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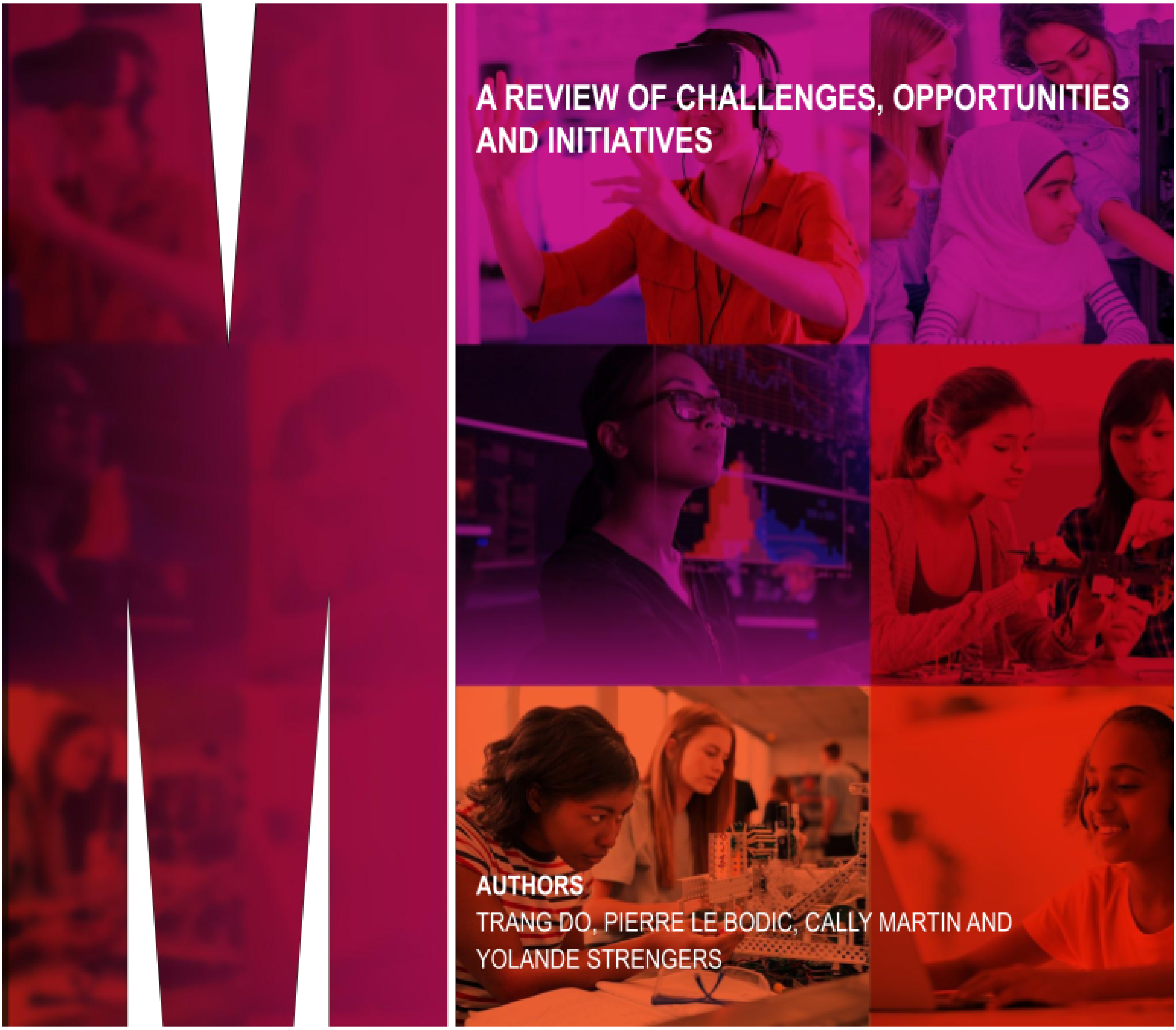
CHAMPIONING GIRLS AND WOMEN IN INFORMATION TECHNOLOGY



A REVIEW OF CHALLENGES, OPPORTUNITIES AND INITIATIVES

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TABLE OF CONTENTS

SECTION 1. INTRODUCTION AND OVERVIEW OF REPORT

It is widely recognised that equality, equity and diversity in the Science, Technology, Engineering and Mathematics (STEM) workforce is important to the future of all nations as we collectively strive for a knowledge economy (Australian Academy of Science 2018). There is a mounting body of evidence that (gender) diversity promotes productivity, creativity and innovation. Towards this end, UNESCO has repeatedly emphasised the imperative of ensuring equal access for women and girls to STEM education from a range of perspectives and approaches. The UNESCO *Cracking the Code* report clearly states that STEM gender equality will provide all genders with the skills and opportunities to contribute to and benefit equally from STEM (Chavatzia, 2017:15). However, despite this recognition and substantial international efforts to encourage more girls and women to pursue STEM-related education and careers, the rate of women enrolling in and completing Information Technology (IT) and Computer Science (CS) degrees has slowed or declined since the turn of the century.

To inform efforts to increase the representation of women at the Monash Faculty of Information Technology, this report presents findings from the current body of peer-reviewed research regarding initiatives, strategies and programs that have been found to influence girls' and women's engagement and decisions to study STEM at secondary and higher education, with a focus on IT and CS fields and degrees. We draw on research published since 2000 that we collected from two academic databases (Scopus and ProQuest) using multiple search terms. Further, this report includes evidence from grey literature (reports, websites etc.) of research and interventions that have been implemented and achieved positive results in increasing the representation of girls and women in both international and Australian education settings. Findings are drawn largely on literature published from US contexts, which we anticipate is due to the fact that it is where most initiatives have been delivered or where research has been conducted and made public. The review focuses on studies that address issues at the undergraduate level in the field of IT.

This report has five main sections. In Section 2, we provide an overview of the individual, interpersonal and structural barriers known to affect girls' and women's decisions to pursue a STEM degree at an undergraduate level. Subsequently, in Section 3, the report presents findings from studies on the experiences of women students enrolled in STEM majors in order to understand factors that influence their experience and attrition during their studies. In this section, we also provide a review of intersectionality research that looks at how race and gender shapes women's experiences throughout their pursuit of STEM degrees. Section 4 explores the various practices with regard to outreach activities, recruitment and retention strategies implemented across the world to promote girls' and women's interests in STEM/IT careers and to attract them to study and succeed in these fields. In the final section, we draw out key implications that should be considered in our development of interventions to increase the representation of women students in the Faculty of IT, and Australian IT and computer science faculties and departments more broadly.

THE PERSISTENT UNDERREPRESENTATION OF WOMEN IN IT-RELATED HIGHER EDUCATION

Among major challenges currently facing most countries in achieving equity and diversity in STEM is the underrepresentation of women in STEM education and careers. A UNESCO report (Chavatzia 2017) illustrates a clear gendered pattern emerging at higher education levels across the world. Women account for just over a third (35%) of total enrolment in STEM-related fields at this level of study. Specifically, from 2014 to 2016, men maintained the majority of those enrolled in Engineering, manufacturing and construction', (73%) and 'information and communication technology studies' (72%) in 115 countries. Among women, the UNESCO report further reveals that only 30% choose to enrol in STEM degrees compared to other enrolments, based on data from 110 countries. Women's participation was particularly low in 'information and communications technology (ICT)' (estimated at only 3% of all women students), 'natural science, mathematics and statistics' (5%), and 'engineering, manufacturing and construction' (8%). Earlier statistics from 27 OECD countries in 2013 suggest that women made up just over a quarter of the total number of people studying engineering, manufacturing and construction (28%), and computing degrees (28%) (OECD 2014).

In Australia, according to data on domestic enrolment collected in the *Equity Student Participation Survey*, the proportion of Women in Non-Traditional Areas (WINTA),[1] including STEM fields, remained static over the five-year period starting in 2014, ranging from between 17.3% and 17.6%, and reaching 17.7% in 2019. Among institutions included in this survey, Group of Eight universities reported the highest 2019 WINTA student share at 24.9% (Koshy 2020). Meanwhile, considering completion of tertiary STEM education, in 2016 women comprised fewer than 15% and 11% respectively of domestic undergraduate course completions in 'Engineering and Related Technologies' and vocational education course completions (Australian Government 2017).

With regard to enrolment in IT-related courses, the previously mentioned OECD multi-country study points out that in Australia, women's enrolment in computing programs was 20% in 2012, which was a notable decrease from 26% in 2000 (OECD 2014). Australia's falling enrolments (men and women) in computing science or ICT degrees were again mentioned in *Australia's Digital Pulse*, a report undertaken by Deloitte Access Economics (2017). Their findings state that overall, enrolment in IT courses has sharply declined since the 2000s, as has completions of IT degrees despite the country's rapid economic growth. ICT undergraduate enrolments for men declined by almost 30%, while a 65% decrease was recorded for women enrolments from 2001 to 2013 (Deloitte Access Economics 2017).

According to data released by the Australian Department of Education, Skills, and Employment, during the 2015-2019 period women made up more than 50% of enrolments and completions in 'Agriculture, environmental and related studies', and 'Natural and physical sciences'; however they were considerably underrepresented across both undergraduate and postgraduate courses in 'Engineering and related technologies' and 'IT'. Their respective enrolment rates were only 18% and 19% in those two fields in 2019 (Department of Education, Skills and Employment 2019). These figures suggest that the representation of women in IT-related degrees in Australia has remained relatively static, despite considerable efforts to increase the proportion of girls and women pursuing degrees and careers in this sector.

At Monash University, the latest data suggests that the number of women enrolling in the bachelor programs in IT and computer science at the Faculty of Information Technology (FIT) has increased or stabilised over the past years (Figure 1 and 2). However, women's underrepresentation continues: they account for only a fifth of all enrolled students in the Bachelor of Computer Science (Figure 1) and roughly a quarter of all enrolments in the Bachelor of IT (Figure 2). The remainder of this report is devoted to understanding why this phenomenon persists, and what efforts and initiatives have been successful in addressing the ongoing underrepresentation of girls and women in IT and other STEM-related fields.

[1] WINTA refers to female enrolment in the following 'non-traditional' disciplines: Natural and Physical Sciences; Information Technology; Engineering and Related Technologies; Architecture and Building; Agriculture, Environmental and Related Studies; Management and Commerce; and the narrow field of Education (Economics and Econometrics).

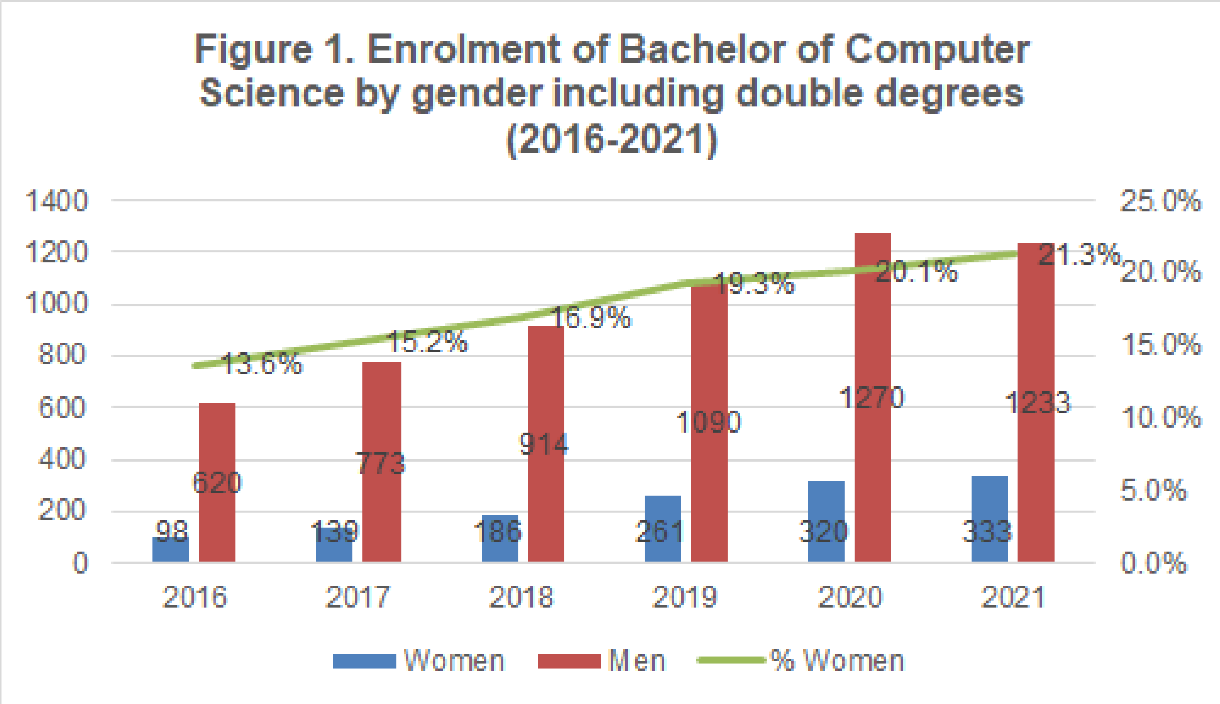
Figure 1. Enrolment of Bachelor of Computer Science by gender including double degrees (2016-2021)
1400
1200
1000
800
600
400
200
0
25.0%
20.0%
15.0%
10.0%
5.0%
0.0%
13.6%
15.2%
16.9%
19.3%
20.1%
21.3%
98
139
186
261
320
333
620
773
914
1090
1270
1233
2016
2017
2018
2019
2020
2021
Women
Men
% Women

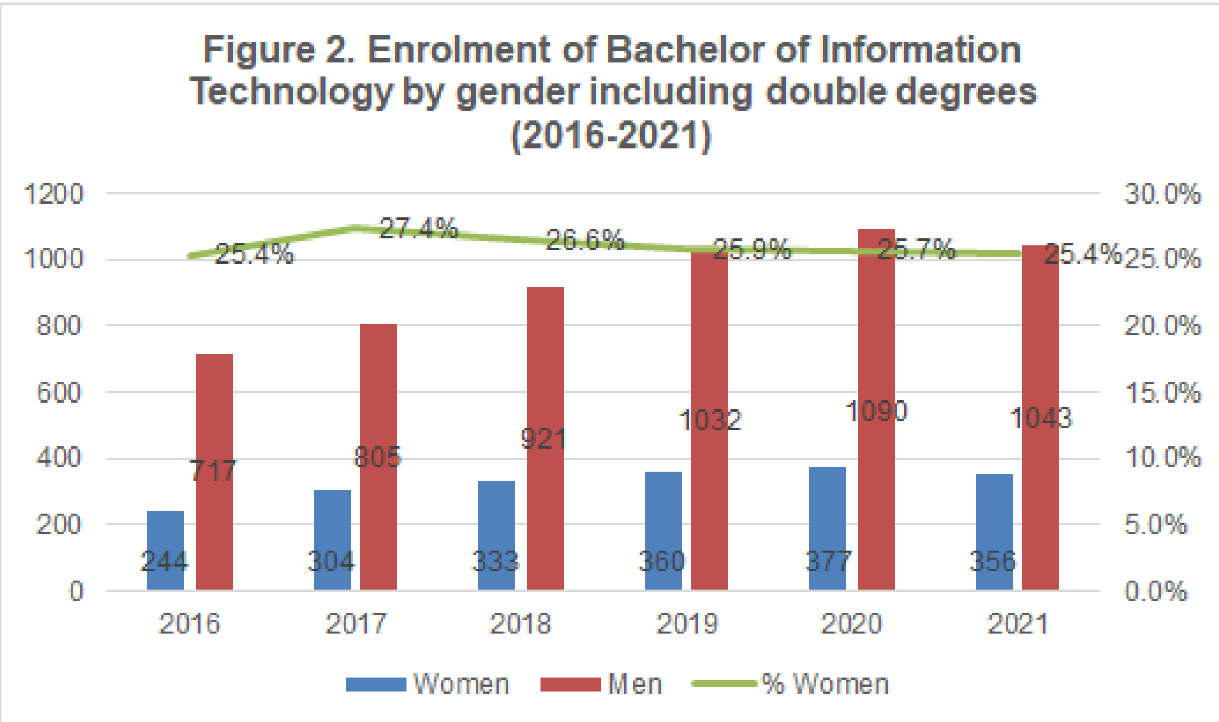
Figure 2. Enrolment of Bachelor of Information Technology by gender including double degrees (2016-2021)
1200
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30.0%
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20.0%
15.0%
10.0%
5.0%
0.0%
25.4%
27.4%
26.6%
25.9%
25.7%
25.4%
244
304
333
360
377
356
717
805
921
1032
1090
1043
2016
2017
2018
2019
2020
2021
Women
Men
% Women

SECTION 2. INDIVIDUAL, INTERPERSONAL AND STRUCTURAL ISSUES

There are substantial empirical studies aimed at identifying and delineating the multitude of issues that influence girls' engagement and decisions to study STEM at higher education levels whilst still in primary or high school. Understanding drivers, as well as barriers, to girls' decision-making in pursuing STEM degrees, particularly computing majors, holds important implications for the design and implementation of strategies that make them feel welcome and excited about pursuing an IT career. In this section, drawing mainly on published research findings, we summarise issues that influence young women's choices in studying STEM/IT into three levels: individual, interpersonal and structural. We begin the review of influences by discussing the overarching presence and harms of gender stereotypes. Gender stereotypes are considered a cross-cutting issue and exert negative effects from an individual micro-level to a structural macro-level as the following studies demonstrate.

THE PERSISTENCE OF STEREOTYPES

A large body of literature reveals that stereotyping perceptions discourage girls' and women's interests in maths and science, and are a major deterrent to their performance and engagement in the field (Almukhambetova & Kuzhabekova, 2020; Canedo et al., 2019). Gender stereotypes portraying STEM as a broadly male-dominant field are pervasive across various cultural settings. There is a widespread belief that men possess superior mathematical abilities over women, and therefore, are in a better position to pursue STEM education or careers as compared to women (Hill, Corbett, and St Rose 2010), even though there is no clear biological evidence that suggests gender differences in terms of maths and science potential or ability (Ceci, Williams, and Barnett 2009). A 2018 empirical study drawing on an international database of 472,242 adolescents showed that in nearly all countries, more girls appeared capable of college-level STEM study than the number who had actually enrolled, and that girls' science performance was similar or better than that of boys in two out of three countries (Stoet and Geary 2018).

Students might be aware of these stereotypes and hold related views about which STEM courses are suitable for women or men as early as primary school (Ambady et al. 2001; Farenga and Joyce 1999). Knowing the common stereotype about boys' supposedly superior ability in fields that are mathematically demanding means that girls tend to assess themselves as less capable than boys with regard to mathematical achievements and hold themselves to higher standards to succeed in male domains. For instance, a study by Correll (2001) examining a national dataset of more than 16,000 high school students in the US demonstrated the influence of gender stereotypes on students' perceptions of their abilities in particular fields. High school boys were more likely to believe that they fared better at mathematics as compared to their female counterparts with equal past mathematical performance. When it comes to verbal ability, girls, on the contrary, perceived themselves as more competent. These findings pointed out the presence of gender stereotypes regarding students' perceptions in particular fields considered to be masculine domains. Correll's research also found that higher mathematical self-assessment among students of equal abilities increased students' odds of enrolling in high school calculus and choosing a quantitative college major (including engineering, chemistry, physics, other physical sciences, computer programming, statistics and mathematics). In a follow-up study, Correll (2004) found that women and men held different standards for what constituted high ability in the "male advantage" condition. This later research revealed a belief among women that they must achieve exceptionally high levels in maths and science to be successful in a STEM field.

Discouraging girls' interest in maths and science from their early years, gender stereotypes continue to be a major issue affecting low enrolment of women and continuing gender disparity in STEM higher education. Before making choices about their study, girls often maintain stereotypical perceptions about STEM subjects being difficult (for their gender), and assume that they will not perform as well as male students in those disciplines (Shillabeer and Jackson 2013). Using a large-scale survey with over a thousand STEM and non-STEM female students in combination with a qualitative study at six different schools in Spain, Olmedo-Torre et al. (2018) revealed that social stereotypes were referred to as the most common barriers to low enrolment of women in STEM degrees (cited by nearly a third or 31.47% of their respondents), followed by their "immediate environment" (such as the number and gender of respondent's siblings and their order of birth) which were mentioned by 14.5% of respondents. Findings from the qualitative component further illustrated the existence of social stereotypes. Accordingly, respondents most frequently regarded women as being more suited to humanities, psychology, social or literature courses, whereas men were thought to be more suited to STEM and technology courses. Respondents also remarked that during their early years, they had not been encouraged to pursue engineering; rather they had been mainly educated for motherhood and received little education in technology.

Existing research draws attention to the IT discipline's image problem – a stereotyping perception of the computing field as a practice that involves socially awkward, glass-wearing and pale-skinned scientists (Cheryan, Master, and Meltzoff 2015), or solitary men and boys with a sole focus on programming or machinery (Hamilton et al. 2016). According to the Australian Computer Society (ACS), the stereotypical IT "geek" is seen as "a 25-year-old, hoodie-clad dude who wears glasses, is antisocial, and loves to hack strings of code in the basement of his parents' home, eating stale pizza and drinking Red Bull until 3 or 4am" (ACS, 2015).

Chang (2018) draws further attention to the stereotypical "Brotopia" coding culture of Silicon Valley technology entrepreneurs. In addition to the masculine geek stereotype, she argues that the success of IT heroes such as the late Steve Jobs has given rise to the idea of an overconfident and charismatic man as the pillar of success in IT companies.

These masculine images of computer science have been a serious impediment for many students entering the field (Wilson 2003), and are shown to impact girls and women more than boys and men (Johnson, Garcia, and Seppi 2019). Locating their study at Carnegie Mellon University in the US, Margolis & Fisher (2002) found a widespread idea of "geek mythology" among students which emphasised that a real computer science student was obsessed with computers. While most students did not identify themselves as such a person, this mythology appeared particularly disturbing to women. In the same vein, several studies in the US and Europe suggest that female students often perceive the computer sciences to be an unsociable and nerdy discipline (Jepson & Perl, 2002; Beyer et al., 2004; Gansmo, Lagesen, and Sørensen 2003) that stands in stark contrast with their self-identity as socially active women (Lagesen 2007) with a stronger interpersonal orientation than men (Croasdell, McLeod, and Simkin 2011). Fears of confirming these stereotypes about the masculine characteristics of STEM fields and the superiority of men in maths and science might also lead girls to dissociate their interests in the areas, through a process of "dis-identification", in order to avoid the risk of being judged by a stereotype (Hill et al. 2010).

Accumulated empirical evidence also suggests that for women and girls pursuing STEM, those with a feminine appearance are assumed not well-suited to be scientists (Banchefsky et al. 2016; Goldman 2012). Such stereotyping perceptions do not only affect girls' views towards the people working in the field but also create societal bias against women who work in STEM (Hill et al. 2010). Examining judgement in professions perceived as masculine, Heilman and colleagues (2004, 2007) recruited undergraduate students for their experiments and asked them to rate the competence and likability of three employees. Their research showed that participants tended to view women as less competent than men unless there was clear evidence of women's success in their work. And when a woman was clearly competent in a "masculine" job, people considered her to be less likable.

To sum up, gender stereotypes associated with IT specifically and STEM more generally being men's fields are pervasive in various contexts across different cultural settings and exert far-ranging effects among girls. These stereotypes can decrease girls' interests in STEM fields, discourage them from fully recognising their abilities and potential, and divert their attention away from pursuing an IT degree. Efforts to promote gender diversity in STEM higher education should therefore continue to pay attention to understanding negative stereotypical associations and strive to counteract dominant stereotypes that hold back girls' engagement in these fields. Among studies aimed at addressing gender stereotypes in STEM, there has been an emphasis on promoting the "growth mindset," a view that women (and all people) can learn what they need to be successful in the fields rather than being "naturally" gifted (Good, Rattan, and Dweck 2012). Educators, as well as parents can communicate the growth mindset to girls in order to reduce the harms of stereotypes and increase their representation in STEM fields, particularly IT (Hill et al. 2010).

INDIVIDUAL ISSUES

In this section we summarise the individual issues that affect girls' motivation and decisions to pursue an IT degree at higher education, specifically: self-efficacy; attitudes and interests; prior exposure to computing; and career perception.

Self-efficacy

Self-efficacy, that is the belief in one's ability to achieve a task or a goal, has been identified as a significant determinant of girls' and other underrepresented groups' engagement and persistence in STEM education (Blackburn 2017; Chemers et al. 2011; Dasgupta and Stout 2014; Grossman and Porche 2014; Main and Schimpf 2017). As previously mentioned, girls and women are more likely to underestimate their own ability in STEM-related subjects and skills than boys and men. Considering this, it is not surprising that high school students who have done well in computing subjects may seek to major or pursue a career in an IT-related field (McInerney et al. 2006), and girls who are more confident in their maths and science abilities are more likely to choose STEM-related degrees or majors (Chavatzia 2017). These findings are well documented. For instance, a Google study (2014) analysing geographically and academically diverse data of 1,000 women and 600 men across various regions in the US found that a girl's interest in and perception of her own proficiency in mathematics and problem-solving significantly predicted the decision to pursue a Computer Science degree. A similar finding was drawn from a study in Ireland which investigated the reasons for women's underrepresentation in a STEM college. Analysing college applications, this study showed that girls were more likely to focus solely on their absolute advantage in mathematics when making decisions about STEM education while for boys, their STEM decisions were based on their comparative advantage in English and mathematics. Specifically, girls who had achieved the top grade in mathematics were about 60 percentage points more likely to go for STEM (Delaney and Devereux 2019).

Attitudes and interests

In research from psychology and the behavioural sciences, attitudes towards computers is among the three aspects of the individual construct in the seminal theoretical model of factors influencing girls' career choice proposed by Adya and Kaiser (2005). This factor has become the departure point for a large body of research exploring influences on the decisions to pursue IT study and career which often suggest that girls' interests significantly predict their pursuit of an IT degree (Ceci et al. 2009; Denner 2011). For instance, Croasdell et al.'s (2011) study of 166 female college students found that "genuine interest in the IS (information system) field" – that being the belief that IS courses are interesting and likeable – was among the underlying factors leading to a woman's choice of a university major. Attitudes towards computers have also been selected as the focus of interventions in various programs promoting girls' participation, particularly to shift girls' values related to computing and improve their interests and technological curiosity (see for instance, Denner 2011; Lang et al. 2020).

Prior exposure

Girls with computing experience are found to have greater interests and higher likelihood of completing an IT degree. This relationship is explained by the argument that early access to computers reduces intimidation and increases one's perceptions of individual capabilities (Adya and Kaiser 2005). Such familiarity also encourages a child's interest and curiosity, and simultaneously, promotes her sense of competency. Additionally, early exposure is believed to offer a potential career path in the field (Google 2014). To corroborate these findings, Master et al. (2017) conducted an experiment in which they randomly assigned 96 six-year-old students either to a treatment group (given experience in programming a robot using a smartphone) or to control groups (no activity or other activity). This study found that when girls were provided with programming experience, they reported higher technology interest and self-efficacy as compared with those in the control group, and did not exhibit a significant gender gap in comparison to boys' interest and self-efficacy.

Career perceptions

A substantial body of research has found that jobs involving social interactions and which value social rewards are more likely to attract women than those which require working with physical objects and/or are more focused on earning high salaries and gaining power (see for instance, Almukhambetova and Kuzhabekova 2020). There is a misperception that a career in STEM is not associated with communal goals, which leads women to move away from the field (Dasgupta and Stout 2014). Some studies further demonstrate a common belief among women that careers in technology fields are difficult to reconcile with raising a family (Astin and Sax 1996). For example, a study by Beyer, Rynes and Haller (2004) found that women were significantly more interpersonally-oriented and family-oriented than men, and that careers in computer science conflict with these orientations.

A person's understanding of STEM's broad applications is therefore important in shaping their aspirations and greatly affects their intention to further study in STEM fields (Archer et al. 2012; Mujtaba and Reiss 2014). In view of this, many studies have found that perceptions about a future STEM career significantly influences girls' attitudes about and pursuit of a degree in these fields. For instance, based on a survey of 166 female college students taking a required management information systems class at a US public university, Croasdell et al. (2011) identified that among the core reasons for majoring in information systems was women's belief in a future good job and a well-respected career (in IS), apart from their genuine interest in the subject. Similarly, Google's study (2014) mentioned earlier noted that how a young woman perceived computer science as a career accounted for 27.5% of her decision to choose the field. Vocation-related reasons were also noted in a recent large-scale European study mentioned earlier (Olmedo-Torre et al. 2018). Specifically, female students widely ascribed their choice of STEM studies to the possibility of finding employment, which was cited by 75% of the respondents participating in that survey.

Traditionally, career awareness education does not start until the final years of high school. However, there are studies revealing that students' career perceptions are shaped from as early as grade 6 (McMahon, Carroll, and Gillies 2001), and that girls' interests in maths and science is lost as they transition from their middle primary years through to the end of secondary school (see, e.g Broadley 2015; Marginson et al. 2013). Considering these findings, there is now growing advocacy for career education to start early, preferably during primary school, to address occupational and discipline-based stereotypes and inform girls about potential STEM pathways, but also to provide professional development for advisors and teachers working with girls early in their schooling (Broadley 2015; Campbell et al. 2020).

INTERPERSONAL ISSUES

The current body of research emphasises the crucial importance of support from a girl or woman's social and peer network in encouraging them to overcome stereotypes associated with their gender, enrol in a STEM/IT undergraduate degree and pursue STEM-related career aspirations.

Parental influence

Support from a girl’s family is shown to have a direct impact on her likelihood to pursue STEM subjects and careers (Google 2014; Spieler, Oates-Indruchova, and Slany 2019; Veltri, Webb, and Papp 2010). These findings are not limited to a US context (for instance, see Croasdell et al. 2011; Leaper and Starr 2019) and are consistent across other settings in Europe (Gabay-Egozi, Shavit, and Yaish 2015), Latin America (Alchieri and Charczuk 2003; Croasdell et al. 2011) and Asia (Almukhambetova and Kuzhabekova 2020). Using qualitative interviews, a recent Kazakhstan-based research project found that girls’ decisions to major in STEM were especially influenced by encouragement from their parents. Notably, support from a male member in their family, i.e father or elder brother, was identified as a crucial factor in promoting the girl's confidence in making STEM choices (Almukhambetova and Kuzhabekova 2020). Current literature additionally highlights the positive effects of having family members who work in STEM-related fields because they increase girls’ exposure to STEM (such as engaging girls in technology-involved activities) and address the perception regarding the STEM work-life balance (Shapiro and Sax 2011; Tenenbaum and Leaper 2003). However, other research has rejected the significance of parental occupation, instead highlighting the crucial role of positive encouragement from family on a girl’s decision to pursue computer science (Google 2014).

Peer influence

Girls’ interests, self-efficacy in technology and preferences to study IT are additionally affected by their exposure to peers with the same interests (Corrigan and Aikens 2020; Spieler et al. 2019). Using a large-scale data panel collected from 218 classrooms and 4,998 adolescents in Sweden, Raabe, Boda and Stadtfeld (2019) revealed that having friends in the same classes who liked STEM significantly encouraged girls’ preferences in the field, and meant they were more likely to adjust their interests to align with those of their classmates. In view of this, the study argued that peer influence acted as a social mechanism lowering the costs and risks of sanctions against behaviours that were not gender-conforming. Existing studies also find compelling evidence that working in a girls-only environment, such as girls-only pairings in computing classes or girls-only coding initiatives, is beneficial for girls because it encourages positive computing identities through socialisation with peers having the same interests and collaborative learning (Alvarado, Cao, and Minnes 2017; Wong and Kemp 2018).

Role models

Having opportunities to interact with a role model in the field, particularly a woman, is found to be an important factor influencing girls’ choices in pursuing STEM education because such interaction enables girls to learn about science and technology and reduce stereotypes of technology as a masculine domain (Spieler et al. 2019; Veltri et al. 2010). Since most STEM fields are dominated by men, knowing about the achievements by women who have overcome such gender biases results in the most benefits (Lockwood 2006) and can increase girls’ self-efficacy, a major factor in their decisions to get involved (Veltri et al. 2010). In this regard, existing research highlights the significance of having an “ordinary” female role model (Young et al. 2013) rather than a supernatural or superstar one (Cheryan, Siy, et al. 2011). A recent study by Young et al. (2013) established that encounters with STEM role models in everyday life – this includes university professors, secondary school women science teachers, female students and female professionals – provided girls with positive experiences. This was because such exposure was associated with pro-science career aspirations and attitudes. Additionally, these ordinary role models shifted women’s implicit cognitions that science was masculine in the culture at large.

Mentors

Mentoring plays a crucial role in forming and broadening girls’ understanding of science and technology; in this regard, research demonstrates the effectiveness of mentoring for providing emotional support, as well as promoting young girls’ interests, self-efficacy and motivation in pursuing a STEM degree (Spieler et al. 2019; Stout et al. 2011). A study of girls who participated in a mentoring program between high school and middle school in northern Utah (US) illustrated that these activities benefited both participating mentors and mentees as it increased their interest and self-efficacy in computer science (Clarke-Midura, Allan, and Close 2016). Similarly, surveying adolescents in the US, Ko and Davis (2017) found that interest in computing was strongly related to having a mentoring relationship and not to gender or socio-economic status. Additionally, students with a mentor – be it a friend, parent, sibling, cousin, teacher or even neighbour – engaged more significantly in computing education and had more diverse beliefs about people in the field. Further, a significant number of studies that focused on evaluating mentoring initiatives run at universities generally showed the benefits those programs created on improving women students’ learning and social experiences at undergraduate and graduate levels. Having a mentoring relationship with a peer or a faculty member was identified as an important element in helping female students counter various forms of isolation, micro-aggression and the shortage of successful women role models in STEM fields, thereby strengthening their sense of involvement and persistence (Bhatia and Amati 2010; Johnson et al. 2019; Ong, Smith, and Ko 2018).

STRUCTURAL ISSUES

School environment

Various studies have found that girls who attend schools with higher quality of teaching and effective teaching strategies are more confident in science and maths (Chavatzia 2017; Heaverlo, Cooper, and Lannan 2013; Spearman and Watt 2013). For example, research has shown that the availability of resources that encourage girls' science interest and the access to informal STEM activities positively affect girls' achievement in science (Dasgupta and Stout 2014). The classroom environment can either reinforce gender stereotypes or challenge them and promote inclusivity. Many studies have illustrated the importance of having gender-inclusive classrooms in building a great sense of STEM identity and positive attitudes towards STEM fields among girls (Cheryan, Meltzoff, and Kim 2011). For instance, one study found that high school girls show more interest in taking computer science in a classroom that does not draw on stereotypically "nerdy" content (Master, Cheryan, and Meltzoff 2016).

Online learning environments have also been shown to positively build girls' perceptions of science and technology. This is because in such contexts, students have more autonomy and teachers often play the role of a facilitator where their perceptions and biases about certain students with higher cognitive abilities may be reduced (Chan and Lee 2007; Slotta and Linn 2009).

Through three behavioural experiments in the US, Cheryan, Meltzoff, et al. (2011) examined the effects of the virtual computer science classroom on students' enrolment intention, sense of belonging and anticipated success. Their study found that when a virtual classroom was changed to one that did not convey stereotypes, it significantly increased women's interest and anticipated success in computer science.

Weibert and Festl (2012) evaluated computer science curricula for teenagers in Germany and recognised that many were considered boring to students which hindered them from truly understanding a programming language, the concept of coding and its relationship with problem-solving. Considering such shortcomings, the authors implemented a curriculum that considered girls' assessment of and access to both computer science and IT professional activity. Their approach showed positive changes in girls' interests and engagement levels in IT domains. With these findings, the authors emphasised the importance of framing computer science as a discipline that helped make the world a better place, and of creating programs and products or new ideas to address existing negative stereotypes about the field.

Several studies have also been conducted to investigate the benefits of introducing sci-fi movies into classroom contexts to challenge deep-rooted gender stereotypes. A study by Zhang (2020) at Lakehead University, for instance, found supporting evidence of a curriculum using sci-fi movies as a feminist teaching pedagogy. Though for most of the participants their educational paths had already been predetermined during their teenage years, after watching three sci-fi movies – *Aliens* (1986), *Lucy* (2014) and *Arrival* (2016) – that challenged gender stereotypes, participants' self-perceptions about their career choices showed the potential to be adjusted.

Teachers

Existing literature has pointed out the negative role of school teachers in reinforcing gender stereotypes in STEM. For instance, in studies conducted by Adya and Kaiser (2005) and Ashcraft, Eger, and Friend (2012), teachers unintentionally suggested that boys were better than girls with computers, and attributed computer expertise more to boys than girls. Likewise, Hand, Rice, and Greenlee's study (2017) with high school teachers and students showed that teachers tended to assign more masculine characteristics to scientists and feminine characteristics to the humanities. They were also more likely to believe in boys' better performance than girls' when STEM disciplines were considered.

On the other hand, school teachers are important in shaping students' attitudes and decisions for pursuing higher education degrees and future careers, particularly in fields where female role models are often lacking (Hand et al. 2017). According to a large-scale study among 11,500 European women, guidance and advice from teachers was recognised as a major driver of students' educational incentives and attitudes, and nearly 60% of the surveyed sample reported having received encouragement from their teachers to pursue a STEM career (Microsoft 2017 cited in Spieler et al. 2019). Exploring transition from elementary school to early college, Rice et al. (2013) revealed that transitional periods, such as late high school, were a critical time when students made decisions about pursuing a STEM major. They emphasised teachers' influence on students' decision-making and the correlation between teacher support in maths and science and with increased student self-efficacy and positive perceptions of STEM fields.

Movies and video games

Movies and gaming industries can reinforce gender stereotypes (Spieler et al. 2019). Women's role in sci-fi movies, for example, has been found to remain within a framework that may reinforce the existing patriarchal structure, even in post-human science fiction texts (Liang 2015). Meanwhile, the gaming public has been criticised for being a "boy's club" that undermines the voice of women when they speak out to disrupt the dominant discourse underpinning the masculine gamer identity (Salter and Blodgett 2012). Exposure to an environment containing masculine stereotypical objects, such as Star Trek posters and video games, have been shown to diminish girls' interests in pursuing technology subjects and careers, because it discourages their sense of ambient-belonging and serves as a deterrent to their interest growth (Cheryan et al. 2009). In addition, girls are also discouraged from playing games by the proliferation of sexualised female characters (Reinecke, Trepte, and Behr 2007), which can also include sexualised violence and rape (Strengers & Kennedy 2020). Looking at in-game content from 571 titles, Lynch et al. (2016) examined the nature of female representations from 1983 to 2014. Their study noticed that while the overall sexualisation of female characters decreased in recent years, some categories of video games, such as fighting games, continued to employ overtly sexualised portrayals. Their analysis further found that the percentage of primary female characters did not evolve or develop over time, women were more likely to be depicted in secondary roles and be objectified to support product marketing, and there was a lack of female game developers or developers more broadly who were gender-sensitive.

Although the number of playable female characters has generally increased, there is only a small handful of video games featuring protagonists who are girls or women. Surveying 1,266 gamers, Yee (2017) revealed that 75% of the female gamers rated female protagonists as “very” or “extremely” important. As shown in a recent study by Google (2017), although more women are playing nowadays than ever before, male characters are depicted in 44% more of the top 100 app icons than female characters. This study also found that the majority of women gamers thought that mobile games were not made for women.

SECTION 3. WOMEN'S EXPERIENCES IN STEM/IT HIGHER EDUCATION

While universities have focused significantly on recruitment efforts, less attention has been paid to ensuring that women enrolling in STEM fields stay to complete their degrees (Blackburn 2017). Insights into women's experiences of studying STEM majors at higher educational levels are crucial in stemming the leaking STEM pipeline. Existing research demonstrates that women often confront an unwelcoming environment, a cold campus or "chilly climate" (Seaton 2012), and encounter gender bias on a regular basis, leading to women's dissatisfaction with their discipline's culture and lowering their confidence in relation to pursuing degrees in STEM fields. For instance, Weinberger (2004) surveyed college students in non-IT majors about their reasons for avoiding majors such as computer science, engineering and electrical engineering. The study showed that about one-third of women expressed their concerns about the classroom culture in IT courses. Comparably Beyer et al. (2004) found that female students felt a high sense of isolation in technology courses. In an early seminal study mentioned earlier, Margolis and Fisher (2002) similarly found that the majority of undergraduate female students they interviewed at the School of Computer Science in Carnegie Mellon University felt dissatisfied with their discipline's culture, which was characterised by expectations of being a computer geek in a male-dominated environment, with a focus on the technical aspects of programming or hacking.

The research additionally noted a decline in women's confidence as they went further into their undergraduate study (Margolis and Fisher 2002), a finding which has also been reported by research conducted among women at graduate level (Wofford 2021). The lower level of confidence among female students as compared to their male peers is a common finding by various studies when it comes to maths or science abilities, computing majors or the ability to excel in STEM fields (see for instance, Cohoon and Aspray 2006), even when women have similar grades (Singh et al. 2007). A synthesis of recent literature on undergraduate experiences in Australia similarly noted lower self-efficacy to be the most prominent issue for female STEM students. Accordingly, women reported having more self-doubt in their abilities and lower confidence regarding their mathematical abilities even when there was no difference in their prior knowledge or previous academic performance (Fisher, Thompson, and Brookes 2020).

Gender differences in self-confidence or self-perception towards one's programming skills was also noted in the survey of 166 computer science undergraduates at Harvard University. This study found that male students rated their confidence in programming at an average of 3.3 (out of 5 after 0-6 months of experience) while the corresponding score was 2.6 for female students (WiCS Advocacy Council 2015).

The lower level of confidence that is frequently reported among STEM women students largely comes from long-standing stereotypes associating successful academic STEM disciplines with cisgender white men as discussed in the previous section (Corbett and Hill 2015). These gendered stereotypes of a typical STEM person coupled with the lack of female role models contribute to women's lower confidence, and also their lower sense of belonging compared to men (Fisher et al. 2020). Illustrating the lack of role models and lack of visibility of women in general, a study conducted by Thomas and Allen (2006) among first-year IT students at the Australian Catholic University in Melbourne showed that over half of the students could not name one woman they knew in IT.

Women's lower confidence might also be explained by their heightened feelings of being a computer science "imposter", which originates from a dominant culture emphasising that the profile of someone who "belongs" in IT should have an intense and immediate attraction to computing from an early age. Many female students do not identify with that profile, resulting in their decreased confidence and interest in continuing. Feelings of not belonging are also influenced by a computer science degree's curriculum, which Margolis and Fisher (2002) found was largely focused on technical aspects of programming at the early stages rather than on broader multidisciplinary applications. Women, who tend to report greater interest than men in broader applications of a discipline, are more likely to perceive their broader educational and career goals as clashing with the technically-focused requirements of certain STEM majors' curricula, creating a deterrent to pursuing and completing their degrees (Mann and DiPrete 2013; Margolis and Fisher 2002).

The potential harm of a curriculum's content on female students' feelings of belonging has been noted in other studies which reveal a common perception that STEM majors require heavy course loads, lack connection between material and application and that the students themselves lack academic skills necessary to complete their courses (Vazquez-Akim 2014). Such feelings, in turn, affect women's level of comfort within classroom contexts. For instance, Alvarado et al. (2017) conducted a study at a liberal arts college and a large research-focused university in the US and illustrated that female students often refused to ask questions in class or interact with the instructor. They also felt less comfortable doing so and therefore reported less confidence in their abilities, even though they performed as well as male students. This was more likely to be observed as the course's content became more difficult.

The low sense of belonging is another major theme that often emerges in studies on women's lived experiences in STEM fields which is believed to result from their prior programming experiences (Blaney 2021; Sax et al. 2018), perceptions towards the campus environment (Johnson 2012), threats to their personal and social identity including the experience of sexism, stereotyping concerns (O'Brien et al. 2015) or a lack of social support (see for example, Rosenthal et al. 2011). On the other hand, research has demonstrated the positive role of departmental and peer support in predicting students' sense of belonging. For example, one study found that when a student felt supported by the computing department and their peers, their sense of belonging in the field of computing was fostered (Sax et al. 2018).

Women also face greater pressure to conform to masculine norms in STEM fields, and are more likely to believe they need to work harder than men to be successful and forge STEM belongingness (Hirshfield 2011; Smith et al. 2013). For instance, Smith et al. (2013) carried out three studies with 149 first year STEM graduate students, including 75 women, at two US universities (University of Oregon and Montana State University) to examine women's perceptions of a male-dominated field and compare how women and men perceived their level of effort in order to succeed in STEM fields. Their findings showed that women felt they had to exert additional effort, and that these feelings were related to a decreased sense of academic belonging. This was, in turn, linked to lower motivation for their graduate study.

ATTRITION AND RETENTION OF WOMEN STUDENTS IN IT DISCIPLINES

Unfortunately, due to many of the issues already raised, women are more likely to discontinue or leave their IT degrees than men. According to a study undertaken at the University of Florida, the likelihood of female students leaving computer science was twice as high as that of their male peers (Kapoor and Gardner-McCune 2018). Available statistics reveal that IT has the largest attrition rate among studied areas in Australia with around one third of students leaving the field (Marks 2007). Many studies have been undertaken to establish the reasons why IT students leave their majors with particular attention to influential factors determining women students' decisions.

There is well-documented evidence establishing the association between women's lack of self-efficacy and the decision to discontinue a computing degree. Specifically, studies have demonstrated a relationship between women's withdrawal from IT and their lower level of self-efficacy resulting from their lack of understanding about their own academic ability as compared to other peers (Fisher et al. 2020) or in relation to their previous excellent high school grades (Cohoon and Aspray 2006b). For students who stay, a large-scale quantitative analysis of 7,209 academic transcripts and 536 survey responses studying gender dynamics in the undergraduate Computer Science program at Stanford University in the US further noted the significant role of self-confidence in determining women's study experiences (for example, their interaction with faculty members), as well as their overall performance (Redmond, Evans, and Sahami 2013).

Additionally, students are more likely to leave their majors when they feel they receive unequal treatment for belonging to an underrepresented group. The *Student Experience of the Major (online) Survey* conducted by Barker, McDowell, and Kalahar (2009) among 294 students of various racial/ethnic groups who had taken computer science introductory programming courses in the US showed that underrepresented students perceived slightly more racism and sexism amongst their cohort. The intention to leave IT majors is also determined by a student's dissatisfaction with the major as identified in the study by Lewis et al. (2008) with 180 students who had declared computer science majors in the US. The study found that a student's experience in programming significantly predicted their intention to stay in computer science. However, technical ability was found to have a less important role than soft skills (i.e. emotional intelligence) in predicting female students' affinity (satisfaction with the major) which was significantly related to their intent to stay (Lewis et al. 2008).

In the Australian context, Ogunbona et al. (2013) investigated factors contributing to students discontinuing their degrees using an online survey conducted among four universities across four different states with 154 former ICT students (18.8% women and 81.2% men) from 2005-10. With respect to female participants, this study revealed that women were more likely to believe that they did not have the expected background knowledge for the course, did not understand the concepts and did not understand the meaning of terms used in the course. 18.5% felt that they lacked encouragement from male staff while more than a quarter (27.6%) believed the course they had withdrawn from prioritised male-oriented content. Dissimilar to common findings drawing the link between female students' attrition and their caring roles, this study found no significant differences in response to significant life issues. Specifically, women students were no more likely than men to be affected by issues such as pregnancy or an illness of her family member.

At the departmental or program level, the aforementioned study by Barker et al. (2009) demonstrated that female students' continuation in an IT major was also affected by low numbers of female enrolment, as well as by reports of higher female attrition rates. Their findings further highlighted the importance of student-to-student interaction as the strongest predictor of a student's intention to stay in their program since it helped overcome stereotypes and build support groups, thereby reinforcing the students' sense of belonging. Similarly, drawing attention to the related university environment, a study at the University of Florida in the US pointed to the lack of timely feedback from their faculty, gender biases in the classroom, and negative team experiences among the main reasons for female students to switch majors and leave Computer Science (Kapoor and Gardner-McCune 2018). In an Australian study mentioned earlier, both female and male former-ICT students stressed that difficulty in obtaining help when required, the teaching style (for instance, fast paced teaching or insufficient explanation) and the course's lack of employment-focused content were contributing factors in their decisions to withdraw (Ogunbona et al. 2013).

INTERSECTIONALITY: WOMEN AND RACE/ETHNICITY

An intersectional approach provides a critical lens to understand how gender intersects with other vulnerable, non-dominant and/or underrepresented groups and attributes to compound disadvantage, discrimination and/or marginalisation. These include: Indigenous peoples and communities; people from low socio-economic backgrounds; people with disabilities; people from racially, ethnically and linguistically diverse backgrounds; and people with diverse sexualities, sexual and/or gender identities and expressions.

In this section we focus on women in STEM with non-white racial and ethnic identities and cultural backgrounds. The experiences of women studying STEM vary across racial and ethnic groups due to the different constructions, performances and experiences of gender, which many studies aim to examine by using an intersectional approach. Existing research on the experiences of ethnically diverse (non-white) women in STEM majors has highlighted the unwelcoming, negative culture of many STEM departments, including frequent encounters of racial stereotypes about women's academic abilities, discriminatory attitudes from faculty and peers, and teaching staff's hesitance to discuss race and gender issues in the classroom. Such experiences negatively affect women's learning and social experiences, as well as their STEM identification (for summary see Johnson 2012).

Capturing the experiences of women of colour in predominantly white universities, many studies have illuminated the different types of racial oppression and gender bias facing this underrepresented group. For instance, Alexander and Hermann (2016) carried out a qualitative inquiry into the experiences of African-American women in STEM graduate programs in the US. Their research found that participants encountered racial microaggressions, low self-efficacy and a lack of institutional support throughout their pursuit of graduate degrees. Specifically, women of colour in their study reported the feeling of invisibility in an all-white academic environment where their opinions were disregarded by classmates and professors. The unconscious acts practiced by their peers were found to render those women participants feeling inferior, ignored and unimportant. The participants additionally reported they could not receive adequate understanding and support from the university's student services when facing social and emotional difficulties.

Based on a six-year ethnographic study of women of colour in STEM majors at a white-dominant institution, Carlone and Johnson (2007) paid particular attention to the identity of women of colour. They illustrated the problematic issue of recognition among those women in a setting that often contradicted their unique vantage point. The white male-dominant composition of the institution coupled with the institutional and historical meanings of being a scientist rendered their attempts to achieve recognition complicated.

Social isolation and sexist treatment are overwhelmingly reflected in empirical studies on the experiences of STEM female students from ethnically diverse communities, which is especially damaging for those who have to confront multiple systems of oppression based on the intersection of their gender and race/ethnicity. A lack of peers from underrepresented racial and ethnic identities in STEM departments was found to cause feelings of segregation among women of colour (Johnson 2007). Additionally, women of colour have reported facing negative judgements by their male peers in relation to their intelligence, which has not only caused feelings of social isolation, but also hindered them from taking part in academic activities (Brown 2000; MacLachlan 2006). Conducting research with a large sample of minority women in STEM graduate programs, Brown (2000) pointed out that interpersonal factors, such as isolation, racism, sexism, being racially/ethnically identifiable and relationships with faculty and other peers imposed greater deterrents to women than barriers at a structural level (for instance, recruiting practices, faculty structure or availability of financial aid and counselling support). In this study, women of colour frequently referred to white men as arrogant and indifferent, while reporting to have been treated as intellectual inferiors by men of colour.

To cope with sexist problems, women graduates often choose to conceal their gendered or raced selves – a strategy to "fragment their identities" (Ong et al. 2011:193). This can take a number of forms, for instance, by spending a lot of time and energy on changing the way they dress, speak and present themselves in order to gain acceptance within their STEM community (Ong 2005). A longitudinal study of women of colour in physics by Ong (2004) revealed the tremendous amount of additional and invisible work young women performed in order to prove themselves as competent learners and gain acceptance from their male physics peers and faculty. The additional hours spent on, for example, attending professors' office hours, working with a tutor or learning laboratory techniques were assumed by these minority women to comprise the invisible, even remedial, work that women of colour accomplished to exist and persist in science. The women in this study also strived for creative ways to access and maintain their membership in the physics culture.

As mentioned earlier, STEM female students often face a diminished sense of belonging significantly due to stereotyping threats and sexist treatment by male faculty and peers, which might lead them to discontinue their STEM studies. For women of colour, their sense of STEM belongingness is often hindered by additional challenges. This is because they may, for instance, be excluded from their department's networking activities, be avoided by white peers in classrooms and labs, or face racism from peers and even faculty members (Johnson 2007; Ong 2005). Using data from 1,722 racially diverse women in STEM majors at 34 institutions in the US, Johnson (2012) found that race/ethnicity plays a powerful role in predicting the extent to which women in STEM experienced an overall sense of belonging to their campus. In addition, the academically and socially supportive culture of the residence hall, as well as their perceptions of a racially-inclusive campus, were the strongest contributors to these women's sense of belonging.

SECTION 4. BEST PRACTICE INITIATIVES AND STRATEGIES FOR RECRUITING AND RETAINING WOMEN IN STEM HIGHER EDUCATION

In this section, we provide evidence of interventions from various settings that have demonstrated effectiveness in ensuring STEM/IT education is more inclusive for teenage girls, address preconceptions that exclude IT as a possible educational path for girls, and promote girls' interests in and motivations to pursue an IT-related degree or major. We pay particular attention to initiatives that focus on girls as there is existing evidence pointing out their greater influence on girls' decisions as compared to mixed gender programs (Molnar, Keane, and Stockdale 2021). Subsequently, we present findings from interventions aimed at broadening the representation of women in STEM at the undergraduate level.

REACHING GIRLS IN SCHOOLS

Promote girls' interest in computer science

Universities, as well as tech companies around the world, have launched a wide range of programs and initiatives aimed at dispelling the myths and stereotypes about computing careers, thereby promoting girls' interest in studying computer science from an early age. Since the late 1990s, the Anita Borg Institute for Women and Technology (ABI), an organisation founded in 1997 in the US, launched the *Artemis Project* within *Women in Computer Science* at Brown University in which they taught girls about computer skills and abstract concepts in a positive and encouraging environment. This project ran a 5-week summer camp for ninth grade girls on the university campus (White 2010). Similarly targeting girls at upper-secondary school age, in June 2005, Boise State University launched the e-Girls overnight workshop targeting ninth and tenth grade girls such as the *Biomechanics of high heeled shoes*, *Computer Networking*, and *A world of career choices* (Todd, Mardis, and Wyatt 2005).

Similarly, Miami University (US) held a week-long residential summer program *Girls on the Go*: *The Mobile Computing College Experience* for second-year high school and junior students in 2012. This program introduced students to computing by exposing them to various fields where computer scientists work, for instance, to create an app allowing zookeepers to record animal behaviours. Participating girls also had a chance to interact with women computer scientists working in wide-ranging areas from education to patent law. Results from post-camp surveys indicated that the program significantly increased the girls' confidence in performing computer science and their understanding of computer scientist jobs (Burge et al. 2013).

Entirely focusing on Artificial Intelligence (AI), Stanford University ran the *Stanford Artificial Intelligence Laboratory's Outreach Summer (SAILORS)* program to recruit grade 10 women students to computer science. This two-week non-residential free initiative was organised by the university's graduate student and professor volunteers, and aimed to specifically address the lack of diversity in AI. *SAILORS* was the first AI camp that provided high school students with a wide overview of the humanitarian applications of the field, as well as the technical methods behind these applications. Evaluative surveys of the *SAILORS* program showed its positive impacts: participating students reported a statistically significant increase in technical knowledge, interest and confidence in pursuing AI careers (Vachovsky et al. 2016).

In a European context, Graz University of Technology (TU Graz) in Austria started the *RemoteMentor* project targeting girls between 14 to 15 years of age in 2018. During their computer science and arts lessons, participating girls used an app developed by TU Graz called Pocket Code that allowed them to create their ideas via storyboards. This app also enabled students to choose famous paintings and create interactive memes through animations and games during their arts lessons, as well as receive real-time online mentoring from a TU Graz's student. TU Graz student mentors would advise the junior girls on their scripts during a 30-minute session. A preliminary evaluation of the project suggested positive results with respect to its effects on promoting girls' motivation. Girls who had participated in this project generally reported their satisfaction with the mentoring experiences and the games they produced during the lessons with Pocket Code (Spieler et al. 2019).

Aimed at encouraging female participation in ICT studies and careers, the *Go Girl, Go for IT* event was first launched in Queensland (Australia) in 2000 and has been rolled out across various states since, targeting secondary schoolgirls aged 13 to 17. Most of the sessions have featured industry presentations with PowerPoint slides and video content. A survey based on 3,711 schoolgirls participating in four events from 2006 to 2012 illustrated that the event significantly influenced respondents' interest in ICT which, in turn, affected their ICT career intentions. This evaluative study further corroborated the success of the event by finding that 90% of the surveyed schoolgirls reported a positive feeling about ICT careers after attending the event (Gorbacheva et al. 2014).

Girls at younger ages have also become major targets of various programs. For instance, the *Georgia Computes!* project, which was implemented for six years at Georgia Tech University (US), invited students from early age groups (grade 4) to senior groups (grade 12) to attend on-campus, after-school and summer computing camps. Those camps were delivered to ethnically diverse girls, including African-American and Hispanic students. An evaluation of the program conducted prior to and after 13 events and 7 workshops found statistically significant improvements in students' attitudes about computing demonstrated through their responses to statements like "Computer jobs are boring", "Girls can do computing," and "Programming is hard." A comparison between the 2006 and 2012 *Georgia Computes!* cohorts further suggested a 237% increase in the number of girls who took the computer science advanced placement exam after participating in the program (Bruckman et al. 2009; Guzdial et al. 2014).

As part of their efforts to engage with younger girls, in addition to the *RemoteMentor* project previously mentioned, TU Graz also launched a *Girls Coding Week* involving younger girls aged 11 to 14 years. In their workshops, participants were introduced to the concept and practice of coding via a range of activities, such as coding without the use of a computer (i.e 'programming' a classmate to act like a robot), having discussions on computer science topics, and participating in hands-on coding units (such as creating their own games). Results of their work were then presented to their parents at the end of these workshops (Brackmann et al. 2017; Spieler et al. 2019).

Focusing on sixth through eighth grade girls, their parents, and teachers, the Center for Women and Information Technology (CWIT) at the University of Maryland, Baltimore County (US) collaborated with 13 public school districts and businesses to host *Computer Mania Day* on International Women's Day. At the event, 300 participating students were divided into small groups and introduced to technology's applications via fun and interactive activities which were run by women role models. Additionally, the organisers delivered information sessions specifically to teachers and parents reflecting on the situation regarding the low enrolment of girls in technology and recommendations to the target audience on how to encourage girls to pursue education in technology. Pre- and post-event surveys showed positive influence of the *Computer Mania Day* on participants' attitudes towards the usefulness and utility of computers and technology. An evaluation study that followed also suggested that students who participated in the event were more likely to enrol in a computer course and consider a career in ICT (Morrell et al. 2004).

In Philadelphia (US), the *Sisters in Science* program was initiated in 2001 targeting fourth grade girls to help them build a better understanding of science and mathematics. The program offered six innovative science programs designed to foster equity, access and inclusion in STEM education, including 20 weekly science experiments. These activities aimed to promote girls' interests in science and challenge the stereotype that girls are less component at or suited to science (White 2010).

Among initiatives run by companies in their efforts to attract more girls into technology, IBM introduced its *EXITE camp* for middle school-aged girls to investigate technology, maths and science. During this US-based camp, girls were given the chance to join activities based on practical issues such as rebuilding computers, designing websites, programming robots and creating presentations (Todd et al. 2005).

Targeting not only girls but other underrepresented groups (African-Americans and Hispanics), the University of Minnesota Centre for Distributed Robotics and the Digital Technology Centre (US) implemented an annual *Technology Day Camp* in 2006 – a week-long day program for middle-school students. Run by graduate student volunteers, the camp offered students real laboratory experience through robotics lessons. For instance, young students were introduced to university life, completed hardware projects, created software or participated in "robot Olympics." The evaluation at the end of the program suggested an increase in participating students' interest in technology (average score from 3.6 to 4.1 out of 5) and in their desire to pursue a career using computers or robots (from 2.25 to 2.8 out of 5) (Cannon, Panciera, and Papanikolopoulos 2007).

Introduce women role models

Drawing on research emphasising the importance of having positive women role models, many initiatives have focused on promoting these to young girls. As part of the *Digital Divas Club* program launched in the state of Victoria (Australia), each school was visited regularly by a research team who observed the classes. Additionally, an IT professional (woman role model) visited each class and spoke about her educational and career pathway and experiences. The program also assigned an undergraduate IT woman student, who was called an "Expert Diva", and promoted her as a role model to each class and to support the classroom teacher (Lang et al. 2020). The *Digital Divas Club* was part of the *Digital Divas Project*, an Australian partnership between three universities (led by Monash University) and their industry partners, who developed and delivered an intervention program in secondary schools aimed at changing stereotypical perceptions of IT courses and careers (Fisher et al. 2016).

The *Getting Everyone To Study Math and Related Technologies (GETSMART*) initiative was introduced at the University of Tampa (US) in early 2008 with an aim to help young women appreciate the value of math, science and IT. *GETSMART* targeted middle and high school students and held various events on campus with students and their parents. The Advisory Board reached out to career guidance counsellors at local, middle and high schools and asked for nominations of one or two female participants for the program who were invited to on-campus events and roundtable discussions. IT women executives who were present at those events served as role models to participating girls. Women academics and recent IT graduates also took a facilitating role in discussions which aimed to explore girls' perceptions of STEM careers and their school experiences with science, technology and math classes. A survey conducted at the end of the initiative revealed their remarkable success. Notably, 78% of participants emphasised the importance of seeing female role models while 67% of the girls plan to introduce their friends to the *GETSMART* program. Results from evaluative surveys and interviews were also provided to the industry executives and program sponsors to highlight the important role that models and mentors play for the participating girls (Veltri et al. 2010).

Promote gender-inclusive school education

In Australia, the *Digital Divas Club* program ran from 2010-2014 with the participation of ten schools with diverse backgrounds including both co-education and girls-only schools across the state of Victoria. The program focused on the school curriculum to generate positive perceptions around computing in the early school years. In order to dispel the stereotypically masculine and geeky image of IT and promote the social impacts of the discipline, the *Digital Divas Club* curriculum did not teach programming languages but rather focused on problem-solving aspects (Fisher et al. 2016). Content was also designed in a way that promoted positive experiences regarding student self-efficacy and persistence with computing courses and career decisions. For example, students in participating schools were asked to create a healthy menu using traffic light colours to indicate foods with high calories. An evaluation of *Digital Divas Club* highly commended the program's outcomes with regard to changes in girls' attitudes to IT. It found that with the implementation of a carefully designed IT curriculum, notably the reinforcement of IT's positive image, alongside a welcoming classroom and opportunities to interact with female role models, girls' confidence and interest in IT increased (Lang et al. 2020).

STRATEGIC RECRUITING INTO UNDERGRADUATE DEGREES

Adjust admission policies

Significant success was recorded at Carnegie Mellon University in relation to the enrolment rate of women entering the School of Computer Science. From 1995 to 2000, this rate increased from 7% to 42% while women's attrition was considerably reduced to roughly the same low level as that for men (less than 10%). Among the strategic recruiting strategies Carnegie Mellon University deployed was to increase the relative number of women by not giving strong preference to highly experienced students (who were usually men) in their admission process (Lagesen 2007).

Meanwhile, a focus on number rather than percentage was adopted at Stanford University. They redesigned their introductory computer science courses to be more appealing to a wide audience and not just as majors, and encouraged as many students as possible rather than being run as a filter course to admit only the best students. Their strategies were based on the concept of "critical mass" – a function of the number of women participating in that community and thus becoming an effective means of "sustaining a supportive peer community among women" (Roberts, Kassianidou, and Irani 2002). This is built on the assumption that a dynamic process would start and inevitably lead to increasing the number of women as soon as a threshold level is reached. This threshold is statistically defined by Etzkowitz, Kemelgor, and Uzzi (2000) as at least 15% to comprise a "strong minority." A resulting improvement in the learning environment is also achievable because minority problems such as too much visibility and unwanted attention have been found to become less prominent once a substantial increase in the number of women is reached (Lagesen 2007).

Relying on a quota for women along with an advertising campaign to re-create the discipline's image, the *Women and Computing Initiative* at the Norwegian University of Science and Technology (NTNU) in Trondheim successfully increased the proportion of women from 6 to 38 during one intake year (1996-1997). This meant that the percentage of first-year women students increased from 5.7% to 37.7% in that year. NTNU's Board passed an annual quota of extra places (30 for the first year and 45 for the next) exclusively for women which allowed up to a 10% reduction in credit points in order to be admitted (Lagesen 2007).

Other universities have focused on making changes to their admission criteria, particularly to reduce requirements in regards to a student's prior experience in programming/computing, which has been shown to give strong preference to men (Lagesen 2007). Carnegie Mellon University successfully implemented this change to address the gender gap in computer science enrolment and completion. Following the change, the university gained a record high enrolment rate of women, rising to 48%, 49% and 50% in their computer science majors during 2016, 2017 and 2018 respectively. These rates well exceeded the national averages in the US at the time. Since 1999, the University has replaced experience with aptitude-oriented criteria, focusing on students' leadership potential while maintaining high SAT[2] maths and science component scores. Admitted students with little or no background in computing/programming can then choose to enrol in first-year courses that suited their experience (Frieze and Quesenberry 2015).

Meanwhile, at the University of Illinois at Urbana-Champaign (US), a holistic review of admission criteria regarding a student's leadership potential has been adopted in order to better identify qualified female engineering applicants since 2015. For instance,

[2] SAT is a standardised test that most US colleges and universities use to make admission decisions.

prior leadership experience beyond school contexts was also considered during the admission reviewing stage. The unconscious practice of "raising the bar" for female applicants was minimised via the school's checking of test scores among both admitted men and women students. An additional level of review regarding gender, minority, nationality and socio-economic status to re-examine underrepresented students was also applied. As a result, test score distributions across genders became comparable in 2016 and the number of women admitted increased dramatically. These students also fared well in their classes (Heeren et al., 2017).

Deliver accessible introductory computing courses

Changes in introductory computing courses are also embraced at various universities in order to promote students' interest in computing, thereby making them accessible to a wider audience. Introductory classes for computing science students and other students from different disciplines or degrees are believed by some IT/computing science departments to provide them with an opportunity to reach students who have already been accepted or enrolled at the university but haven't yet decided their majors (Achenbach, Barker, and Thompson 2018). For instance, in order to facilitate students' access to a technical field, Stanford University (US) developed a popular introductory course and so-called "Bridge programmes," including a summer intensive seminar titled *The Intellectual Excitement of Computer Science* aiming to actively address the misconception that computer science is only about programming. As a result of these initiatives, an impressive pattern of women enrolment in computer science was reported: for five years since the program's implementation, women represented half of the participants and 17 out of 22 participating women later chose to major in computer science (Roberts et al. 2002).

The *Beauty and Joy of Computing* introductory course (open to non-majors) at Berkeley University (US) aimed to expand the class beyond "just programming" and make it "kind of right-brained as well" by underscoring computing's impacts in the world and adding programming exercises that required students to work in pairs. The result of this initiative was impressive with the introductory computing course being taught five times and almost half of the students in the top fifth of the class being women. The course also succeeded in attracting students from non-technical majors and it was reported that half of participating students were women (Harvey 2012).

Drawing on their findings that students without prior computing experience were often uncomfortable when classmates demonstrated advanced knowledge of course content, University of Virginia (US) similarly worked on making their introductory course format more inclusive. Their effort has achieved notable success in attracting women students at a rate that was four percentage points higher than the national rate (Cohoon 2007).

Offering bridge programs have also demonstrated benefits for women students without prior experience in programming, leaving them well-prepared for successive courses. In this regard, many IT departments have attempted to build their programs in a way that is more appealing to students from other fields of study by bridging technology and other majors (Johnson et al. 2019), such as the case of the University of Illinois at Urbana-Champaign. Their aim was to create cohorts of students with strong computing foundations along with advanced work from an Arts or Science discipline. Since 2010, they have developed new CS+X degrees, including CS+Anthropology, CS+Astronomy, CS+Chemistry, and CS+Linguistics. The annual rates of women enrolment since the first admissions were recorded have risen from 27% to 30% (Heeren et al. 2017).

Providing students who have not declared their majors with opportunities to gain summer research experiences was a recruiting strategy implemented at Harvey Mudd College (US) based on established findings on the importance of research experiences in increasing interests in computer science (Peckham et al. 2007). In 2006, the college began to offer research experiences to women students who had not yet declared a major in the summer after their first year. Those opportunities had previously been available only to those who had done well in their computer science major. Such changes resulted in remarkable success in promoting women's decision-making and computing identity and closing the confidence gap between men. Specifically, their evaluation study suggested that 66% of 44 participating women in the 2007-2011 cohorts went on to choose computer science as their major compared to the corresponding rate of less than 20% across the college (Alvarado, Dodds, and Libeskind-Hadas 2012).

Target prospective students

The Computer Science Department at the University of Texas at Austin (UTCS, US) set a goal to increase the number of women entering their undergraduate programs and in one year succeeded in doubling the number of women enrolled. Specifically, in the fall 2013 semester, they had 415 new students, including first-year new students and transfer students, among whom 73 were women (accounting for 17.6%). Their recruitment strategy involved multiple practices, including a UTCS-run *First Bytes* residential summer camp targeting high school girls. In the 2013 semester, 19 former *First Bytes* campers were admitted to the Computer Science department and 12 of these young women eventually enrolled. In addition, scholarships to incoming women students were offered. UTCS also enabled current undergraduate students to meet with prospective students and their families when they gave tours and talked about life at UTCS via UTCS Ambassadors, and paired prospective women with current women students (Thompson et al. 2014).

The University of Michigan launched a "carpet bombing" campaign as part of their recruitment strategy in which they placed banners and posters on buses running across their campuses. Further, they redesigned their department's website to have a modern look and to be welcoming to women which include many interviews with different races, nationalities and genders (Achenbach et al. 2018).

In their initiative to recruit more women to computing majors, Virginia Tech's Computer Science Department offered both teacher workshops and regional high school visits. With external funding, including from Google and Microsoft, the faculty organised high school teacher workshops to foster collaboration and partnership with teachers and the faculty. In addition, they presented regional high school visits at traditional engineering fairs and female-dominant engineering classes, or in girl-only classes at specialist schools (DuBow et al. 2013).

An extensive information campaign was also launched through the *Women and Computing Initiative* mentioned earlier, funded by the Confederation of Norwegian Business and Industry and other Norwegian companies. It consisted of a screen advert shown at all cinemas in Norway for one month, as well as a brochure to be sent to girls, science teachers and advisors at 326 different upper secondary schools. Additionally, the initiative held an information day for applicants who had already been admitted to NTNU. All admitted women applicants were invited to the department's presentation where they heard talks from women working in the ICT industry, attended popular science lectures and participated in an online course and other activities. In total, 52 women participated and approximately 80% of those who took part in the information day accepted the offer and began to study computer science (Lagesen 2007).

Directing attention to disciplines with a high concentration of women was a recruitment strategy employed by Northwest Missouri State University (US). Specifically, technology was integrated into the *Interactive Digital Media* bachelor program which taught students a combination of coursework from computer science, art and mass communication. This program appealed to incoming women students because it not only capitalised on computing technical skills, but also equipped them with skills in written and visual communication, art, photography and design. In 2005, 35% of students who enrolled in this program were women, as compared to 15% women enrolment in the computer science department (Todd et al. 2005).

MAXIMISING THE RETENTION OF WOMEN IN STEM EDUCATION AND IT DEGREES

Changes in teaching methods and curricula

To ensure their programs are more engaging to women students, universities have initiated broad changes in their teaching methods and curricula. Starting with introductory classes, many universities have separated students by their levels of experience in their belief that inexperienced students might feel intimidated when enrolling in classes with more experienced classmates (Achenbach et al. 2018). As empirical research suggests, offering separate introductory classes is beneficial to recruitment outcomes because it allows the department to attract students who have enrolled but not yet decided their majors, such as the examples of the universities of Virginia and Berkeley reviewed in a previous section. Such interventions also positively impact the retention of students who have already made their decisions.

For example, many universities have made great strides in promoting the contributions an IT degree and career can make to a person's self-development and society at large. At the University of Michigan, for instance, computer science students started their introductory course with concepts defining the field, its application to a student's life, the impacts it has on other majors at the university, as well as in every aspect of life (Achenbach et al. 2018). Likewise, as a strategy to address the gender gap, Harvey Mudd College introduced a new curriculum in their computer science introductory course in which students were taught substantial programming experience in a variety of disciplines or application areas. Additionally, they were exposed to major intellectual and societal contributions in the field. As a result of their interventions, this liberal arts college recorded a steady enrollment rate of 40% women among the total enrolled students in computer science majors during the four-year-period starting 2008. An increase in the number of women who chose to take additional computer science courses was also recorded at Harvey Mudd College over that period (Alvarado et al. 2012).

Curriculum adjustments were also adopted at the School of Computer Science at Carnegie Mellon University which customised their curricula to different groups of students who possessed varying levels of previous programming experience (Todd et al. 2005). However, the School opposed the proposition of accommodating women-friendly learning styles. Rather, changes were made to ensure academic integrity which benefited all students (Frieze and Quesenberry 2015).

In addition to curricula, the method and practice of teaching is another important aspect that draws universities' attention regarding their efforts to retain women students. Pair programming has become a popular practice introduced by various IT departments with demonstrated effectiveness in promoting students' learning experience. This is achieved by developing a sense of community rather than a competitive environment in the labs which contributes to students' sense of computing identity and belonging (Achenbach et al. 2018; McDowell et al. 2006; Thompson et al. 2014). In their programming assignments, this required students to work in fixed pairs with the same partner over the entire 10-week term. Every week, students had to find a minimum of six hours to meet with their partner and do their assignments. A lab tutor would recommend adjustments to the pair's working style when necessary (Porter and Simon 2013). By implementing pair programming in their introductory classes along with increasing peer instruction and changing course content, the University of California (San Diego) recorded an 18-percentage-point increase in retention rate of all students from 71% to 89% (among women, this rate increased from 73% to 87%) over three and a half years since 2008.

Similarly, the Computer Science Department of the University of California (Santa Cruz) assigned two students at a computer workstation to write and test program codes. This social interaction was found to significantly enhance students' confidence and performance. It also showed that students were more likely to stay in a computer-related major. The pair practice was believed to provide a more realistic workplace simulation because it entailed teamwork and collaboration (Todd et al. 2005).

At Monash University's Faculty of IT, an initiative is underway to trial embedding additional equity, diversity and inclusion content, examples and teaching practices across a number of core undergraduate and postgraduate units. The aim is to understand what opportunities exist to make individual units more inclusive, and to promote and develop content and skills in understanding and applying equity diversity and inclusion principles across the faculty's curricula.

Promoting women students' learning experiences and sense of computing identity

Departmental culture that includes the expectations, assumptions and values that guide the actions of faculty members, professional staff, other staff and students has become an important consideration for universities with regard to their recruitment as well as the retention of women pursuing STEM-related degrees or majors (Hill et al. 2010). In reviewing the various interpersonal and social factors that result in women students' negative experiences at undergraduate and graduate levels, many studies emphasise the central role of building a positive departmental culture in order to promote students' feelings of belonging to, and involvement with, their departments, and to grow their sense of computing identity. In this regard, initiatives to enhance the learning experiences of women students have focused on providing them with various forms of mentoring inside or outside the classroom contexts, including student-run or faculty-involved programs and collaboration with the industry.

Student-run mentoring programs have been widely embraced across universities and delivered to both existing and incoming students. As already discussed, positive student-student interaction has been proven to promote students' engagement and their sense of community, which is beneficial to their overall learning experiences and continuation of their studies (and careers), especially for women (Achenbach et al. 2018; Johnson et al. 2019). Against this backdrop, the University of Texas at Austin created *Computer Science Pods* and required incoming students to enrol. Incoming students were divided into groups of 20, took courses in computer science and maths, and each week a student mentor met with them with the facilitation of a staff member (Achenbach et al. 2018). A chain mentoring program was similarly launched at Brown University (US) in which students received support from those who were a year ahead in their education (Todd et al. 2005). Peer-to-peer mentoring (between first- and third-year undergraduate students) is also offered to students at Monash University's Faculty of IT to support students transitioning into university life and give more senior students mentoring experience. Interaction between students and academic staff has also become the focus for many universities' mentoring interventions to foster students' understanding of their faculty and their sense of computing identity (Achenbach et al. 2018) while promoting staff's attention to the experiences of their students. For example, the Computer Science & Engineering Department at University of Washington-Seattle (UW) invited high-performing women students to attend an afternoon tea with the program's Intro Programming Instructor where they had a chance to socialise with existing students, study advisors as well as alumni in industry. In addition, UW recruited a cadre of teaching assistants, 40% of whom were women, to facilitate students' learning process in the classroom and lab. Similarly, the Computer Engineering department at Santa Clara University (SCU) promoted faculty-student interaction by hosting an informal luncheon for women enrolled in computing majors every term and held an annual *Women in Engineering* dinner to celebrate all female engineering students. SCU recorded an impressively high rate of women enrolment which made up 33% of their junior class in computing majors in 2013 (Thompson et al. 2014).

The establishment and operation of *Women@SCS* at Carnegie Mellon University was another driver in the School of Computer Science's successful efforts in attracting and retaining women. Run by a committee comprising undergraduate students, graduate students and faculty members, *Women@SCS* featured a *Big/Little Sister Program* for undergraduates which matched a first-year new student with an existing one for mentoring support, and the faculty-student lunch series where women students could meet role models and interact with them informally (Frieze and Quesenberry 2015; Women@SCS 2020).

Maintaining regular attention to women students' learning and social experiences within the department has been shown to be instrumental in providing timely help to those who require special assistance, which in turn will contribute to successfully retaining women who might consider leaving their majors or degrees. In this regard, University of Washington-Seattle deployed and trained advisory staff to reach out to students who were struggling with their study, engaging them in conversations on goals, concerns, as well as encouraging them to seek help. As a result, the university reported a significant increase in women's graduation rates from 21% to 26-27% during the initiatives' implementation (Thompson et al. 2014).

Targeting 'at risk' students – including women students, those from low-income families, first-generation students and students of color – Lamar University (US) adopted a hybrid approach to recruit, retain and transition undergraduates in STEM via the *Students Advancing Through Involvement in Research Student Talent Expansion Program (STAIRSTEP)*. The program was run through a five-year grant from the university and ExxonMobil from 2009 to 2014, and employed various strategies informed by best practices proven to enhance students' academic and professional development. Applications for participation in *STAIRSTEP* were assessed based on students' GPA, grades, gender, race, ethnicity, income, first-generation status, references and a statement of purpose. Upon selection, participating undergraduates were assigned to teams comprising both first-year students and seniors. They received a competitive stipend of US$1,500 for each spring and fall semester they participated in research, outreach and transitioning (career-focused) activities under the guidance of a faculty mentor (approximately 10 hours a week). Throughout the course of *STAIRSTEP*, participants could access peer and faculty mentoring when they encountered difficulties. Participating students also acted as coordinators in *STAIRSTEP*'s outreach activities which targeted local high schools and community college students in order to attract them to STEM. Evaluations of the program regarding the computer science discipline showed that 100% of participants were retained as majors during the five-year period following the inception of *STAIRSTEP*. During this surveyed period, participants' grades in major courses were also higher while attrition rates were consistently lower as compared to cohorts enrolled prior to the program. In terms of enrollment, an increase of 104% was recorded from 2008 to 2013. Additionally, the number of community college transfer students in the major reached the highest level which was four times higher than that in the pre-*STAIRSTEP* period. Findings from the evaluation study further suggested that a sense of community rather than isolation or competition was reinforced among the participants (Doerschuk et al. 2016).

Beyond a university context, *MentorNet*, an initiative founded in 1997, provided connecting opportunities for motivated students from many of the world's leading universities and colleges using an online platform. Participants received one-on-one, email-based mentoring relationships with their industry, government and academic mentors. *MentorNet* also featured an e-forum for participants to discuss topics such as work-life balance. In addition, the breadth of careers reflected by this program's mentors helps women who freshly enter the field to see the diversity of the professions (Todd et al. 2005; White 2010).

Specifically targeting US black women, *Black Data Processing Association (BDPA)* was established in 1975. *BDPA* aimed to address the lack of minorities in middle and upper management, low recruitment and poor preparation of minorities for these positions, and an overall lack of career mobility for minority groups. They promoted the presence of women who had already been in the field to prospective students who were considering the field of technology. The Association supported local groups in creating women-only study groups and fostering mentoring and training for women (White 2010). After forty years of operation, *BDPA's National High School Computer Competition* program has benefited tens of thousands of high school students with regard to coding and application development, and simultaneously provided scholarship opportunities to students which enabled them to obtain college degrees (BDPA 2020).

In order to enhance the positive experiences of women and encourage their success in STEM fields, opportunities to connect with peers and faculty members can also be extended beyond one's university. Giving students opportunities to attend large conferences and meet with a broader community of women exposes them to the dynamism of the field and benefits the universities' recruitment and retention of underrepresented women students (Alvarado et al. 2017). A research project by Wright and Tamer (2019) found that when first- and second-year students were given the opportunity to attend technical conferences, their sense of belonging and self-confidence was increased, which was instrumental in an institution's efforts to retain them. Considering this, universities such as SCU, UW and Harvey Mudd College sponsor student attendance at the Grace Hopper Celebration (GHC) Conference every year (Alvarado et al. 2017; Thompson et al. 2014). Launched by the Anita Borg Institute, *GHC Conference* is held annually and considered the largest event for technical women in computing, which offers participants the opportunities for mentoring, motivation, networking, technical and career development (White 2010). Enabling access to conferences was also part of the *Go WEST's* project at University of Southern Queensland (USQ), where women received funding to attend an international conference in Paris (McDonald et al. 2010). Similarly, Monash University's Faculties of IT and Engineering sponsored staff and students to attend the inaugural *Grace Hopper Down Under* celebration in 2019, with positive reports on an increased sense of belonging in their discipline from those who attended.

Student-run clubs and initiatives can also enhance the learning experiences and sense of belonging and identity for underrepresented students. At Monash University's Faculty of IT, for example, the faculty-backed student initiative *DiverseIT* runs social, networking and career-building events focused on diversity issues, including gender representation in IT disciplines and fields. The group also conducts research with diverse IT students to capture their experiences and views on studying at Monash, which informs the faculty's curricula and teaching practices.

Professional development opportunities and industry partnerships

Informed by findings that highlight the relationship between career path knowledge and persistence in STEM study, many universities have focused on equipping students with job market skills and opportunities to explore local companies. A cross-sectional, survey-based study of students enrolled at the University of Florida conducted by Kapoor and Gardner-McCune (2019) in 2016, for instance, highlighted the crucial role of industry-based internships in strengthening students' commitment to pursuing a major or career in computer science. Accordingly, 41% of the studied students mentioned that the internship positively impacted their career goals, promoted their interest in computer science, or increased their determination to pursue a major in the field.

Not only do students entering the field of computer science benefit from mentoring programs, but also those who are new to the technology workforce. For this reason, universities have increasingly paid more attention to providing professional development mentoring via their industry partnerships in order to enrich existing students' perspectives about the diversity of future careers. The UW, for instance, facilitated connections between their women students and more senior women in industry to help them identify long-term opportunities and career paths as part of their women-retaining strategies (Thompson et al. 2014). Likewise, at Lamar University, *STAIRSTEP* promoted professional role models by including members of underrepresented groups, such as members and associates of the Association for Women in Computing, as guest speakers in the research seminars and career forums organised for their participating undergraduates (Doerschuk et al. 2016). At USQ the *Go WEST* project built a mentoring and support network between industry, academia and schools via the hub of Science, Engineering and Technology (SET) women at USQ. Over 18 months, the project developed a partnership with the local Toowoomba Regional Council to discuss collaborative mentoring and industry experience, whereby engineering women from the Council were invited to attend USQ activities. The project additionally launched a *Smart Women/Smart State* award application workshop which was followed by mentoring activities for applicants, delivered directly by the project team members. To encourage women to succeed in STEM, *Go WEST* also provided financial support to women academics to compete in Computer Society ICT Awards (McDonald, Loch, and Cater-Steel 2010).

Facilitating professional opportunities for women was also a focus of the School of Computer Science at Carnegie Mellon University, via the *Women@SCS* platform, to prepare them for future career paths. Extending their activities beyond the School's context, *Women@SCS* provided peer-to-peer advice sessions and interviews, speaking skill workshops, along with community outreach to middle school girls run by the School's students. These interventions contributed to enhancing women's visibility, leadership skills, and empowering them to demonstrate their abilities and counter stereotypes facing women in STEM (Frieze and Quesenberry 2015; Women@SCS 2020).

At Monash University, the *Women in Technology (WIT) Mentoring program* was launched in 2019 by the Faculty of IT to encourage women students' involvement, retention and success in IT. The program forges mentoring relationships between current students (both undergraduate and postgraduate) at the Faculty of IT and accomplished professionals working in industry via networking and celebration events. As of 2021, the program has helped 309 women and one non-binary student expand their networks, gain critical insights into the field, grow professionally and get a headstart in their careers.

BUILDING PARTNERSHIPS

Many universities have recognised the need for concerted efforts and collaboration to address women's underrepresentation in STEM. Launched in 2014, *Building, Recruiting and Inclusion for Diversity (BRAID)* is one such initiative. *BRAID* was co-founded by Harvey Mudd College and the AnitaB.org and involves 15 computer science departments across the US (including two private and 13 public institutions). Each participating institution received funding for three years to lead their initiatives which focus on increasing the percentages of students from underrepresented groups (racial/ethnic minorities and women) majoring in computer science. In addition, *BRAID* has formed the *Momentum* research team, which is tasked with conducting a mixed-method, longitudinal study of over 10,000 college students, instructors, department chairs and staff in undergraduate computing departments whose research outputs have been drawn upon at different parts of this review (AnitaB.org 2021; Momentum 2020).

BRAID also facilitates external collaboration via *BRAID Affiliates,* which operates on an annual, rotating basis. Institutions who wish to participate in *BRAID Affiliates* are invited to apply and upon selection, are eligible for small grants to support their own on-campus efforts that fulfill *BRAID* commitments, as well as have access to *BRAID's* wide-ranging events and broad network (AnitaB.org 2021).

INSTITUTIONAL SUPPORT

The review of successful interventions in recruiting and retaining women generally stresses the vital role of securing institutional support in terms of funding, guidance, and cultural and philosophical advocacy in order to sustain systemic outcomes and ultimate success (Achenbach et al. 2018; Frieze and Quesenberry 2015).

At Virginia Polytechnic Institute, for instance, diversity-related service activities were incorporated towards annual evaluation of the faculty's performance and reflected in their annual Activity Reports. During their implementation, the Diversity Committee listed and kept updating activities that called for faculty engagement, including one-time and longer time commitments. It was estimated that from its implementation until 2014-2015, the percentage of faculty participation in diversity-related activities reached 73.8% (Achenbach et al. 2018).

Within the *Go WEST* project at USQ, the implementing team used their evaluation's evidence to advise Pro-Vice Chancellor of Social Justice and Equity in the drafting of the University's five-year Social Justice strategic plan (McDonald et al. 2010). Institutional support was also crucial for the program's success at Lamar University. For faculty mentors who participated in STAIRSTEP, the university allowed them to receive release time from one course each semester. In reviewing the *STAIRSTEP's* progress and achievements, Doerschuk et al. (2016) stated that during its implementation, department chairs were consistently supportive and acknowledged the contributions the program had made. Their evaluation also emphasised the importance of "faculty buy-in" (Doerschuk et al. 2016: 694) which was encouraged by recognition and rewards.

Monash University's Faculty of IT established the role of Associate Dean (Equity, Diversity and Inclusion) in 2020. The role involved the agenda-setting of a three-year Equity, Diversity and Inclusion (EDI) plan delivered in partnership with the faculty's EDI Committee (which the Associate Dean chairs). The plan includes a range of initiatives intended to improve the experiences of underrepresented staff and students, and also pursue additional outreach and recruitment opportunities that target underrepresented groups in IT like girls and women. The faculty now reports annually on the plan and has greatly increased its EDI public presence and promotion of women role models through its website, media opportunities and speaking and outreach activities. The faculty is closely monitoring the impacts of these initiatives on the proportion of women students and staff, and also in relation to the student experience.

SECTION 5. CONCLUSION

Our review of scholarly and other relevant materials has explored a range of intersecting and compounding issues that explain women's underrepresentation in IT and STEM-related education at the tertiary level. We have identified a number of wide-ranging concerns that begin from primary school and affect girls' (and later, women's) interests and decision-making regarding the pursuit of a higher education in IT and related STEM disciplines. These issues typically start with stereotypical perceptions portraying IT and STEM as male-dominated and male-suited fields, which become major deterrents to girls' participation in maths and science from a young age, and also negatively impact on their experiences and performance if they still choose to enter a STEM/IT field.

Our findings highlight the importance of the immediate environment in challenging these stereotypes, including the role of family (especially a father, brother or other trusted male), peers, mentors, teachers and other role models. In addition, structural issues such as school environment, cultural and social portrayals of girls and women in films, video games, and pop culture more broadly play a critical role in dissuading or nurturing girls' interests in IT and STEM. A significant part of our review focused on identifying interventions that have been implemented globally (mainly the US) and in Australia, and have already demonstrated successes in recruiting and retaining women into higher education in IT/STEM fields.

While this review was conducted to inform the initiatives and strategies at Monash University's Faculty of IT, our findings provide valuable insights for other educational institutions and faculties who are also concerned with increasing the representation of girls and women in IT-related tertiary education, and STEM education more broadly. We recommend future and ongoing research to expand the scope of this review and to continue providing best practice and evidence-based guidance to inform our understanding of the issues facing underrepresented groups in IT and STEM disciplines and careers. Further research is also needed to understand how to support the participation of other underrepresented and/or potentially disadvantaged groups in IT and STEM fields, such as people with disabilities, Aboriginal & Torres Strait Islander people, those from low socio-economic backgrounds and the LGBTQI+ community. Understanding the needs and challenges facing these diverse groups, as well as the intersectionality between them, will be critical for identifying areas for action to address their underrepresentation and provide an equitable, inclusive and diverse environment for all students of IT.

APPENDIX

SEARCH TERMS

Recruitment and retention of women in STEM and IT

- STEM / “IT” / “information technology” / technology / comput* / “computer science*”
- educat* / teach* / learn* / pedagog* / recruit* / train*
- gender / female* / girl* / women
- barrier* / bias* / gap* / success* / engagement* / inclusion* / intervention* / participat*
- “higher education” / universit* / college* / undergrad* / bachelor*
- school
- “early year” / preschool* / kindergarten*
- workforce / career* / job* / profession*
- Australia / Asia-Pacific

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