone needs for success in STEM. Girls new to STEM need environments where it's safe to hone these skills. Girls may not have experience leading their own work in this way.

Create Gender Neutral Learning Spaces

As with language, objects and features in the learning environment can also convey indications of gender. How learning spaces are constructed and decorated can be inviting or discouraging to girls. Sammet and Kekelis (2016) suggest learning spaces contain neutral objects such as plants, posters of nature, and non-technical reading material, while avoiding overly masculine objects in STEM learning spaces like computer parts, video games, and markers of geek culture like Star Trek posters. Similarly, gender bias in teaching materials should be vetted out, such as narratives with men and women in stereotypical roles.

Out of Classroom Activities – Excursions, Workshops, Camps, and Opportunities in Community

Girls respond to novel STEM experiences outside the classroom. Excursions to sites in the community such as museums, plant nurseries, technology companies, and media labs expose girls to role models and provide valuable opportunities to see STEM in action in the community (Chiu et al., 2015). Teachers can also advise girls and parents of extracurricular opportunities such as STEM camps, STEM clubs, robotics competitions, and workshops run outside the school. These opportunities can help generate interest in STEM and expand STEM experiences for girls beyond the classroom (Microsoft, 2018).

Increase Opportunities to Develop Spatial Reasoning Skills

Spatial reasoning involves:

> ...the process of being able to mentally consider and manipulate spatial properties of objects and consider how these objects relate to each other. It involves being aware of space, being able to represent spatial information and applying reasoning to interpret the spatial information (National Research Council, 2006). (Lowrie et al., 2017, p. 26)

Spatial reasoning is an important STEM skill as well as a general life skill. We use spatial reasoning to read maps, understand the sequence of patterns at a stop light, to walk through a space, and to organise objects on a shelf. Girls are at a disadvantage in developing spatial reasoning skills at early ages when discouraged from participating in play traditionally viewed as masculine such as climbing and building structures. Spatial reasoning skills correlate with performance in mathematics and science in later years (Halpern et al., 2007). Teachers should encourage girls to play with building blocks and toys, drawing objects from different perspectives, and encouraging use of spatial words to describe spatial relationships such as higher, lower, bigger, smaller, closer, farther, taller, and shorter.

Encourage Tinkering

Related to building spatial reasoning capacity, girls need opportunities and resources to tinker. Early research on learning by making can be traced back to Seymour Papert who advocated that children needed to be creators through playful exploration (Papert, 1980). His work can be attributed as the inspiration for makerspaces. Makerspaces provide an environment for students to be creative, collaborate with other students, solve problems and demonstrate digital competence (Vuorikari, Ferrari, & Punie, 2019). This can include items such as LEGO© or Meccano© blocks to build and ordinary items to pull apart to see what they are made of and how they work. Install a tinker table in the classroom and allow free tinker times at lunch, recess, or other parts of the day. Tinkering encourages inquisitiveness, understanding of systems, and spatial skills.

Include Parents in Girls' STEM Success at School

Parents are critical influencers in how girls view and engage with STEM. Children are naturally inclined to be curious and want to solve problems by experimenting and parents are well suited to assist with providing their children with these opportunities through home-based interventions and activities (Kumar, 2016). Teachers can create shared experiences to enable parents to see their daughters participating and succeeding in STEM. This can help to alter the understanding parents may have of girls in STEM if parental views are negative or stereotyped about STEM actives and careers (Campbell et al., 2020). Some suggestions by Chapman and Vivian (2016, p. 50) include:

- Host orientation and family evenings that family members can be involved in.
- Provide updates for family members on achievements and opportunities and events to celebrate achievements.
- Provide resources for families to engage in STEM learning activities at home with their children.
- Provide information resources for parents that inform them on STEM career opportunities and pathways.

BEST PRACTICE SUPPORT – WHAT TEACHERS NEED TO ENABLE BEST PRACTICE: CONCEPTUAL APPROACHES

Creating an engaging, inclusive, and encouraging learning environment can be quite challenging for teachers. So, it is crucial to identify the support initiatives that could improve STEM teaching capabilities. Teachers should be able to choose from a range of opportunities available through various partnerships, such as community, industry, research institutions and universities. Teachers cannot do everything, but there are collaboration avenues that they should have at their disposal to enrich STEM education.

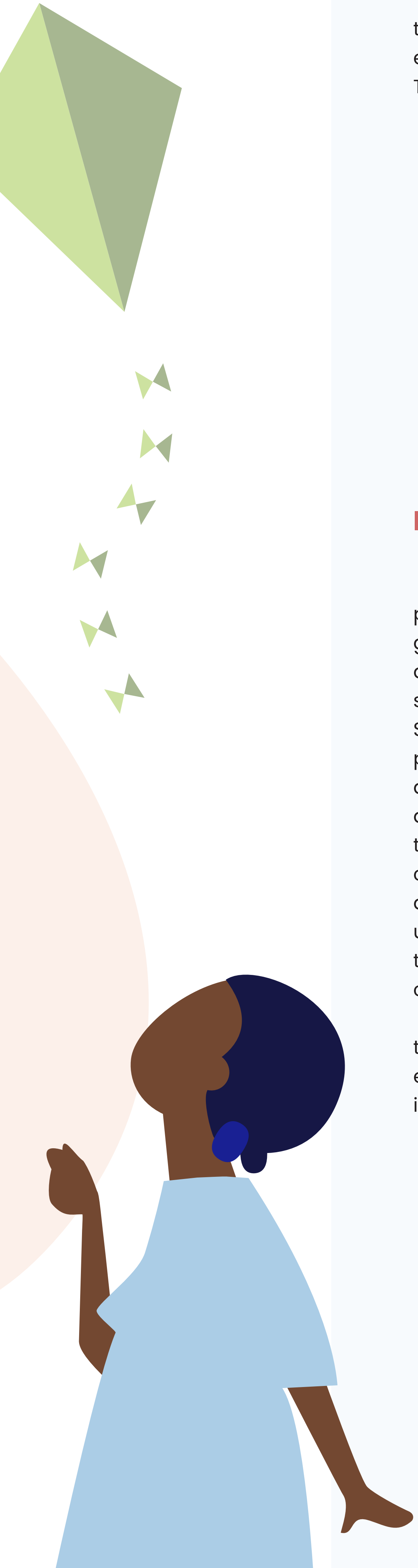
A Whole of School/School-Wide Approach to STEM

The most successful STEM programs have happened in schools where a school-wide approach was adopted (Chiu et al., 2015). STEM practices and content are not only scaffolded from lesson to lesson within a classroom, but with a view to scaffold from year to year. Conceptual foundations and skills developed in primary years are built upon in later years. This tactic creates a framework for teachers across the school to collaborate and design scaffolded STEM experiences together. School wide approaches require strong school leadership which drives change, and a supportive environment for teachers to develop their pedagogy. Stating STEM practice and learning as part of the school mission and vision statements can help place STEM teaching at the heart of the school's work.

Partnerships in the Community, with Industry, and with Universities

As discussed previously, partnerships outside the classroom are a critical component of the STEM ecosystem model. Partnerships with community, cultural and industry groups provide opportunities and resources towards implementing a STEM curriculum, as well as influencing family and community attitudes towards STEM, which in turn influence girls' ideas about STEM fields and engagement with STEM. Positive female STEM role models may be sourced through these partnerships, as well as access to experiences or resources that are not easily replicated within the classroom. Partnerships with industry groups or peak bodies, universities, museums, and STEM-interest community groups should be sought for collaboration to reach a shared vision for STEM education of girls (Education Council Australia, 2019).

Burrows, Lockwood, Borowczak, Janak, and Barber (2018) investigated girls aged 9 - 15 years who participated in an action research project into water quality in a local river after a restoration project. The project brought together community members from the local university, the Girl Scouts, and parents



to support the project. Through the experience, the girls learned engineering skills that incorporated skills from other STEM disciplines. The researchers described:

> The Girl Scouts and community members were fully immersed and experienced a true, integrated-STEM, authentic science project. The authors identified this water quality project as authentic science, or integrated STEM project, because it met the definition of participants working in the natural world working towards a problem, exploring information, using technology, utilising mathematics, analysing evidence, developing conclusions, refining questions and methods for future use, communicating results, and recording the results for others to use. The individual STEM components of the data can also be clearly identified (Burrows et al., 2018, p. 12).

Involvement of Parents and Community

Following on from the best practice recommendations above, parents, family and communities are crucial partners in engaging girls in STEM. Parental understandings of STEM and STEM careers, and their attitudes towards women in STEM are key factors in shaping girls' understandings and attitudes. Many successful school STEM programs involve parents and families in STEM education by providing information to parents that counters STEM misconceptions, advising parents on how to structure conversations with their daughters about STEM, and suggesting ideas for STEM activities that can be easily completed at home. Connecting with girls' communities is also vital, especially for girls from culturally diverse and/or disadvantaged communities. Frequent feedback loops and use of co-design opportunities should be harnessed to strengthen the STEM and education ecosystems in these communities, and close gaps for students from these backgrounds.

Kumar (2016) offers practical guidance for teachers on how to discuss home-based opportunities with parents to assist with engaging students in STEM. Some suggestions teachers can follow include:

- Encourage parents to talk about their work routines and ask their children to label what they have described into STEM skill categories (communicating, using math, following steps, asking questions)
- Suggest to parents to initiate conversations about different STEM professions, such as engineering, environmental science, or data analysis, as a way their children can make changes in the world they care about (such as developing green energy, clean water, work with many different people, find cures for diseases)
- Encourage parents to engage in play with their kids that help develop spatial skills, such as folding and cutting shapes with paper, organising closet shelves, or tinkering with old gadgets.

Parents can prompt their children with follow up questions such as 'What led you to take this action?', 'Do you think the size/numbers/proportions would have made any difference?', and 'Why?' to help their children make connections between the activity and STEM thinking.

- Discourage parents from saying comments such as, 'It's OK if you don't like math, I didn't either when I was your age,'. These types of comments can lead children to believe they have no aptitude for understanding and learning new STEM skills or content.
- Encourage parents to engage with their children at museums, at science centres, and on educational websites that offer free STEM information and learning activities.

BEST PRACTICE SUPPORT – WHAT TEACHERS NEED TO ENABLE BEST PRACTICE: PRACTICAL ACTIONS

Multiple research studies have demonstrated that primary school teachers need support in providing effective integrated STEM education. At the same time, it is a known fact that most primary school teachers' teaching background is generalist in nature (i.e., they do not have a major or a specialisation) and they have to deal with an already overcrowded curriculum. Teachers need practical strategies and support to assist with teaching specialised STEM disciplines. Actions, approaches, and access to materials as discussed below could provide that support.

Dedicated Time for Planning and Instruction in the School Day/Curriculum

STEM practice, and in particular project-based, inquiry-led, or design-based learning takes time. Additionally, it takes time to plan these teaching activities, with consideration for how they connect to the curriculum requirements and the methods teachers will use to make real world connections explicit to students. Teachers also need time to collaborate with other teachers when developing plans and scaffolding the learning objectives. For many, integrating STEM practice will be a paradigm shift from the existing pedagogical practice. Plus, primary teachers will be developing their own skills in teaching STEM as they progress. Teaching STEM is process oriented rather than outcome oriented. Student STEM skills also develop over time. Inadequate time to development, facilitation, and monitoring of student progress will hamper efforts to embed STEM in primary education.

STEM Embedded in the Curriculum

Curriculum could be contextualised with real world issues rather than abstract concepts. Rosicka (2016) reported that in 2016 there still had not been a concerted effort to create an integrated STEM curriculum in Australia and that introducing curriculum change would require cultural change in the education system. Primary teachers may have an easier time integrating cross-subject projects or inquiry-led methods into their classroom as primary education tends to be more holistic and less discipline siloed as compared to secondary education.

The compendium of exemplary practice characterises a successful STEM curriculum as having challenging content, being inquiry-based, experiential, and being clearly defined and understood by all stakeholders (Bayer, 2016). Its properties include the following:

- Content related to real-world applications.
- Content that facilitates critical thinking, problem solving and team working.
- Goes beyond minimum competencies.
- Reflects local, state and/or national standards.

However, stakeholders in Australia should develop an agreed-upon definition of STEM curriculum to guide them, shift to an emphasis on STEM practices, and move from discipline-separated to an integrated STEM curriculum (Timms et al., 2018).

Teacher Professional Development and Capacity Building

The need for primary teachers to build their STEM capacity and access regular and ongoing professional development in using STEM practice as pedagogy is a universal recommendation in the literature (Margot & Kettler, 2019; Shernoff, Sinha, Bressler, & Ginsburg, 2017). Most primary teachers are generalists with no qualifications or majors in Mathematics, Science, Engineering or Computer Science therefore, needing further assistance in the teaching of these highly complex disciplines. Mathematics and Science have been identified as two subject areas in particular which should be priority targets for primary teachers in Australia, as these disciplines are foundations for learning in later school years (Caplan et al., 2016). Margot and Kettler (2019, p. 1) found:

> ...that while teachers value STEM education, they reported barriers such as pedagogical challenges, curriculum challenges, structural challenges, concerns about students, concerns about assessments, and lack of teacher support. Teachers identified support avenues that would improve their effort to implement STEM education included collaboration with peers, quality curriculum, district support, prior experiences, and effective professional development.

Options for teacher professional development are varied, and include online courses and seminars, workshops, peer-to-peer learning, communities of practice, and in situ learning in which teachers learn through the delivery of an activity or project with their students under the guidance of a STEM specialist or professional development educator. However, professional development should be regarded as a continuous journey, it should not stop after a single contact or experience with a professional development opportunity, but needs to be scaffolded, reflective and ongoing.

Adequate Up To Date Specialised Resources, Materials, and Technology

Successful STEM teaching relies on teachers having access to the right kind and wide range of resources and materials, including up to date technology. In hands-on activities, there needs to be a sufficient supply of materials for each girl to have her own materials to work with. This is because when they are required to share, shyer girls give in to more dominant students. This disadvantage could prevent them from being able to learn experientially, and from finding their own strength and building skills in STEM. There is a plethora of online resources from a range of sponsors and places, most with free access. However:

> There is a lack of comprehensive, 'teacher-friendly' classroom resources to assist in delivering science content in particular. We see a role for detailed, prescriptive 'plug and play' modules of work to support non-specialist primary teachers to overcome their lack of confidence and discipline knowledge to deliver rigorous instruction... While there is an abundance of science teaching resources, the vast bulk of these materials is not organised into coherent modules or sequences of lessons. Teachers need considerable discipline expertise to discern high quality materials from dross and to integrate these resources into pedagogically sound modules. Survey evidence and stakeholder feedback suggest that many teachers lack confidence in their ability to parse the available resources for quality and then incorporate them into lesson sequences. Teachers' uncertainty about how to make effective use of resources was a frequently cited reason for eschewing science instruction. The introduction of meticulously developed, sequenced and universally accessible primary science modules would boost the confidence and efficacy of non-specialist teachers (Caplan et al., 2016, p. 27).

Access to STEM Specialist Teachers

The Australian Office of the Chief Scientist recommended in 2015 that "all primary teachers should have access to specialist STEM teachers as co-teachers, coordinators, mentors, and providers of sustained professional development" (Prinsley & Johnston, 2015, p. 5) as an interim measure until Australia could graduate more incoming primary teachers with a STEM specialisation. Caplan et al. (2016) identified the two key roles STEM specialist teachers should fulfil in primary schools: firstly, to develop and deliver STEM content while tracking how it advances outcomes for students across the primary school, and secondly, to support the non-specialist teachers and lead their professional development in STEM pedagogy. The recommendation is not without controversy. Gamse, Martinez, and Bozzi (2017) reviewed the research on United States programs which utilised STEM experts. They found ineffective research designs, evaluation, and reporting, plus gaps in knowledge about effectiveness of STEM experts on student learning outcomes. However, it needs to be stated "that science specialist teachers in primary schools are not the answer if they simply provide release time for class teachers who then don't have to worry about science teaching" (Timms et al., 2018, p. 7 citing Pezaro 2017). The non-specialist teachers should aim to develop their own skills and confidence to become more sustainable for long term engagement and capacity building.

CONCLUSION

Multiple previous studies recognised the need to facilitate girls' interest in STEM subjects from primary school years. However, there are multiple obstacles preventing or delaying the implementation of these initiatives. The major issues include a lack of knowledge, capacity and confidence exhibited by primary school teachers as well as a lack of support avenues for those who are willing to integrate STEM into the already overcrowded curriculum.

In this report we examined the Australian situation in applying integrated STEM to primary school environment, comparing it to policies and initiatives in the developed countries. Since the situation in Australia needs urgent attention and intervention to keep Australia on par with the progressive world, this report analysed the reasons behind the obstacles and proposed actions that address the identified problems.

Since primary school teachers are at the front of educating children, they need support in capacity building and professional development, easy to find structured well-organised materials with clear curriculum mapping and advice on integrating them into lessons without disrupting or compromising traditional curriculum.

For the benefit of primary school girls, it is important to develop strategies on removing stereotypes, and replacing them with inspirational and encouraging comments. The inspiration can emanate through interactions with successful female role models as well as participation in hands-on STEM activities connected to real-world issues. Schools need to address primary school teachers' lack of knowledge, confidence and capacity in incorporating STEM learning into the curriculum. Sharing best practices, stories of success and failures, trials and errors should become part of teachers' education and qualifications upgrade courses.

Finally, this report proposed specific actions to support teachers in their endeavours. The proposed actions were classified into three categories: direct best practice in and out of the classroom, best practice support - conceptual approaches, and best practice support - practical actions.

Only by involving principals, teaching staff, parents, policy makers and communities at large, the initiatives in promoting STEM fields of study and developing enterprise skills can be successfully implemented.

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