Gender Insights in Computing Education

Foundational Evidence Review

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Executive Summary

The Fourth Industrial Revolution is driving rapid technological advancement, leading to the World Economic Forum estimating that more than 1 billion people will require reskilling by 2030 (Zahidi, 2020). Global initiatives, such as introducing computer science education in primary and secondary schools, are being implemented to achieve this ambitious target. However, despite efforts to promote equity and diversity in Computing and STEM education, a gender gap persists in multiple countries. Studies conducted in Israel, Australia, Canada, the United States, and the UK show evidence of this disparity (Warner et al., 2022).

The ultimate objectives of the I Belong programme from NCCE1 are to support teachers in England in breaking down barriers to girls' engagement with computing and encouraging their take-up of GCSE computer science.

This evidence review was created based on the NCCE's focus areas for promoting equity in computing and increasing the participation of students who identify as girls or nonbinary students in national and international research on the following topics:

- Maintaining girls' positive attitudes towards computing as they transition to secondary school.
- Supporting high-quality teaching in KS3 computing.
- Increasing girls' aspirations about continued study and computing-related careers.
- Building an inclusive culture in the computing classroom through curriculum enrichment and industry engagement provision.

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1 NCCE means The National Centre for Computing Education
Main Report

Introduction

Globally, women are significantly underrepresented in STEM, accounting for only 28% of the STEM\(^2\) workforce and 16.5% of patent inventors (Piloto, 2023; UN Women, 2022). Moreover, a male-centric and inflexible work environment exacerbates this problem, rendering STEM fields unattractive to women and underrepresented groups and posing a significant barrier to achieving gender equity and diversifying the STEM workforce (Ibid., 2022).

Despite significant progress towards gender equality and rising interest in computer science over the past decade, women's underrepresentation in STEM remains a persistent problem. Women comprise only 24% of STEM professionals in the United States, 17% of STEM professionals in the European Union, 16% of STEM professionals in Japan, and 14% of STEM professionals in India, according to global statistics (Ibid., 2023). These figures demonstrate the need for concerted international efforts to close the gender gap in STEM fields. Moreover, as we approach the 2030 deadline for the SDGs, it is crucial to prioritise investment in women and girls to achieve parity in CS education.

The research studies analysed and included in this review highlight the need to identify the root causes of the gender gap in CSE\(^3\) and how various factors, such as intersectionality and context, can influence student participation. However, this complex problem has no silver bullet (Ashcraft et al., 2012). Therefore, school and subject leaders must take an all-encompassing approach to promote equity in CSE, considering all pertinent factors. This requires effective policies and interventions that address the underlying causes of the gender gap and support and encourage female students to pursue CSE studies and careers. Moreover, inclusive computing education requires systemic, institutional, and programmatic reforms to promote diversity and equity and to challenge the female sense of belonging and identity (Ruttenberg-Rozen and Hynes, 2021).

The gender gap in Computer Science Education (CSE) is pervasive globally, and the United Kingdom is no exception (Adrion et al., 2020; Floyd, 2020; Funke et al., 2015; Kemp et al., 2019; Miller and Presto, 2018; Samarasekara et al., 2021). It denotes the significant underrepresentation of women in computer science across various subjects and career levels (Wagner, 2016). In England, this disparity is most pronounced in GCSE computer science courses, where female students are underrepresented and have a lower propensity to pursue

\(^2\) STEM means Science, Technology, Engineering and Maths

\(^3\) CSE means Computer Science Education
advanced education. This disparity can be attributed to several factors, including gendered preconceptions, a lack of resources, and an absence of female role models (Royal Society, 2017).

There is a need for practical strategies and resources to address the gender gap in computing. Ada Lovelace is a well-known female role model frequently referenced in school curricula to encourage young women to pursue a career in computing (de Freitas et al., 2019; Spencer, 2013). However, closing the gender gap in science, technology, engineering, and mathematics (STEM) requires a multifaceted approach, including instilling confidence in girls and incentivising women to enter and remain in STEM fields. In addition, positive exposure to various sustained computer science interventions over time can influence girls’ subject choices and career paths, highlighting the significance of practical strategies and resources in the curriculum (McGowan et al., 2017).

This evidence review examines the most recent research on the gender gap in K–12 CSE and on CSE in higher education and career pathways. It explores the factors that influence the participation and experience of female students in computer science. In addition, it discusses the limitations of previous efforts to increase female participation in STEM fields, emphasising their ineffectiveness in achieving their intended results (Sinclair and Kalvala, 2015). The focus will be on several key areas, including maintaining positive attitudes towards computing among girls as they transition to secondary school, supporting high-quality teaching in KS3 Computing to improve attainment and perspectives, increasing aspirations for further study and computing-related careers, and building an inclusive culture in the classroom through curriculum enrichment and industry engagement provision. To identify effective interventions for addressing the gender gap, the review will also examine the NCCE’s Gender Balance in Computing research programme.

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4 The NCCE is the National Centre for Computing Education
Methodology

Publications related to CSE were collected and reviewed from various sources, including ACM Digital Library, IEEE, Elsevier databases and many others, to examine CSE literature in the timeframe allocated. To start, the author created a set of high-level subcategories based on the project overview and objectives set by the NCCE\(^5\): maintaining girls’ positive attitudes towards computing as they transition to secondary school, supporting high-quality teaching in KS3 Computing, increasing girls’ aspirations about the continued study and computing-related careers and building an inclusive culture in the Computing classroom. Then, each paper was reviewed to organise the literature, with critical elements identified and recorded in a spreadsheet document. As a result, a classification system was developed, enabling studies to be categorised and used to inform planning for the I Belong programme.

\(^5\) NCCE means National Centre for Computing Education
Findings

International Context

The gender gap in computer science education is pervasive in the global technology industry. Consequently, women are less likely to pursue technology-related studies and are frequently excluded from artificial intelligence (AI) and other technological advancements (UNESCO, 2023). Moreover, the fact that women obtain only 7% of ICT patents across all nations accentuates this underrepresentation. It emphasises the need for additional research to identify and eliminate the systemic barriers that prevent women from achieving equal representation and technological advancement.

Moreover, research has shown that the gender gap in computer science education begins early in primary school. Consequently, girls are less likely to pursue technology-related fields of study despite performing equally well in mathematics and science as their male counterparts. In 2018, only 28% of engineering and 40% of computer science graduates were female, indicating that despite efforts to promote gender equality, the underrepresentation of women in technology-related fields persists (Lewis et al., 2021). Moreover, the Programme for International Student Assessment (PISA) reveals that while nearly 8% of boys in OECD countries aspire to work in occupations related to information and communications technology, less than 1% of girls have the same aspiration (UNESCO, 2020). These statistics demonstrate the critical need to address the gender gap in computer science education at a young age to encourage more women to pursue careers in technology.

GCSE Computer Science in England

Despite the inclusion of computing in the 2014 English National Curriculum, female participation and other underrepresented demographics remain low (DfE, 2022; JCQ, 2022; Shadbolt, 2016). In the United Kingdom, only 21% of GCSE computer science students are female, and this disparity persists at the A-level and university levels, where only 14% and 19% of CS students are female, respectively (BCS, 2022; JCQ, 2022). The ratio of boys to girls opting for CS GCSE is 4:1 (Ibid., 2021). Moreover, the percentage of girls selecting the GCSE computer science option decreased from 40% in 2013 to 32% in 2016 (Kemp, 2017). Nonetheless, there is hope for a more equitable representation of females in CSE, as the number of girls taking the exam increased to 17,264 in 2022 (JCQ, 2022).

Kemp et al. (2019) examined the intersectionality of gender, socioeconomic background, and ethnicity in female participation in GCSE computer science by analysing the English national pupil database. Interestingly, girls from lower socioeconomic backgrounds and ethnic minorities were

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6 OECD means the Organisation for Economic Cooperation and Development
found to be more likely than their peers to enrol in computer science courses. Additional research is needed in this area. Nevertheless, the study discovered that girls in mixed-gender schools and large female cohorts performed the worst in computer science. It has been argued that the changes to computing qualifications in England are inequitable for girls and could reduce their participation in CSE beyond Key Stage 3 and future careers (Ibid., 2019).

Lastly, there has been a recent decline in the percentage of students earning a 7/A or higher in computer science, including a drop from 39.7% to 34.1% between 2021 and 2022 (Ibid., 2022). Despite this trend, female students continue to outperform their male counterparts in the subject, with 40.6% of girls earning a 7/A grade in 2022 compared to 32.3% of boys.

Promoting female participation and achievement in Computer Science education is crucial. Policymakers and industry experts believe increasing the proportion of women in STEM occupations can mitigate skill shortages (White and Smith, 2021). However, the data demonstrates that the STEM “pipeline” experiences attrition at every stage, from the low number of girls participating in and opting to study GCSE Computer science to the declining number of female students pursuing higher-level CS education and careers.

**Maintaining Positive Attitudes Towards Computing during the Transition to Secondary School**

**Overview**

This section examines gender differences in computer science education as students move from primary to secondary school. It also examines the teaching practises of experienced and novice teachers, which can inform interventions for all computer science teachers, including aspects such as collaboration and communication that may not be emphasised enough (Funke et al., 2015). It has been suggested, for instance, that mandating CSE courses for pre-service teachers could improve the subject. Notwithstanding, there may be unintended consequences, such as female students finding CS less challenging after taking the course but having less confidence in their ability to teach it (Repennning et al., 2019).

**Teachers’ Professional Development**

Teachers’ lack of subject and pedagogical knowledge has been identified as a common challenge in teaching computing, and some teachers do not receive professional development (Gal-Ezer and Stephenson, 2014; Sentance and Csizmadia, 2017; The Royal Society, 2017). Therefore, school leaders must provide subject-specific professional development so all teachers

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7 CSE means Computer Science Education
can design and teach a high-quality computing curriculum (Ofsted, 2022). The NCCE supported over 60,000 teachers and educators in continuing professional development (CPD) between 2018 and 2022, representing over 20,000 schools and colleges in England (NCCE Impact Report, 2023).

Research indicates that enhancing teacher subject knowledge, self-efficacy, and value perception is essential for expanding participation in computer science education, especially among underrepresented groups (Nugent et al., 2021). As Goode et al. (2020) and Gürer et al. (2019) recommended, CS courses should provide technical knowledge and pedagogical approaches, address teachers’ efficacy issues, and use objective tasks to support subjective data. In addition, there is evidence that incorporating gender-sensitive materials into the CS classroom has resulted in a more inclusive environment (Bockermann and Moebus, 2018; Geldreich et al., 2019).

The NCCE is an ideal platform for providing scalable support to teachers and school leaders in need in the future, regardless of their level of experience, gender, or geographic location. Overall, it is evident that professional development for teachers, coupled with inclusive pedagogical practices, can significantly contribute to closing the gender gap in computer science education.

**The Importance of the Primary Years**

Introducing a high-quality Computer science curriculum to girls early in primary school is crucial for addressing the gender gap in computing, which can be traced back to the development of gender-based stereotypes in the preceding years (Rizvi et al., 2021). Moreover, prior experiences are essential for enhancing students' learning progress as they transition to KS3. Hinckle et al. (2020) examined the relationship between students’ levels of CS exposure, interest, attitude, and self-efficacy. They argue that early exposure to computing helps girls develop positive attitudes and self-assurance, highlighting the importance of providing opportunities for girls to gain exposure to the field as early as possible in primary school.

However, research has demonstrated that gender disparities in computing can manifest in various ways (Vandenberg et al., 2021). Tsan et al. (2016), for instance, analysed the effect of gender composition on collaborative group performance and found that all-female groups produced inferior artefacts. Angeli and Valanides (2020) also discovered that different scaffolding techniques benefit both boys and girls. Moreover, they found an interaction effect between gender and scaffolding techniques for young children using Bee-Bots, with girls benefiting more from the collaborative writing activity. Moreover, other studies have examined gender differences in the acquisition of computational thinking (CT) skills between boys and girls in primary school, with many concluding that boys have a distinct advantage (Zhong et al., 2016).

Teachers must recognise and comprehend the complexities and potential for gender imbalances in their schools' computer education programmes. Consequently, implementing effective strategies and interventions can guarantee that all students have equal learning opportunities. The following sections will provide a summary of the research in this area.
Teaching Computational Thinking

More than forty years ago, Seymour Papert (1980) coined "computational thinking" and proposed that computers could enhance thinking and transform knowledge accessibility patterns. Later, Jeanette Wing (2006) presented CT as a way of thinking, particularly in problem-solving planning and analysis, reiterating Papert’s ideas. Consequently, incorporating computational thinking (CT) and computer science into K–12 educational systems is now a globally recognised phenomenon (Passey, 2017; Ibid., 2006). As CT is a relatively new addition to the curriculum, many teachers may be unfamiliar with its definition, creation, evaluation, and incorporation into lesson plans (Hsu et al., 2018; Yadav et al., 2017).

Baroutsis et al. (2019) and Grover, Pea, and Cooper (2015; Baroutsis et al., 2019) have provided teachers with opportunities for professional development to support the development of CT in younger students. In addition, Espino and González (2016) emphasise the significance of developing computational thinking skills in children at a young age so they can solve problems, design systems, and comprehend human behaviour using fundamental computing concepts. In addition, the authors propose that their findings can serve as a basis for developing a methodological guide to promoting teaching computational thinking from a gender perspective in national and international schools (Ibid., 2016).

Numerous studies have identified various factors contributing to gender differences in CT. Polat et al. (2021) investigated the effect of grade-level Maths performance and computing attainment on CT performance and perception and discovered that boys outperform girls in CT. However, a separate study by Howland and Good (2015) revealed that girls tend to experience more significant learning gains when developing computational skills.

In addition to investigating gender differences in CT performance, some studies have investigated gender-related issues in the learning process, such as the time it takes female students to achieve the same level of CT as male students (Atmatzidou and Demetriadis, 2016). Moreover, Rachmatullah et al. (2022) discovered significant gender differences in the CS attitudes of middle school students, highlighting the need to consider sociocultural factors that may influence girls’ attitudes towards computer science in various cultural contexts. Problem-solving instructional strategies have also enhanced students’ computer technology (CT) skills and self-efficacy, particularly among girls (Ma et al., 2021). Finally, Mouza (2020) studied the effect of an after-school computer curriculum on students’ comprehension of computational concepts and found that both boys and girls made significant, long-lasting gains.

Using game design in programming environments to teach computational thinking is a growing study area. Recent studies have investigated the potential for game design to address the gender gap in computer science education, with varying conclusions. For instance, Abdullah et al. (2021) found no statistically significant difference between male and female students’ CT abilities in the animation and game genres when using Scratch projects as a measure. Howland and Good
(2015) evaluated Flip, a programming language 11- to 15-year-olds use to create their 3D role-playing games. It was discovered that girls wrote more complex scripts than boys and exhibited a pattern of more significant learning gains in computational skills. In addition, a gamified software application called Meri Kahani has been designed to improve the computational thinking skills of young women and encourage them to pursue careers in STEM and computer science (Masood et al., 2021).

Sun et al. (2022) investigated the impact of various programming approaches on the CT skills of 12-year-old students. The study's methods enhanced students' computer technology skills, and the gains were maintained two months later. The study included plugged-in and unplugged activities, suggesting both methods can effectively teach CT skills. Future research could explore combining these methods to maximise student learning outcomes.

In contrast to previous research indicating that visual programming languages such as Scratch or Alice are effective for developing computational thinking (CT) skills and teaching computer science (CS) concepts, Delal and Oner (2020) propose that CT skills can be taught unplugged. Their study, which focused on middle school students, revealed that Bebras challenges improved CT skills, with boys demonstrating significant improvement and girls demonstrating improvement on moderate-to-complex questions. Intriguingly, female students performed better on difficult questions, and restricting computer access improved students’ computing technology skills. However, the study emphasises the need for additional research to develop tasks and evaluation methods for all difficulty levels.

Educators increasingly use the Bebras Computing Challenge to promote computer science and computational thinking among students. However, Pluhár et al. (2002) found significant differences between the scores of boys and girls in international competitions. To address this issue, a recent study in Ireland provided primary teachers with computer technology (CT) workbooks and teacher workshops to facilitate the practical and pedagogical teaching of CT skills, including the co-creation of teaching materials with in-service and pre-service teachers to practise these skills collaboratively and build confidence in delivering CT material (Lehtimaki, 2022).

Physical computing can also be used to teach CT in interdisciplinary settings. Luo et al. (2020) monitored the development of primary school girls who participated in a summer camp with Dash robots and the Blockly app as part of a science curriculum incorporating CT. As a result of implementing checkpoint activities, immediate and corrective feedback, and unplugged activities to scaffold coding concepts, the results revealed that the girls’ CT practises improved significantly. A study conducted in Finland discovered that younger children were more likely to use a programmable and interactive Teddy Bear toy to learn basic computational thinking (CT) skills and that younger females preferred interacting with devices with a “softer look and outfit” (Jormanainen and Tukiainen, 2020). These developments could be advantageous for teaching computational reasoning and programming to younger students. It is essential, however, to exercise caution and consider the need for targeted and embedded professional development in
teaching CT, as well as ample time for teachers to collaborate with coaches on curriculum development (Israel et al., 2015).

Conversely, some research suggests that gender does not affect the development of CT (Alsancak, 2020). Nonetheless, given the contradictory findings in CT instruction, teachers, policymakers, and subject leaders must stay abreast of current best practices by actively reviewing relevant literature and incorporating it into teachers’ professional development (Kilic, 2022). To promote gender equality in computational thinking and creativity, teachers must be aware of potential gender differences and develop strategies to support and encourage female students. Interestingly, research shows that teachers’ gender does not impact their students’ CT performance, but their years of experience in the classroom do. Moreover, teacher development programmes significantly impact student performance more than a computer science undergraduate degree (Kong and Lai, 2023).

Teaching Programming

While there is an emerging consensus in computing education research regarding the teaching of programming, the field is still young and limited by small-scale studies with brief time frames and informal settings (Waite and Sentence, 2020). This highlights the added complexity of considering the gender gap, as literature reviews such as this one contain only two examples of findings related to teaching girls programming (Ibid., 2021).

Computer programming is often considered challenging in secondary schools and universities (Kallia and Sentance, 2018). Nonetheless, the influence of gender on educational programming is being investigated by an increasing number of studies, with some reporting significant effects. Others, however, have found no correlation between gender and variables related to programming (Cheng, 2019). In this review section, several studies will be summarised with examples of findings that positively impact educational programming for girls, future adoption of initiatives, or professional development in schools.

Gender was the most influential predictor of computational thinking preferences in programming education, according to Yildiz Durak et al. (2021). However, they acknowledged that previous studies had produced contradictory results. In addition, they reported that personal characteristics and variables were significantly associated with attitude and interest in programming, whereas self-efficacy and importance did not significantly influence programming.

Furthermore, self-esteem and gender play a significant role in computing education. In addition, Kallia and Sentence (2018) examined the calibration, self-efficacy, and self-evaluation of 11th-grade students in computer programming, focusing on gender differences. The results indicate that boys feel more confident in computer science than girls and are better at predicting their programming performance. Girls tend to underestimate their abilities, but this is not correlated.
with their self-evaluation or self-efficacy in computer science. The study emphasises the need to investigate factors affecting students’ perceived computer science capabilities.

Next, according to Faherty et al. (2021), self-esteem influences multiple aspects of teaching and learning, with the highest levels found in information and data literacy and the lowest in programming. In the meantime, Christensen’s (2021) research revealed that girls prefer computing activities that involve PEOPLE, whereas boys prefer THINGS. Teachers should, therefore, consider this and implement PEOPLE activities to engage female students, particularly those without programming experience.

In Finland, Fagerlund et al. (2022) discovered that students’ programming motivation is proportional to their proficiency in computational thinking (CT) and the classroom emphasis on CT. Boys were more motivated to programme than girls, and teachers’ intrinsic motivation varied by gender, subject, and prior experience—moreover, students’ programming motivation correlated with their CT test scores and teachers’ emphasis on CT. The study suggests increasing girls’ programming motivation and providing teachers with positive CT experiences relevant to their subject to increase intrinsic motivation among teachers who lack prior programming teaching experience and interest in the topic.

According to a study by Funke et al. (2015), most computer science teachers did not perceive gender differences in programming. Those who did, however, reported that girls with a more structured approach are less curious and less self-confident. In addition, Woo and Kim (2022) found in their research conducted in South Korea that, even though female students exhibited similar tendencies to male students, cooperating with friends as a differentiating factor was a crucial learning technique. They argue that it is necessary to implement teaching and learning techniques to strengthen team projects so girls can work with their friends. In addition, Jenson et al. (2018) discovered that pre-existing programming knowledge significantly influenced post-test performance and that same-gender groups experienced favourable outcomes. Girls were more engaged in single-gender groups, whereas boys in mixed-gender groups required teacher discipline.

Programming education can foster a more inclusive learning environment by incorporating gender-sensitive materials (Bockermann and Moebus, 2018; Geldreich et al., 2019). Moreover, Chatbot, a software platform designed to teach high school students fundamental computer science concepts, significantly increased female students’ task completion rates (Benotti et al., 2017). In a further study, Yağcı (2016) investigated the relationship between pre-service IT teachers’ learning styles and attitudes towards computer programming. The study found that most IT pre-service teachers preferred a deep studying approach and that there was a positive correlation between their deep studying approach and their attitude towards programming. Therefore, the author recommends that programming courses be designed with students’ perceptions and readiness for programming in mind and that student-centred learning environments be made available. In addition, the course content should be organised to increase students’ motivation to attain the desired skills and competencies, and problem-based learning
should be encouraged to develop higher-level reasoning and problem-solving skills. These findings highlight the significance of addressing ITT students’ attitudes and approaches towards programming to promote success in programming education and considering ways to incorporate this into subject knowledge enhancement and teacher training.

Steinmaurer (2019) presents a case study of sCool, a mobile learning game that teaches computational thinking and Python programming. The study assessed the game’s impact on girls’ coding class performance, game engagement, emotions, and perceptions. The first group had greater engagement and experience with game-based learning. Girls had the most favourable view of the game, while boys completed their practical missions quickly.

However, collaborative gameplay can initially disadvantage students with less gaming experience in computer science learning, resulting in male participants outperforming their female peers regarding learning gains (Buffum et al., 2016). Nevertheless, over several weeks, the study found that girls eventually caught up. Next, when novices are paired with experienced partners, they may opt out of the activity, whereas pairing two novices may increase frustration. Gender pairings can affect the performance, processes, and attitudes of collaborative problem-solving, with male-dominated groups jumping directly into solution development and female-female groups engaging in more diverse and interesting conversations (Lin et al., 2020). It is challenging to create an equitable learning environment across age groups, according to Denner et al. (2014). However, paired programming has positively influenced female high school students’ programming skills and intentions. Gransbury (2022) investigated the effect of two different paired programming modes, Divvy Up and Puzzle, on the collaborative programming behaviours of high school female students. She discovered that properly implementing paired programming involving a “driver” and a “navigator” positively impacted students’ programming skills and motivation to study computer science.

Nanavati et al. (2020) describe a district-wide Python course for eighth-graders that employs unplugged, creative writing, graphics, and robotics to introduce computer science concepts via Ridley Scott’s The Martian. The course significantly improved students’ self-assurance, enthusiasm, and intention to pursue computer science careers. Similarly, Jenson and Droumeva (2016) propose using games to introduce students to computer programming in a risk-free environment, allowing them to explore new concepts and develop computational thinking skills. Moreover, according to Tuparova et al. (2020), girls who participated in another study involving a model that combines game-based learning with project-based, problem-based programming, cross-curricular links, and e-learning philosophies achieved higher programming and problem-solving scores than those in the control group.

In addition, Seraj et al. (2019) investigated the effect of block-based programming environments (BBPEs) on the programming interests and skills of girls aged 10 to 14. The study’s results demonstrated that using Google Blockly positively impacted the programming interests and abilities of female students, who expressed a greater desire to continue their computer science education. These findings highlight the importance of using BBPEs to promote programming
interests and skills among female students, preparing them for future programming learning opportunities.

Several findings emerged from evaluating the efficacy of block-based programming environments for teaching programming concepts to elementary and secondary school students. For instance, one study discovered that girls were more interested in creating stories and apps, whereas boys preferred constructing games. Moreover, collaborative projects received higher grades than individual projects, highlighting the importance of early exposure to collaboration in computer science courses. Nonetheless, the study emphasises the need to address the educational needs of underrepresented minority groups (Grover et al., 2018).

Furthermore, McBroom et al. (2020) found gender gaps in performance in ten introductory and intermediate computer science courses, while minimal variation was observed in programming aptitude between genders in other classes. Interestingly, more ninth-grade girls than ninth-grade boys completed Blockly’s introductory activities. However, additional research is required to determine whether the observed gender gaps were unique to the studied year groups and to examine students’ behaviour in settings where gender gaps exist. In a different study, there were no significant gender differences in middle school students’ attitudes towards programming. However, females with experience in block-based and robotics programming environments had the most positive attitudes (Gul et al., 2022).

Another study investigated the use of physical computing and the effect of teacher gender on young children’s understanding of programming concepts following an introductory robotics programme (Sullivan and Bers, 2018). The results demonstrated the need for diverse role models in the classroom by indicating that girls’ performance improved significantly when a female teacher was in charge. Increasing the number of opportunities for female mentors in elementary and secondary schools can increase girls’ exposure to STEM fields and reduce gender disparities. However, focusing on gender differences can reinforce gender stereotypes (Docterman, 2014). To improve computer science education without reinforcing gender stereotypes, teachers must expose students to various role models.

Next, the Code’n’Stitch project intended to implement a gender-sensitive pedagogical framework for handicraft lessons in Austrian secondary schools utilising the Pocket Code app (Spieler et al., 2020). As a result, girls were more engaged in mentoring sessions and more interested in online coding and game development using the Pocket Code app. The mentor’s gender had no impact on the programming experiences of young women. Nevertheless, the study highlighted the critical role of inclusive and supportive learning environments in encouraging girls’ participation in coding activities, highlighting the need to create such environments (Ensher, Heun, & Blanchard, 2003). Finally, Gutica (2019) examined how participation in a coding workshop consisting of coding exercises and the CodeBlock game could increase high school girls’ interest in computer science. The workshop’s facilitators were undergraduates who designed and implemented the game, which has the added benefit of exposing young women to technologies used by post-secondary students and increasing the likelihood that they will pursue post-
secondary education in CS-related fields. Although this workshop may spark girls' interest in computer science, findings suggest that more should be done to sustain that interest over time.

**Culturally Responsive Pedagogy**

Despite increasing efforts to promote inclusivity in computer science education, the gender gap and underrepresentation of women and minorities continue to exist. One explanation is the absence of culturally relevant computer science activities in the curriculum, which fails to consider women's intersecting cultural identities or the potential social impact of their innovations (Scott and Zhang, 2014). Although efforts have been made over the past two decades to develop culturally responsive and relevant computing curricula to address the underrepresentation of certain groups in computer science (Leonard and Sentance, 2021), the problem persists.

As mentioned, Kemp et al. (2019) analysed the English national pupil database. They published the intersectionality of gender, socioeconomic background, and ethnicity concerning female participation in GCSE Computer science. These data-driven studies are essential for an intersectional understanding of the gender gap (Vargas-Solar, 2022). With this evidence, there is also a wide variety of methods based on evidence for increasing the interest and engagement of underrepresented students in computing education. These methods use culture-based approaches considering learners' characteristics and social contexts while delivering relevant topics for a fair and authentic learning experience (Eglash et al., 2013). In recent years, more resources, such as the Quick Read: Culturally Relevant Pedagogy, have become available to assist English computing teachers (NCCE, 2021).

Thus, strategic initiatives to create inclusive computing environments and expand the pipeline of individuals pursuing computing careers are urgently required (Erete et al., 2021). Furthermore, Codding et al. (2021) argue that pedagogical and instructional modifications are needed to promote inclusive and rigorous learning that engages all students with a diverse and equitable curriculum. In contrast, Gordon and Heck (2019) found that only 16% of computer science teachers feel equipped to incorporate students' cultural backgrounds into the classroom. Therefore, to promote inclusive pedagogy for all students in computer science, it is necessary to establish long-term professional development programmes that foster professional learning communities.

Culturally responsive pedagogy (CRP) prioritises students' cultural identities and backgrounds as essential to creating effective and meaningful learning environments that promote relevance and equity across institutional, personal, and instructional dimensions (McKoy et al., 2017; Gay, Geneva, 2018). To effectively implement CRP, teachers must reflect critically on negative attitudes towards specific cultural, linguistic, or ethnic groups. For instance, Margolis et al. (2017) found that teachers frequently hold negative views regarding the compatibility of CS and students, which can perpetuate biases and learning barriers. Therefore, Codding et al. (2021)
emphasise the significance of integrating professional development (PD) and culturally responsive pedagogy (CRP) to equip teachers with the knowledge and skills to create engaging and inclusive learning environments and to eliminate biases while meeting cultural needs. These findings corroborate previous studies (Ryoo et al., 2015; Goode et al., 2020) on providing opportunities for continuous professional development that promote inclusivity in CSE.

**Culturally Responsive Computing**

Culturally responsive computing (CRC) is defined by Solyst et al. (2022) as an approach that prioritises students’ identities and lived experiences, enables them to become agents of technosocial change, and connects them to their communities. Focusing on CRC principles such as interdependence, introspection, and asset-building, their study investigated the impact of power relationships and identity formation on students’ computer science engagement. Findings indicate that CRC can help close the gender gap in computing education and prepare students to become agents of technological change. Additionally, online CRC programmes are being developed to make CRC accessible to students who have been historically excluded, and this study provides recommendations and insights for creating and operating virtual CRC camps.

Next, Scott et al. (2017) analysed an intervention to engage high school students of colour in computer science. Even after the intervention, the findings revealed that female students of colour demonstrated lower engagement and interest than male students. It was determined that women of colour in computing face unique obstacles, highlighting the need for interventions that address their experiences. The study highlighted the significant underrepresentation of women in computing and suggested that short-term interventions might not be sufficient to overcome the obstacles they face.

Access to computer science education remains an issue for Native American and female students in the United States despite recent efforts to increase participation in computing (McAlear et al., 2022). Access to technology at home exacerbates structural and psychological barriers to STEM education for underrepresented students of colour, including Native students. In 2018, only one Native American woman earned a PhD in computer science. This lack of access to rigorous STEM courses indicates disparities in STEM education. However, the literature suggests that culturally relevant curricular and pedagogical approaches can help girls of colour become agents of social change, question existing forms of exclusion, and develop a sense of accountability for collective goals.

In addition to professional development, recent research demonstrates that teachers use technology tools, such as App Lab from Code.org, to encourage students to choose projects that help them identify with and contribute to their communities (Jain et al., 2022). Earsketch is another example of an educational platform that combines music production and programming. This learning environment has effectively taught computing concepts to underrepresented ethnic and gender groups in formal and informal settings, demonstrating a culturally relevant and
artistically integrated approach consistent with the close relationship between music and computer science. In addition, Earsketch has been found to increase students’ interest and content knowledge in computing, with female students demonstrating the most significant improvement in attitudes towards computing (Magerko et al., 2016).

Computer science and Python programming are challenging to teach in secondary schools in Slovakia due to a lack of resources and non-specialist teachers (Awaah et al., 2020). One study, however, investigates how the CTCA\(^8\) teaching method proposed by Okebukola (2020), which is based on culture, technology, and context, can make computer science education more relevant and engaging. Pre-service and in-service teacher preparation must include CTCA experiences to be effective. Moreover, the study found that the CTCA technique was superior to a lecture approach for teaching Python programming based on a statistically significant difference in student performance (Ibid, 2022).

Supporting High-Quality Teaching in KS3 Computing

The following section will examine approaches to teaching computing from the literature identified by the NCCE as focus areas to investigate, such as students’ identity, belonging, competitions, enrichment activities in computing, and the adoption of physical computing with gender-specific interventions. Additionally, teachers’ self-efficacy beliefs can significantly impact their teaching practices and students’ learning outcomes (Mavroudi and Divitini, 2017). In computer science (CS) education, Childs et al. (2021) found that CS teachers tend to be more isolated and less likely to collaborate than teachers of other subjects. To address this issue and increase female participation in CS courses, the study investigated the effectiveness of a two-year teacher-directed approach using a networked improvement community (NIC). The NIC empowered teachers to identify the root causes of female underrepresentation and implement teacher-led interventions in their classrooms and schools. Results showed that the collaborative approach effectively addressed the challenge of increasing female participation in CS.

Increasing Aspirations

1. **Approach**

Various approaches to promoting computer science education and closing the gender gap in the field have been investigated in numerous studies. For instance, the Computer Science Unplugged Project utilised HCI-related activities, such as the Chocolate Factory activity, to promote computer science as an intellectually stimulating and engaging subject for girls (Amaral et al., 2015). In addition, Broscheit et al. (2018) conducted a workshop on a girls’ day that included

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\(^8\) CTCA means the cultural-techno-contextual approach
environmental and digital technology projects in a fictional setting. This method proved effective for increasing girls’ interest and participation in computer science when knowledge transfer was facilitated by providing a practical and meaningful context for learning.

Murphy's (2020) study emphasised the significance of understanding the factors influencing interest and success in STEM, such as motivation, attitudes towards engineering and technology, technology anxiety, and behavioural intent. The study suggested that intrinsic motivation was associated with positive outcomes, while situational motivation had adverse effects. Next, the KAUA framework introduced by Bollin et al. (2020) can assist teachers in collecting data regarding students' personalities, interests, verbal and mathematical self-concepts, and gender gap, which are all crucial factors in motivating students to pursue computer science. Additionally, Jin and Divitini (2020) discovered that adolescents in Norway with a greater affinity for technology (AFT) were more likely to have positive learning intentions mediated by perceived usefulness, emphasising the significance of perceived usefulness in promoting continued learning among teenagers.

Other research has examined specific programmes or interventions. Gomez et al. (2018) aimed to reduce the gender gap in Entertainment Computing by identifying gender and inclusion-related challenges and opportunities. Miller and Webb (2015) discovered that completion rates of Frogger games varied by race and gender, with higher completion rates among female and minority students. In contrast, African-American and Hispanic/Latino boys had lower rates, suggesting that computer problem-solving skills may play a role in submitting fully functional video games. Çakır et al. (2017) assessed the short-term impact of a game design workshop on girls’ attitudes towards computer science. They discovered that the workshop improved girls’ attitudes, confidence, and competence in computer science, emphasising the significance of positive identity exploration.

These studies indicate that understanding individual differences in motivation, attitudes, and identity exploration is necessary to promote computer science education and reduce the gender gap in the field.

2. Identity

Peters and Rick (2014) argue that a theoretical framework that integrates psychosocial and sociocultural perspectives is crucial to support the development of students’ identities in the computing classroom. They suggest that project-based learning experiences that emulate professional software development can effectively address low engagement, retention, stereotypes, and the gender gap in computing.

Despite traditional interventions encouraging girls to study computing, resulting in a declining interest in IT careers, Fisher et al. (2015) describe the implementation and success of a longer-term intervention programme called Digital Divas that ran over four years in secondary schools. The programme includes designed teaching modules, role models for girls, and data collection through pre- and post-surveys, focus groups, and classroom observations. The study found that
Digital Divas increased girls’ interest in IT and their confidence with it and recommended a successful school-based intervention programme designed to resonate with girls.

Their framework for delivery includes designing a curriculum appealing to girls and creating a supportive learning environment that fosters a positive attitude towards technology. Role models, ideally women who are near-peer in age, can help to engage and promote IT in the classroom. Ongoing reinforcement is also essential, as it continually emphasises that IT is a viable career path for women.

The study aimed to identify critical components associated with four factors - school curriculum, role models, learning environment, and ongoing reinforcement - that affect girls' interest in IT to create more effective school-based intervention programmes. They found that incorporating group work and creativity into the school curriculum was important for engaging girls, despite some teachers believing boys are better suited to computers. However, findings revealed that girls were less likely to study computer science in their final years of secondary school and pursue a computing career. The availability of options for high-achieving girls, teachers’ lack of technical self-efficacy, and unrealistic expectations of an intervention like Digital Divas are all possible explanations for the lack of short-term attitude change.

Various other studies have explored students’ attitudes towards computer science education and the impact of gender on their career decisions. For instance, Webb and Miller (2015) developed a survey to monitor students’ attitudes towards CS education. They found that boys are likelier to use computers, take computer classes, and express interest in studying CS at university. However, the study also found that pedagogical approaches that include guided discovery may help reduce gender differences in computer science education. Similarly, Berg et al. (2018) explored attitudes towards female computer scientists in Scotland. They found that gender stereotypes, role models, and media influence significantly determine attitudes towards computing as a female career choice. The study recommends increasing the number of female role models in the computing industry, creating games, programs, and activities for girls, and changing perceived stereotypes to attract more females to the industry.

Gender significantly impacts technical self-efficacy and interest in computer science, as demonstrated in Brauner et al.’s (2018) study, which surveyed 112 high-school students and found a significant gap in career decisions and declining participation of women in STEM. There is also strong evidence that students adjust their preferences to those of their peers, and girls tend to retain STEM preferences when other girls in their classroom also have STEM preferences (Raabe et al., 2019). Therefore, future measures should target students earlier to tackle this issue.

To address the inaccurate perceptions and stereotypes about IT professionals, the DigEquality FF project challenges stereotypes. It aims to inspire educators to help girls and underrepresented groups in computing, as Comber et al. (2021) reported. The study suggests that while stereotypes strongly impact student perceptions, teachers can positively influence them. The
project also aims to foster gender equality and uncover young students’ potential interest in computer science.

Additionally, Wong’s (2016) study investigated the perceptions and aspirations of digitally skilled young people aged 13-19 in computing and found a persistent gap between those who can use computers and those who pursue careers as computer scientists or professionals. The traditional stereotype of computing as a field for clever but antisocial people still exists, which may discourage young people, particularly girls. The report emphasises the need to expand identities in computing to make the field more attractive, particularly for underrepresented groups such as women.

Finally, to broaden participation in computer science, Everson et al. (2022) suggest that it is important to understand students’ experiences and identities. They argue that previous work has connected CS concepts to cultural practices, but emerging sociotechnical counternarratives provide new opportunities to connect CS to students’ lives. The researchers conducted a high school course in a diverse classroom, allowing students to incorporate critical themes into their learning. They found that navigating trust, positionality, and inequitable education systems was necessary to create a safe space for crucial conversations. Once established, students embraced counternarratives, built community, and supported each other in their learning.

3. Belonging

This section will examine additional literature on students’ sense of belonging in computer science; additional references can be found throughout the review in various other sections. Even as more studies are published, including school-based research from the Gender Balance in Computing Initiative (NCCE, 2018-2022), higher education studies continue predominating.

According to Cheryan et al. (2009), students’ sense of belonging in an academic setting is based on their perception that they fit in with the objects within that setting. Students interpret the people, displays, and activities in the classroom to determine if they belong. If these signals indicate that a particular type of person belongs in the classroom, but the student does not identify with this type, then the classroom and the student are “mismatched.” As a result, girls will identify less with computer science stereotypes as their gender roles converge with men. There have been efforts to attract girls to computer science and engineering, but academic stereotypes persist, making it challenging to alter gender stereotypes and cultural attitudes. Nevertheless, a classroom environment that challenges prevalent stereotypes should break down this barrier and increase a girl’s sense of belonging (Master et al., 2016).

In the context of higher education, gender, socioeconomic status, and social belonging all impact belonging (Fernández et al., 2023). Important decision-making factors for women enrolled in STEM-focused university programmes are a sense of belonging and an interest in pursuing different STEM majors (Veldman et al., 2021). In schools, stereotypes can affect girls’ interest in computer science programmes, and girls are less likely to identify with computer science stereotypes due to their alignment with male gender roles. (Cheryan et al., 2015) These
stereotypes can be gatekeepers, limiting girls’ future educational opportunities and career aspirations.

Factors impacting US students’ interest in computer science include self-perceived ability and fit, encouragement, and differentiation strategies (Wang et al., 2017). The significance of middle school in shaping girls’ interest in computer science careers cannot be overstated. Therefore, it is essential to examine the CS environment in middle schools to comprehend the impact of stereotypes (Opps and Yadav, 2021). Positive relationships with female teachers, inclusive teaching practices, and collaborative work foster a sense of belonging among female students in high school computer science courses. However, persistent factors may discourage girls from pursuing computer science beyond the introductory level, highlighting the need for additional research and interventions to support their long-term engagement in the field (Moya et al., 2023).

Inclusion and diversity policies in higher education have theoretical and practical implications, and broadening the representation of people in STEM fields can increase girls’ interest in and sense of belonging. Changing stereotypes, however, requires teachers and other advocates for gender equality to continue their efforts and maintain their awareness. In computing, stereotypes discourage those who do not identify with them from entering the field. Furthermore, exposure to stereotypical computer scientists who exhibit characteristics that do not align with students’ perceptions of themselves can reduce aspirations, and girls may not see the relevance of computer science to their future (Hamer et al., 2023).

Overall, the research indicates that non-stereotypical environments that welcome girls can help reduce gender stereotypes, instil a sense of belonging, and encourage girls to consider a career in computer science. Computer science teachers should consider classroom practices that foster female students’ confidence, comfort, interest, and sense of belonging.

4. Competitions

Computer science competitions can be a valuable tool for increasing girls’ participation in computer science (Roberts, 2000; Bubica et al., 2014). Girls are more likely to prepare for competitions, and volunteering in programming competitions can improve their motivation to learn and enhance their skills. In addition, the study by Roberts found that volunteer programming competitions positively impacted many students, especially females, by providing them with an engaging and energising activity that motivated them to learn and improve their skills (Ibid., 2000). These results suggest that computer science competitions may encourage more girls to participate in and succeed in computer science.

Nevertheless, a study of VEX mentors and students revealed a gender disparity, with male students and mentors outnumbering their female counterparts (Sullivan and Bers, 2019). Male students are more confident and engaged in technical abilities and construction tasks than their female counterparts, who require more assistance and are less engaged. In addition, mentors perceive female students as requiring more help and less engagement than male students, indicating that robotics competitions need to be more inclusive and supportive of all genders.

National Centre for Computing Education
In addition, preliminary findings from a multi-year study on young women's interest in computing revealed that confidence and self-efficacy are crucial factors in staying in the field, particularly for less confident individuals (DuBow and James-Hawkins, 2016). Additionally, the study investigates how the NCWIT Aspirations in Computing Award can foster a sense of belonging in the field. These results suggest that computer science competitions can be a valuable tool for promoting girls' participation in computer science among educators. Still, more inclusive and encouraging environments are required to ensure the success of all genders.

5. Enrichment

Gender disparities in computing education have long been a problem, with various enrichment initiatives attempting to close the gap. For instance, Lang et al. (2015) examined the Digital Divas Club, an Australian outreach programme to encourage young women to pursue careers in computing. However, while the initiative did increase student confidence, it did not fully influence their desire to pursue computing careers, highlighting the need to address school culture and teacher self-efficacy. The authors suggest normalising girls' participation in computing and setting conservative expectations for a shift in attitudes. The Digital Divas programme highlights the difficulties of achieving long-term impacts on the professional lives of students through a single semester-long curriculum.

McGowan et al. (2017) highlighted the gender imbalance in computing careers and Code Club’s positive influence on career choices, as secondary school students and Code Club members had positive attitudes towards computing careers. Similarly, Barksdale et al. (2022) reported that an after-school programme positively affected middle school girls' perspectives on computation. Meanwhile, Corneliussen and Prøitz's (2016) study on Norwegian Code Clubs in rural areas emphasised the need for a clear recruitment strategy targeting girls and introducing playfulness with technology to develop their interest and competence in digital technologies, as girls currently remain a minority in these clubs. Gender stereotypes suggest that boys are more outgoing while girls are more focused and determined (Aivaloglou and Herman, 2019). There are also disparities in how well each gender responds to instruction, collaborates, and prefers different types of projects. Groups attending a code club can be a solution because they are small, taught differently, and feature independent work and formative evaluations.

In addition, summer camps and programming workshops have been the subject of numerous studies. For example, Herrero-Alvarez et al. (2022) investigated a new summer camp curriculum that increased female participants' self-efficacy, career identity, and confidence in AI and ML content. After attending a camp that contextualised AI and ML concepts with socially relevant topics, confidence in AI and ML content, self-efficacy in computer science, and career identity increased among female survey respondents. Historically, women have been uninterested in computer science programmes, but this new curriculum shows promising signs of reversing this trend.

Wang et al. (2020) presented findings concerning a Python programming summer camp that emphasised the significance of motivation through modern technology and a fun learning
environment. In addition, the study highlights the difficulties that high school girls face in programming and careers related to computer science, with some preferring practical opportunities and more programming time. Results also indicate that prior programming experience and programming time are related to the capacity to develop programming skills. Clarke-Midura et al. (2019) examined a summer programming camp for middle school students utilising the App Inventor block programming language. According to the study, the camp significantly increased the students’ interest in computer science (CS) careers, intrinsic motivation, self-efficacy, and parental support. Moreover, the findings highlight the significance of family support, particularly from fathers, for their child’s CS learning experience and career decisions. In addition, it suggests that mothers be encouraged to spend quality time with their children discussing app development.

Since 2016, Nias Pro, a non-profit organisation in Chile, has offered high school female students coding and computer science workshops and competitive programming courses (Vidal et al., 2021). The initiative is interesting because the organisation aims to dispel misconceptions and allow girls to create technology while organising programmes to increase the number of female competitors in the Chilean Informatics Olympiad. It also seeks to address the gender gap in computing and increase the opportunities for women to pursue careers in technology. Finally, Stupuriene et al. (2021) found that physical computing and CT can positively influence girls’ adoption of technology in summer school settings, reducing their apprehension and increasing their intention to use technology.

6. **Physical Computing**

Incorporating physical computing into STEM education has significantly improved female students' self-efficacy in computer science, thereby increasing girls' engagement and motivation (Psycharis et al., 2021). Moreover, physical computing platforms can teach computer science concepts and introductory programming, which increases girls' engagement and motivation due to "intrinsic process motivation," suggesting that engineering design can be an effective pedagogical strategy to encourage girls' participation in computer science and CT (ibid., 2021).

The IM HAPPY project delivered four computing modules, including a LEGO Mindstorms-based Robotics module, to residents of two Northern Ireland Neighbourhood Renewal Areas (NRAs) (Asinobi et al., 2015). In addition, classes in approved secondary schools and community centres within the NRAs received four bite-sized computing modules. The Robotics module had the highest enrolment and completion rate (78%) among students aged 16 to 17, with females being the most prevalent. Additionally, females tended to work in all-female groups, while males worked in mixed groups. Intriguingly, all-female groups constructed a puppy robot, indicating an emotional attachment to the object. Another project created STEM activities for middle and high school students involving robots. The results suggest that both genders were inspired by the NAO and Cozmo robots' language training applications (Keller and John, 2020). Moreover, the vocabulary training workshop was most likely to encourage young women to pursue careers in computer science. Females were more likely to join robotics groups, and after interacting with Cozmo robots, more than half of female students' perspectives on computer science improved.
The Maker Cards teaching approach, which uses the Calliope physical computation device, was evaluated in workshops with 54 girls aged 10-14 (Root et al., 2019). The results showed that the approach was valuable for the participants in implementing their ideas. Still, they only used the hardware aspects and example programmes and did not look at the complete content of the Maker Cards.

In addition, wearable technology has become increasingly popular in K-12 education. However, gender-appropriate pedagogical practices are needed to help girls gain self-confidence and success in tasks requiring multiple skill areas. For example, a study by Nugent et al. (2019) found that both males and females showed improved learning outcomes with wearable technology instruction, with males demonstrating higher self-efficacy in programming and circuitry. This highlights the need for gender-sensitive pedagogical practices to foster female self-esteem and support career orientation in STEM. Reimann et al. (2010) also proposed a smart textiles project involving artistic approaches to engage girls and young women in technology and engineering. The course explores contemporary media artworks in fashion and technology and integrates creative processes with a playful approach to computing and engineering education.

Finally, the "Guyanese Girls Code" (GGC) training programme was launched in 2018 using micro:bit to combat negative ICT perceptions among seventh to ninth-grade female students (Layne et al., 2020). The programme successfully increased female interest in computer programming, but limited training options in Guyana indicate the need for national strategic efforts to retain this interest. In addition, data from this study suggests that focused interventions are necessary to prevent a decline in female interest in ICT as early as age 11.

7. Mentoring

In addressing the gender gap in computing, it is impossible to overstate the significance of role models and mentors. However, it is essential to note that they serve different purposes (Friend, 2015). Role models provide efficacy information based on similarity, which can inspire individuals by demonstrating that if someone similar to them is successful in computing, they can also succeed. In contrast, mentors provide relational support and encouragement, as well as personalised guidance and advice, to individuals as they navigate their educational and professional paths. Therefore, role models and mentors can significantly encourage and empower women to pursue and succeed in computing careers.

Mentors shared their experiences as women of colour in STEM+CS fields as part of the BRIGHT-CS initiative (Madrigal et al., 2020), which positively affected student outcomes and social-emotional characteristics associated with retention. Bandura and Walters (1977), who discovered that young people tend to imitate those they perceive to be similar, discovered that role models significantly motivate middle and high school students' interest in computing. Additionally, Denner (2011) found that role models significantly motivate middle school girls' interest in computing, while D'Souza et al. (2008) found the same for high school students.
Lee's (2019) study of a coding camp led by first-year undergraduate instructors at a local university provides valuable insights into the need for mentorship opportunities and resources to foster relationships among young students from low-income urban neighbourhoods in Newark, New Jersey. Before the camp, the majority of students lacked role models or mentors in computing, highlighting the significance of near-peer mentors and guest speakers from the local community in assisting students in identifying computing-related individuals early in their academic careers. In addition, the students viewed the instructors as mentors in computing, indicating a good match between mentors and mentees. In addition, research by Clarke-Midura et al. (2018) suggests that middle school students find near-peer mentors, who are only a few years older than them and are not necessarily the most skilled in computer science, to be highly relatable. This relatability increases their self-efficacy and interest in computer science. Clarke-Midura et al. (2016; 2017) propose a mentoring strategy in which high school girls mentor middle school peers during a two-week AppInventor-based computer science camp. The study results indicate that this strategy increases self-efficacy and interest in computer science. Mentoring also provided the participants with social encouragement, academic exposure, career perspectives, and self-perception.

The CLICK study aims to increase female participation in computer science (CS) by matching industry mentors with female secondary school students in Ireland (O'Farrell et al., 2021). With CS-specific mentor sessions and panel discussions featuring inspirational female speakers, the mentorship programme aims to foster community among female students. Although the designathon was cancelled due to COVID-19, preliminary results suggest that the project could encourage continued research in computer science and increase female participation in the field. This pilot study offers a promising solution to the problem of low female participation in CS and calls for additional research to build on its success.

Moreover, RuizCantisani et al. (2021) identify the influences on the mentoring process and its effects on women. Their four-step approach includes designing and implementing the programme with high school students and female STEM professors as mentors, evaluating its impact, and identifying areas for improvement. Finally, Gutica’s (2021) paper examines the gender disparity in computing education and careers in Vancouver, Canada, and proposes an intervention to encourage high school girls to pursue computer science education. Following the expectancy-value theory of motivation, the intervention increases participants’ interest, enjoyment, positive learning gains, and confidence in their abilities. Furthermore, when mentored by postsecondary students, extracurricular activities such as coding and playing games in AR and VR environments positively impacted girls’ interest and achievement in CS, reduced their stereotypical views, and broadened their perceptions of the field.

**Continued Study of Computer Science in KS4**

Practical actions are needed to encourage girls to pursue computing as an optional subject choice aged 14+, including promoting female role models. Leonard et al. (2021) found that
female pupils had fewer positive attitudes towards computing, with mixed-sex high schools having lower scores for feelings of belonging than single-sex schools. The study recommended early interventions to increase female representation in computer science by addressing confidence, attitudes, and perceptions. Kallia and Sentence (2018) highlight the importance of identifying factors that affect students’ perceived capabilities in computer science, as boys feel more confident and predict their programming performance better than girls. However, girls tend to underestimate their abilities, which does not correlate with their self-evaluation or self-efficacy in computer science.

Friend (2015, 2017) conducted two studies on the development of interest in computing among middle school girls. The first study found that girls who developed an interest in computing during middle school maintained their interest by the end of high school and were open to computing as a career. The second study examined the impact of mandatory computer science classes on middle school girls’ attitudes towards computing and found that experience alone is insufficient to inspire interest in computing. However, girls who are open to computing and receiving social support will likely identify as potential computer scientists. Thus, the studies recommend encouraging and supporting girls’ interest in computing, even without school opportunities, and providing mentorship opportunities to sustain their interest.

In Estonian schools, Kori and Luik (2020) explored the motivation of male and female students to study computer science (CS). The findings indicate that boys exhibit more motivation to study CS than girls, which highlights the need for teachers to consider what motivates students and put more effort into inspiring girls. The study identified several factors, including stereotypes, lack of female role models, and non-supportive classrooms, that contribute to gender disparity in CS education. Students are encouraged to participate in informatics competitions such as Bebras to increase enthusiasm for the field.

Next, Vieira and Couto (2020) emphasise that teachers are critical in shaping students’ attitudes towards computer science. Girls’ underrepresentation in the field can be attributed to distorted perceptions of their abilities and gender stereotypes reinforced by teachers. Finally, Kori and Luik (2020) explored the motivation of male and female students to study computer science (CS) in Estonian schools. The findings indicate that boys exhibit more motivation to study CS than girls, which highlights the need for teachers to consider what motivates students and put more effort into inspiring girls. This study identified several factors, including stereotypes, lack of female role models, and non-supportive classrooms, that contribute to gender disparity in CS education. Students are encouraged to participate in informatics competitions such as Bebras to increase enthusiasm for the field.

Early interventions are needed to increase female representation in Computer science by addressing confidence, attitudes, and perceptions. Girls’ interest in computing can be sustained through marginally positive expressions of interest, but mentorship opportunities and social support are essential to encourage and support girls’ interest in computing. Teachers must also
consider what motivates students and put more effort into inspiring girls to pursue Computer science careers.

**Continued Study of Computer Science Post-16 years**

The gender disparity in digital job aspirations among GCSE-level computer science students in England is substantial and consistent with previous research (Hamer et al., 2023). Girls, who tend to gravitate towards creative computing, may be effectively engaged by incorporating digital art into computing education. Furthermore, historically, technical computing has been associated with men. More boys than girls have higher self-beliefs in coding, which can influence their aspirations to become computer scientists (Ibid., 2023).

The high-tech industry seeks more graduates in computing, especially women, who are currently underrepresented, and increasing high school computer science education is seen as a viable solution (UNESCO, 2023). Positive data are observed in Israel, where there is a slight gender gap in computer science enrolment at the high school level, which slightly widens at the most advanced exam level. Consequently, evidence suggests that offering advanced computer science courses to female high school students significantly influences their pursuit of a bachelor's degree in computing (Armoni and Galoni, 2014). Increasing the availability of computer science education, particularly at the advanced level, could thus encourage more women to pursue careers in computing, closing the gender gap.

A plethora of international studies have investigated ways to increase the participation of women in computing education beyond the age of 16. Lee (2020) demonstrates the significance of incorporating computer science (CS) education into secondary schools to encourage female participation in maths-intensive STEM fields and that limited exposure to CS courses is a significant factor contributing to the underrepresentation of female students, despite their high maths self-efficacy. Thus, implementing a comprehensive CS curriculum at the secondary level, which includes integrating CS into regular classes, can assist in closing the gender participation gap in CS. Gutta et al. (2022) proposed a model for a virtual hackathon to encourage underrepresented minority high school girls to pursue careers in computing. Additionally, the authors advocate for women-only education initiatives as a promising method for enhancing women's experiences in the field.

Next, Faenza et al. (2021) investigate how girls' participation in summer camps can affect their future academic decisions. Their Digital Girls initiative with Italian universities has been recognised as a model for closing the gender gap in ICT-related disciplines. Moreover, Wang et al. (2015) found that exposure to computer science courses and encouragement were the most influential factors in girls' decisions to pursue computer science-related degrees, while the role of uncontrollable factors was limited. The exposure of college-bound women to computer science courses in or outside of school was highly beneficial. In addition, parents played a vital role in providing girls with experience and confidence in these fields.
Next, the SAILORS initiative is intended to attract high school girls to artificial intelligence (AI) and computer science by providing a two-week non-residential programme (Vachovsky et al., 2016). The schedule is organised by graduate students and professors who contextualise technical AI concepts through social impact and address obstacles that may discourage 10th-grade girls from pursuing computer science. Participants' technical knowledge, interest in AI careers, and confidence in their ability to succeed in AI and computer science all increase statistically significantly. SAILORS provides role models, faculty support, and a grassroots community. Research projects provide students with hands-on experience, boosting their confidence and enthusiasm for AI and possibly igniting a long-term interest.

In addition, Spieler et al. (2019) propose the "Get FIT in Computer Science" MOOC as a promising solution to the computer science challenges faced by adolescents. This online initiative aims to introduce high school students to the field of computer science and promote inclusivity and gender equality. It is designed for young women with little or no knowledge of computer science, all teenagers seeking a more realistic view of the field, and instructors who can use the course materials to teach classes.

Furthermore, Outlay et al. (2017) examined the effect of incorporating Girls Educating Them About Information Technology (GET IT) on girls’ career interests. They discovered that girls’ interest in IT careers increased one year after camp completion. Next, Finzel et al. (2018) designed the mentoring programme Make IT to encourage female high school students to pursue computer science, resulting in all participants declaring their intent to pursue CS studies. Isvik et al. (2020) launched the FLAMES programme, another initiative consisting of an 8-week summer school internship for high school girls, which proved to be novel and socially relevant. Mooney et al. (2018) surveyed university-level female students and discovered that mentorship, role models, and a supportive community are crucial for retaining women in computing.

Next, Trinity College Dublin’s CodePlus is a non-formal computer science outreach programme for women only (Lawlor et al., 2020). The results of a large sample size (n = 856) revealed significant changes in critical attitudinal and intentional variables associated with girls' desire to study computer science. This emphasises the significance of cooperative learning strategies and the relevance of computing's societal implications for encouraging female students to pursue computer science. The success of similar changes in teaching strategies at Harvey Mudd College and Carnegie Mellon University is evidence of this, and the authors propose that the CodePlus model encourages women to pursue careers in computer science.

Since 2010, female academics from the Department of Computer Sciences at the University of Brasilia have led the Meninas.comp Project to empower girls pursuing computer science and engineering degrees (Holanda et al., 2020). The project provides high school students in grades 10 through 12 with programming workshops focusing on game design, robotics, and app creation for mobile devices. In 2015, only 5% of Brazilian high school seniors were interested in computer engineering. Despite obstacles, the project has increased the diversity of CS majors at
the University of Brasilia, with 23% more women enrolling in Computer Engineering in 2018 than in 2017.

Using NetsBlox, Stein et al. (2022) developed the Computer Science Frontiers (CSF) curriculum to increase high school students’ access to emerging computing fields, particularly girls. The research aims to create a diverse and gender-balanced workforce by arousing students’ interest in advanced computing topics and establishing pathways for them. This involves investigating how project-based activities can increase female students’ interest in computing and determining which advanced topics are suitable for high school. Furthermore, open-access modular materials will facilitate the dissemination of research results.

BridgeUP: STEM is a programme that addresses gender and opportunity gaps in the STEM pipeline for women, girls, and underprivileged youth (Secunda et al., 2018). The programme integrates programming with scientific research and includes a tiered mentorship initiative involving American Museum of Natural History researchers. Eighteen scholars conducted computational astrophysics research in their first year. BridgeUP: STEM targets non-senior high school students and provides exposure and preparation for educational and career pathways through coding courses, lab research, mentoring, and community events. It emphasises the design of bridge programmes that foster students’ sense of belonging, self-assurance, and perseverance in computing (Johnson et al., 2021).

Next, a study of 52 upper-secondary school students in Germany (Keil et al., 2020) reveals that male and female students have different perceptions of computer scientists. In contrast to male students, female students have negative perceptions of the field. To provide a more accurate depiction of the field of computer science, it is suggested that future research investigate the influence of confounding variables and consider universal, required, and positively framed informatics education.

Finally, the study by Winter et al. (2021) investigated the experiences of 15 female first-year CS undergraduates in the UK. Female CS students were more likely to use hedging language and personalise the problem, which has implications for educators. Mentioned was the gender disparity in CS education and workplaces, which has adverse effects on women, such as sexism, alienation, and unconscious biases in technology design and development. There is a need for more in-depth qualitative research on women’s field experiences.

**Longitudinal Studies**

Despite numerous initiatives encouraging girls to pursue degrees and careers in Computer science (CS), few studies have demonstrated their efficacy in addressing the persistent gender gap in CS education and the tech sector. Despite the efforts of the government, schools, and industry in the United Kingdom, the proportion of women in the field remains an issue. Sinclair and Kalvala (2015) argue that substantial sums have been spent on ineffective solutions.
However, Miranda (2022) suggests that one possible explanation for this is that such studies require longitudinal research, following girls from school to higher education, and suggests tracing the profiles of male and female CS students, including their academic paths, motivations, and influences in choosing a CS course, to recommend interventions in pre-university education that encourage more girls to choose CS. In addition, it is essential to determine the percentage of girls who choose the CS field without taking a CS course before university and compare the differences between boys’ and girls’ motivations and influences.

The seminal work “Unlocking the Clubhouse” (Fisher and Margolis, 2002) sheds light on the gender gap in computing education. In addition, Collain and Trytten’s 2019 study expands on this prior research by analyzing the pre-college experiences of eleven students and their paths to computing degrees. Literature indicates a significant gender gap in computer science education; however, this is less prevalent at Carnegie Mellon University. The findings emphasize the importance of institutional differences in studying gender disparities in computing. In addition, the study emphasizes the importance of introductory computer science courses in high school for girls to enter the field of computer science, with one-third of women citing these courses as essential entry points. The influence of students’ upbringing and exposure to technology on their interest in computer science is substantial.

Moreover, the NCWIT⁹ conducted a six-year longitudinal study that followed girls and women from high school through college and into the workforce (Weston et al. 2019). According to the study’s findings, consistent opportunities to learn computer science (specifically programming) and address systemic biases within the field are crucial for the widespread success of women in computing. In addition, Zhao and Perez-Felkner (2022) also suggest that improving high school students’ perceptions of their mathematical and scientific abilities can reduce disparities in STEM-related fields.

In response to Australia’s ICT worker shortage, initiatives have been implemented to attract prospective students to ICT courses and improve their self-efficacy and positive attitudes. Previous gender-focused interventions have shown immediate positive effects on the attitudes and confidence of female students regarding IT. However, one longitudinal study investigated the long-term effects of three levels of IT interventions on the attitudes and aspirations of elementary school students towards computer programming (Fletcher et al., 2021). The findings indicate that the immediate positive effects of interventions diminish over the subsequent two school terms, particularly in terms of students’ desire to pursue programming. In addition, the study highlights gender differences in baseline levels of interest and self-efficacy in programming, with male students beginning at higher levels than female students, suggesting that societal bias may contribute to female students’ lower levels of self-efficacy and interest in STEM subjects. However, female students benefit from interventions to increase interest and self-efficacy in programming more quickly than their male counterparts, possibly due to different levels of intention before the intervention. Findings highlight the need for additional research to investigate

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⁹ NCWIT means The National Centre for Women & Information Technology
potential gender-based differences in workshop content, activities, and outcomes and to determine the optimal time to administer interventions to ensure long-term benefits.

Main and Schimpf’s (2017) literature review examines interventions to close the gender participation gap in computing across four stages: pre-high school, high school, college, and employment. They noted that pre-college interventions provide hands-on experiences, introduce girls to positive role models, and offer information to promote a greater interest in computing and technology. In contrast, college interventions include redesigning courses, modifying course requirements, and encouraging participation in mentoring programmes and conferences. The review emphasises the need for longitudinal research to understand more about students’ paths into computing and the most effective interventions at various stages. Researchers and practitioners can create a more equitable and diverse computing community by considering the multiple factors influencing participation and adopting a life-course perspective.

Twenty years have passed since the inception of gender equity programmes tailored to the undergraduate computing context. Focusing on university faculty perceptions, Hamilton et al. (2016) evaluate the effectiveness of gender equity initiatives in computing education. Despite these efforts, women remain underrepresented in computer science courses, and retention rates remain low. Effective gender equity initiatives should monitor enrolment and retention rates, evaluate their success, and secure university administration backing. Moreover, early intervention and awareness programmes can help address disengagement.

Friend (2017) investigates the nature and persistence of girls’ interest in computer science during middle school and beyond in the United States, beginning at 11. In addition, the study’s findings indicate that girls interested in computing grew increasingly interested by the end of middle school. A strong correlation existed between expressing an interest in computing and developing an interest in pursuing a career in computing. However, participation in computing-related activities such as classes, clubs, and hobbies was not necessarily correlated. By the end of high school, participants had a more decisive and definite attitude towards computing, especially regarding their interest in computing as a career and a university degree. The findings of the study have significant implications for policymakers. First, it emphasises that if the girls’ interest in computing is more than marginal, it can be sustained even without school opportunities. In addition, the study revealed the disparity between aspirational and embodied expressions of interest in high school, which diminishes the importance of continued opportunities during this period. Therefore, school leaders and teachers should prioritise creating and maintaining an environment that sustains students’ interest in computing, especially during the crucial transition period from middle school to high school.

A large-scale study of 500,000 secondary school students in Israel found that advanced maths, physics, and computer science courses in secondary school positively correlate with STEM persistence in higher education (Nitzan-Tamar and Kohen, 2021). Additionally, the study revealed the impact of demographic and educational factors on career decisions. According to research, gender and ethnicity influence choice and persistence in STEM fields, with underrepresentation
of women and ethnic minorities. Women are less likely to earn bachelor’s degrees in STEM fields and account for less than 30% of degrees in computer science and engineering. However, they account for 47% and 59% of chemistry and biology bachelor’s degree recipients, respectively. By analysing an individual’s educational decisions throughout their lifetime, the study investigates the factors that influence a person’s path towards STEM or non-STEM careers. It identifies eight tracks and highlights a crucial transition between choice goals and actions that leads to a "leak" from STEM to non-STEM careers.

Next, Lang et al. (2020) contend that visible and appropriate female IT role models can encourage young women to pursue computing careers. Exposure to same-sex experts can improve the implicit self-concept of female students, and the literature recommends providing girls with suitable role models. There is, however, little empirical data regarding the effect of role models on fostering girls’ long-term IT interests. Perceived similarity to role models is essential for attracting and retaining women in STEM fields, but sharing the same gender may not be sufficient. This study examined a four-year, long-term programme to alter girls’ attitudes towards computing and increase their interest in IT careers. It resulted in a comprehensive model of ‘Factors that Influence Girls’ Attitude to IT’. The curriculum was delivered in single-sex classes, and opportunities to interact with role models were scheduled during regular class time. The research demonstrated that this method increased girls’ confidence and enthusiasm for IT. In addition, the study produced a comprehensive model of the factors that influence girls’ attitudes towards IT and serves as a valuable resource for those implementing similar programmes.

Building an Inclusive Culture in Computing

Evaluating the efficacy of initiatives to increase girls’ and women’s participation in computing through curriculum enrichment and industry engagement is essential to addressing the gender gap in computer science education. A project in Australia sought to map STEM initiatives across all sectors and investigate the available evidence of their efficacy (McKinnon, 2021). While there was a concerted effort to engage girls and women in STEM, the lack of meaningful evidence of impact raises concerns regarding resource allocation and attaining gender equity policy objectives. Without proof of effectiveness, it is unclear whether resources are allocated to initiatives with a positive long-term impact. This lack of efficacy research ultimately benefits no one.

Leadership

Girls and women continue to be underrepresented in science courses and careers, particularly in physics, computer science, and engineering, despite outperforming male students in most educational indicators in high-income countries. As social institutions, schools play a crucial role in addressing and eliminating gender disparities in these fields, which are frequently ignored in
existing literature (Pinson et al., 2020). Despite decades of efforts to improve the representation of women in STEM fields, including research, policy, and practice, particularly in technology, progress has been limited (Yates and Plagnol, 2020). In their qualitative study of women’s experiences studying computer science at a university in the United Kingdom, one of the findings investigates the underexplored topic of male champions who support diversity in the field, offering a novel perspective. They can assist in shifting the dialogue from “women’s issues” to diversity and social justice in the discipline (Ibid., 2021). This is an intriguing subject to examine from the perspective of school computing leadership.

Significantly, the “Nordic Paradox” refers to the mismatch between gender equality and poor results in recruiting women in the technology and computing fields. To elaborate, Corneliussen and Tveranger (2018) described a pilot programme in Norway that introduced programming in secondary schools but lacked gender diversity measures. They suggest that awareness, support, self-confidence, and role models are essential for overcoming cultural stereotypes and promoting inclusion. Therefore, if school leaders want their computing and programming initiatives to be successful, they must incorporate gender-sensitive strategies.

In Australia, there is a lack of women in computer science, which is reflected in the low number of women in top-level positions in government and business. A 2017 survey of secondary school computer science teachers revealed that addressing diversity in digital technology education requires taking socio-ecological factors into account at multiple levels of influence (Mitchell et al., 2018). Teachers must be aware of the key messages conveyed by the growing body of research on diversity in computer education. Nonetheless, it will be ineffective if teachers lack the time, training, and resources to address the issue in the classroom and curriculum development. Furthermore, societal gender assumptions may discourage girls from pursuing computer science even when resources and a curriculum are available. To effectuate change at the local level, educators need assistance with material resources and manageable workloads. Awareness and training remain essential components of change efforts.

CAPE Framework

The underrepresentation of females, particularly those from low-income backgrounds and of African/Caribbean descent, in optional GCSE Computer science, is a significant issue, given that all children in England between the ages of 5 and 16 must take computing (Kemp et al., 2018; 2019). The CAPE framework can assist school leaders and teachers in identifying barriers to equity in the subject (Fletcher and Warner, 2021). It examines four factors: capacity, access, participation, and experience, and emphasises the need to address the root causes of underrepresentation at each level in computer science. This includes systemic barriers such as

10 CAPE means Capacity, Access, Participation, and Experience
unequal access to CS courses for low-income and underrepresented students, stereotypes about who pursues a career in computing, and male-dominated spaces that discourage female students.

The framework (Figure 1) encourages educators to focus on precursor conditions and leading indicators of systemic inequities rather than solely on outcomes such as CS exam pass rates or degree completion. By considering all four levels, school leaders and teachers can better comprehend systemic barriers to equitable outcomes and determine how to measure and take action to create a more inclusive CS education system that capitalises on the contributions of a diverse national population.

![Figure 1: Capacity, Access, Participation and Experience (CAPE): A Framework for Assessing Equity in CS Education (Fisher and Warner, 2021)](image)

**Enrichment**

Several studies have examined innovative strategies for promoting informal computing education initiatives to increase diversity in computer science. For instance, Braswell et al. (2021) created a virtual summer camp for Black and Latina girls during the COVID-19 pandemic to provide informal computer science learning opportunities. As a result, the camp improved the participants’ computing confidence and outcome expectations. Similarly, Styilnski et al. (2021) created the AR Girls programme, which employs interdisciplinary approaches to introduce girls to
computer science and foster the development of soft skills through location-based AR walking tours. The four guiding principles of AR Girls are stealth science, place-based education, non-hierarchical design, and learning through design, all of which help to increase girls' interest and confidence in computer science. Moreover, through partnerships with small art organisations and collaborations with science professionals, the initiative has adopted the use-modify-create strategy for rapid and active engagement, which is essential for successful out-of-school learning. Initial evidence suggests that interdisciplinary learning can increase girls' interest in computer science and facilitate the development of soft skills.

Next, Solyst et al. (2022) designed a curriculum that empowers students from diverse backgrounds by combining culturally responsive instruction and a computing framework. The programme's emphasis on asset-building, reflection, and connectivity promoted community building and CS student engagement. Diverse online learners had varying levels of engagement, and prior knowledge of computer science affected power structure discussions. The role of pedagogy in engaging diverse learners in computer science is crucial.

In addition, Thompson et al. (2023) emphasise the significance of parental involvement in children's extracurricular activities, particularly for historically marginalised youth. Their study highlights the Digital Youth Divas (DYD) programme, which emphasises community building from a transformative justice perspective. The intervention improved Participants' perceptions of computer science and computational work. It also increased their knowledge and expertise in computational thinking and fostered a positive perception of computer science and computational work.

**Industry Engagement Provision**

It is suggested that curriculum enrichment and industry engagement be incorporated to build an inclusive culture in the computing classroom. This strategy can be implemented in schools for girls and other underrepresented groups if the intervention meets the identified education priority and the quality of the initiative is ensured. McKinsey & Company (2018) presents a study conducted with 32 technology companies to assess their philanthropic and corporate social responsibility (CSR) initiatives to reduce the gender gap in the technology industry. Despite a strong desire to increase diversity, only 5% of the $500 million spent on philanthropic giving in 2017 was allocated to gender imbalance programmes, according to research. In addition, less than 0.1% of philanthropic investments aim to remove barriers for women and girls of colour pursuing careers in technology. This demonstrates a mismatch between the targeted support identified and the capacity available from industry engagement provision.

The Texas Workforce Commission-funded DesignHER Code Camp, which Stewart et al. (2020) evaluated, illustrates this strategy well. This outreach programme aimed to teach middle school girls computer programming and encourage them to pursue careers in underrepresented fields.
Participation in programming and interactive games positively changed the girls’ attitudes towards STEM and coding. This initiative is a model for engaging students in STEM careers.

Next, the STEM Ambassadors programme, funded by UKRI and administered by STEM Learning, aims to increase student engagement with Science, Technology, Engineering, and Mathematics (STEM) subjects and careers in the United Kingdom, with specific programmes for computing. The findings of a Sheffield Institute of Education study on the impact of the STEM Ambassador programme on students’ attitudes towards STEM indicate that hands-on activities were more effective than lectures. Moreover, student-led initiatives and mentoring relationships were regarded more highly (Price et al., 2022). The study suggested prioritising face-to-face interactions, ensuring that students have control, differentiating between recruitment and retention strategies at the primary and secondary levels, and establishing sustainability and connections with other STEM initiatives. According to Blake and Percy (2022), STEM Ambassadors are inspired to volunteer and inspire the next generation. The perceived impact of their interactions with students and educators ranges from moderate to substantial, and they seek to link STEM and curriculum learning with potential careers and future opportunities. However, Ambassadors have reported that teachers need more direction regarding their expected role, as it is frequently confused with a substitute teacher’s. Given the gender disparity in computing, the STEM Ambassador programme can promote and provide equitable opportunities for children and young people, particularly girls.

In 2021, another STEM Learning initiative, in partnership with Goldman Sachs Gives, provided intensive STEM summer camps to 18 schools in England (The Charity Spark for STEM Learning, 2021). The objective of the Science-focused camps was to assist students in enhancing their curriculum knowledge and re-engaging with formal learning environments following COVID-19 disruptions. They are an interesting initiative for a computing specialism that promotes belonging and self-efficacy. In addition, the centres enabled teachers to learn new strategies and receive CPD. The evaluation revealed that the camps significantly impacted students with average academic achievement and students from underrepresented groups. A more structured approach to professional development for teachers would support consistent school progress. For instance, some schools suggested shorter days over five days, and repeating the experience with the same cohort of students would be beneficial. Furthermore, the STEM career engagement portion could be emphasised. Nonetheless, the camps were viewed favourably, and students who attended performed well on exams, remained motivated, and exhibited greater scientific confidence.

IBM’s NERD initiative, launched in Italy in 2013, aims to encourage secondary school girls to pursue computer science (Coccoli et al., 2020). More than 12,000 girls and 100 IT specialists

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11 UKRI means UK Research and Innovation

12 NERD means Non-E Roba per Donne?, which is Italian for “Isn't this stuff for women?”
have participated, and universities across Italy are now involved. The programme is dependent on volunteer project leaders and female STEM role models. NERD provides invaluable opportunities to develop leadership, organisation, management, and peer training skills. According to the programme's data, participants report increased satisfaction, problem-solving skills, analytical reasoning, and interpersonal communication abilities, all essential in the STEM job market. Teachers can use this as a model to encourage girls to pursue STEM careers and cultivate well-rounded professionals with transferable skills.

Taylor-Smith et al. (2022) propose a Participant-centred Planning Framework to help teams design practical activities to address the gender imbalance in the tech industry and computing education. The framework, derived from a research study that identified success factors such as role models and was successfully tested, can be applied to other underrepresented groups. The authors emphasise the significance of evidence-based approaches and provide a framework for promoting best practices and encouraging more girls to pursue computing. An online resource containing case studies and evaluation methods will be developed to support this objective.

In addition, Muraski and Iversen (2022) describe three strategies that three Wisconsin school districts implemented to expand their computer science and IT curricula for all students and the pipeline of local IT and digital professionals. They argue that the maturation of regional collaboration efforts permits school districts to expand computer science offerings more efficiently and to use regional partnerships to increase the likelihood of success for their actions. The state of Wisconsin partnered with higher education institutions, adopted Microsoft's TEALS\textsuperscript{13} initiative, and developed digital skills for kindergarten through eighth grade. TEALS assisted high schools by initially being present in their computer science classrooms and providing curriculum materials. From 2017–18 to 2020–21, the programme expanded from 32% to 75% of high schools, substantially increasing the number of participants and the average number per school.

Many nations have programmes to identify and support talented students in various fields, including academics, music, and sports. Similarly, campaigns exist to identify talented students in cybersecurity and digital safety (Lorenz et al., 2021). CyberPin is an initiative to identify gifted Estonian students in grades 1 to 6 through a one-month competition with more than 8,000 participants that reveals performance differences based on gender and mother tongue. The CyberCracker study of Grades 4 to 9 revealed that girls excel at less complex tasks requiring social skills, whereas boys excel at tasks requiring technical skills and more complex thought. According to the Grade 9 PISA results, it has been observed that identifying gifted students early can help identify their potential pathways and conserve school resources. Cybersecurity initiatives must emphasise the development of creative problem-solving and critical thinking skills, and schools need guidance and support to improve cybersecurity education. In addition,

\textsuperscript{13} TEALS means Technology Education and Literacy in Schools
future research should investigate the influence of robotics and information technology on students' cybersecurity and cyber safety skills.

Moreover, Shan and Yang (2022) investigated the effect of accessible cybersecurity programmes (CPs) on high school girls' participation in the tech industry, given their pre-existing interest in technology. The researchers surveyed 55 girls about their access to and experience with high school computing programmes and their aspirations in the computing community. They discovered that CPs alone did not significantly increase girls' participation but that providing multiple opportunities and access to CPs in areas with limited resources did increase their interest. The study emphasises the significance of supporting the growth and development of cybersecurity programmes to increase the participation of underrepresented groups in technology.

The global shortage of cybersecurity workers is a growing concern, with only 11% of the workforce female (Frost and Sullivan, 2017). To combat this issue, organisations must address the gender gap in the field, and initiatives such as CyberPatriot have successfully increased female students’ interest in pursuing careers in cybersecurity. Reducing the gender gap is essential for addressing the shortage of cybersecurity professionals and encouraging more women to pursue careers. For instance, female participants in CyberPatriot competitions demonstrate more significant positive changes in their perceptions of cybersecurity professionals than their male counterparts (Dunn and Merkle, 2018).

The United States Air Force Junior Reserve Officer Training Corps (JROTC) launched a Cyber Academy in 2020 to educate high school cadets on cybersecurity skills and career awareness (McGill et al., 2020). The online course taught by instructors from Moraine Valley Community College, Brookdale Community College, and Madison Area College had a retention rate of 96% despite meeting 3 to 5 hours per day for eight weeks. In addition, following the training, girls’ self-efficacy in identifying cyber threats reached the same level as that of boys.

Furthermore, Krohn et al. (2020) discuss the initiatives taken by an Austrian university to address the gender gap in computer science. Their research aims to attract gifted girls to computer science, support female bachelor’s and master’s students, and redesign courses and teaching materials to narrow the performance gap between male and female students. One initiative is the two-year Cyber Tutoring programme, which aims to provide girls with valuable experience in academically-focused creative projects. The programme involves a collaboration between thirteen girls aged 13 to 16 and women in senior STEM positions. The tutors propose ideas, collaborate with the girls on their projects, and involve them in the department’s research projects. The majority of interactions take place online. In addition, the programme includes leadership seminars and peer tutoring in computational thinking to enhance academic and technical understanding.
The NCCE Gender Balance in Computing Research Programme

The Raspberry Pi Foundation, STEM Learning, BCS, The Chartered Institute for IT, the Behavioural Insights Team, Apps for Good, and WISE collaborated to implement several interventions in the Gender Balance in Computing initiative (NCCE, 2023). These interventions were conducted in 500 primary and 250 secondary schools in England over four years, from 2018 to 2022, focusing on four research topics, summarised below.

Teaching Approach

The study evaluated three approaches to teaching computing: pair programming, peer instruction, and storytelling. Pair programming did not significantly affect girls’ attitudes or intentions to study computing. However, teachers found the strategy effective and suggested refining certain elements. In addition, the peer instruction trial did not demonstrate a significant increase in girls’ intent to study computer science, but it was found to be engaging and inclusive. The storytelling intervention was acceptable to students and manageable for teachers. However, quantitative results were inconclusive due to the pandemic’s high attrition rates and methodological limitations. Recommendations include longitudinal tracking of GCSE subject choices and the simultaneous implementation of multiple strategies to engage girls in computing. Despite null impact findings, teachers should be offered lessons, training, and peer instruction resources.

Belonging

The randomised controlled trial revealed no statistically significant evidence that either intervention increased girls’ intention to study computer science at the GCSE level or improved their attitudes towards computing. Nonetheless, feedback from teachers and students of 9- and 10-year-olds indicated that both interventions were well-received and engaging. Girls in the Code Stars group had a slightly greater intention to study computer science, but this difference was not statistically significant. The intervention My Skills My Life was well-received by educators, with some noting increased student interest and motivation in computing careers. Although COVID-19 disrupted the messaging component, the Code Stars lesson prompts were constructive and fun. Additional lessons focusing on AI could increase girls’ interest in computing. Independent evaluators recommended a reduction in content, an increase in guidance for the My Skills, My Life intervention, increased opportunities for girls to interact with female role models, and a review of the Code Stars communication mechanism. Investigating enhancements that address other obstacles to girls studying computer science is also necessary.
Informal Learning

The objective of the Gender Balance in Computing programme was to increase girls' participation in formal computing studies by demonstrating the benefits of non-formal learning. Secondary school students participated in non-formal learning using an adapted Apps for Good course, and primary schools ran Code Clubs using adapted materials. Girls reported an improvement in their attitudes towards computing but no significant increase in their intention to pursue GCSE computer science. The added demands of COVID-19 diminished the efficacy of the interventions. Additional recommendations include making the content more explicitly linked to computer science as a GCSE subject, emphasising engaging activities and technical skills to boost girls' confidence, and identifying methods for measuring longer-term outcomes.

Relevance

The relevance intervention, created by the Raspberry Pi Foundation and Apps for Good, increased girls' interest in computing by demonstrating their ability to solve real-world problems in relevant contexts. The solution involved creating a set of lessons for Year 8 students in secondary schools in England to deliver for up to 13 weeks. The pilot study was independently evaluated to generate recommendations and modifications incorporated into the trial's resources. Ninety-seven schools participated in the randomised controlled trial, which was conducted between January and April of 2022. Participating schools were randomly divided into two groups: a "control" group that taught their standard computing lessons and a "treatment" group that delivered the intervention using the new Apps for Good resources developed for this study.

While the relevance intervention did not demonstrate statistically significant evidence of increasing girls' intention to pursue GCSE computer science, the exploratory analysis revealed a small positive effect on girls' perceptions of computing's relevance and interest. Some teachers found the intervention resources helpful, while others encountered delivery challenges. Moreover, some female students reported increased engagement and enjoyment in computing classes, particularly the creative components. The evaluators recommended combining the intervention with other approaches, modifying resources for increased engagement and ease of delivery, and establishing systems to track the impact of the intervention.

Subject Choice and Options Materials

The research team conducted five exploratory studies to determine how computer science presentation influences student preferences for the subject. The complex and masculine language used to describe computer science in option booklets was identified as one of several barriers that may discourage girls from selecting computer science as a GCSE option. In addition, many parents have limited knowledge of computer science and steer their children towards more
familiar subjects. Some students were unaware of the variety of careers related to computer science. In light of their findings, the researchers suggest using a checklist to encourage more girls to pursue careers in computer science.
Recommendations

This review emphasises the importance of identifying the root causes of the gender gap in CSE, how intersectionality and context can affect student participation, and how gender disparities in computing can manifest in various ways. However, school and subject leaders must take a comprehensive approach that considers all relevant factors and recognises there is no silver bullet for this complex problem to promote equity in the field. Inclusive computing education requires systemic, institutional, and programmatic reforms to promote diversity and equity and increase girls' sense of belonging and identity.

Understanding the "Nordic Paradox" (Corneliussen and Tveranger, 2018) may help English educators avoid perpetuating this issue. Norway, a country with one of the highest rates of gender equality but a significant gender gap in computing, shows the importance of raising awareness to combat the "normality" of the low number of girls in computer science. The idea that "girls just are not interested in programming or computers" from teachers or families must be challenged. Furthermore, recommendations from the GBIC\textsuperscript{14} programme, such as longitudinal tracking of GCSE subject choices and the simultaneous implementation of multiple strategies to engage girls in computing, should be extended into the second phase of the NCCE.

Understanding the Gender Gap

Teachers can design and assess inclusive learning environments by considering students' varying social and cultural capital (Vrieler and Salminen-Karlsson, 202). Recognising that changing pedagogical practices can be difficult, the CSC (Computer Science Capital) model has the potential to assist educators in achieving this goal. To name a few, changing teaching practices or ways of thinking about computing pedagogy takes time, patience, professional development, encouragement, and support; however, models such as the CSC or other frameworks, including CAPE, included in this review should be investigated further to determine their effectiveness in achieving intended outcomes.

The CAPE framework establishes a baseline of computing equity, informs equity-focused initiatives in schools, supports evaluation and progress tracking, and can help school leaders recognise and understand the complex nature of the computing gender gap, including intersectionality issues and inequalities across the CS education ecosystem. Finally, it serves as a model for implementing a multifaceted approach in the classroom, with interventions addressing the numerous factors influencing girls' attitudes towards the field.

CQF Adoption

Reviewing the Computing Quality Framework (CQF), assisting teachers in adopting and demonstrating progress using data and evidence-informed approaches, commitment and

\textsuperscript{14} GBIC means Gender Balance in Computing, the research programme from the NCCE (2018 – 2022).
leadership, and sharing best practices and collaboration through 'I Belong Champions' can all promote and evaluate progress towards equity in computing education. Multiple dimensions of the CQF must be considered to ensure the effectiveness of interventions and encourage more girls to consider GCSE CS as an option subject. Interventions can be better designed to improve student outcomes by addressing various aspects of equity, such as access, stereotypes, and support.

**Leadership**

It is recommended that schools provide teachers with the time, training, and resources they need to address gender inequity in computing education effectively. While there is research literature on the gender gap, this knowledge must be translated into practical action in the classroom and curriculum development. Furthermore, because societal gender assumptions may discourage girls from pursuing computer science, teachers should receive ongoing support to create an inclusive environment and promote gender equity in computing education. Male champions should be considered to support diversity in the field in conjunction with a teacher on the leadership team or as a school's Inclusion Champion participating in the NCCE initiative.

**Teachers’ Professional Development**

**Subject Knowledge Enhancement**

Teacher professional development focuses on improving subject knowledge, self-efficacy, and value perception, particularly among girls and underrepresented groups. To accomplish this, CS courses should provide technical knowledge and pedagogical approaches while addressing teacher efficacy issues. Furthermore, prioritising a gender focus in computing teachers’ PD (professional development) and classroom implementation, including teaching programming in primary and secondary schools, is critical to creating a more inclusive classroom environment.

The NCCE’s professional development programme is an ideal platform to provide scalable support to teachers and school leaders, regardless of their experience level, gender, or location. It can help ITT\(^{15}\) and current teachers develop relevant subject knowledge and pedagogical approaches for all students and embed methods from the gender insights program. In addition, it is crucial for a smooth transition and progress in learning as secondary school teachers build on pupils’ prior knowledge as children move into KS3\(^{16}\).

Furthermore, it is critical to ensure that programming instruction is gender sensitive. Teachers should be aware of the importance of self-esteem in teaching and learning, especially in programming, where self-efficacy levels are lower than in other subjects. Future computer science courses should emphasise teacher efficacy issues and incorporate programming

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\(^{15}\) ITT means Initial Teacher Training

\(^{16}\) KS3 means key stage three with students aged 11-14 years
projects into their training to encourage deep learning and improve teachers’ attitudes towards programming.

Evaluating the current courses offered with subject knowledge enhancement around teaching computing in primary schools and analysing the number of teachers who have completed a course to support them in teaching programming should be considered. Furthermore, discrete courses for teaching key stage one or two classes and the mandatory inclusion of a programming course in the Primary Certificate accreditation may be beneficial. For example, only 379 teachers completed the "Primary Programming and Algorithms" course in-person or remotely during the academic year 2021/22.

**Approaches**

According to the literature, the curriculum’s lack of culturally relevant computing activities contributes significantly to the persistent gender gap and underrepresentation of girls in computer science. In light of this, it is suggested that teachers be encouraged to adopt culturally relevant computing practices that consider their students’ diverse cultural identities, particularly girls, and include activities that highlight computing’s potential for social impact. A quick read of a ‘culturally relevant pedagogy’ is already available on the NCCE website’s resources page. It should be included in future CPD courses for primary and secondary school teachers. Teachers can promote inclusivity in computer science education and inspire a new generation of diverse and socially conscious computing professionals.

Teachers can receive targeted training on effective CT teaching strategies through the Gender Insights (GI) programme to further develop computational thinking (CT) skills for all students. It is recommended that the positive impact reported by teachers during the GI programme be continued and expanded across all strands and school key stages. The GI programme includes four research themes and seven interventions to encourage young women to consider computing-related subjects as a possible future career path.

**Increasing Aspirations**

To close the gender gap in computing, practical steps must be taken to raise aspirations through confidence, attitudes, and perceptions. Furthermore, encouraging and supporting girls’ interest in computing, providing mentorship opportunities, and promoting female role models are all recommended.

**Competitions**

Consider computer science and broader STEM competitions to increase girls' participation in computer science. Although more research is needed to determine the impact of these competitions on students’ career interests, particularly with a gender focus, some studies have found positive results. For example, high levels of "perceived self-efficacy in cybersecurity tasks, rational decision-making style, and investigative interests" correlated with a higher likelihood of
young people later choosing a cybersecurity career (Dunn and Merkle, 2018). In addition, it has been found that competitions can positively impact girls' motivation and willingness to learn and improve their skills.

Models such as the BCSWomen Lovelace Colloquium and the NCWIT Aspirations in Computing Award can be considered to further support girls' persistence in computer science. These initiatives have fostered a sense of belonging in the field and provided a forum for students to share ideas, be recognised for their contributions, network, and receive advice from women and non-binary people in academia and industry.

**Mentoring**

Mentoring programmes, particularly those led by peers and role models, can significantly boost girls' interest, self-efficacy, and success in computer science. It is recommended that STEM Ambassadors and other workplace volunteers receive more appropriate training to provide equal support and engagement to all students to address the gender imbalance in robotics and computer science competitions and employer engagements. The study by Sullivan and Bers (2019) emphasises the importance of increased inclusivity and support for female students in technical abilities and construction tasks. As a result, providing enhanced gender-sensitive training to volunteers can help raise their awareness of gender biases and provide them with strategies to engage all students equally.

**Enrichment**

Summer camps, programming workshops, and outreach programmes can help to close the gender gap in computing education. They can boost female confidence, interest, and motivation in computing careers. Teachers and educators should normalise girls’ participation and set conservative expectations for attitudinal change to achieve long-term effects. Recruitment strategies aimed at girls, the introduction of playfulness with technology, and the promotion of family support are also critical.

**Physical Computing**

Explore ways to support teachers in incorporating physical computing into the computing curriculum and enrichment activities. This can enhance girls’ computer science self-efficacy and engagement.

**Employer Engagement**

Encourage schools to access and participate in the STEM Ambassador programme and industry initiatives that encourage girls to pursue careers in computer science by connecting classroom
learning with potential careers and future opportunities. It is critical to provide clear guidance and training for teachers and employer representatives to maximise their impact.

It is recommended that ‘I Belong’ champions, senior leaders, and computing teachers be supported in selecting effective initiatives to promote and increase the participation of girls and women in computing education. A mapping exercise nationwide to identify existing initiatives and quality-assured collaborations can populate a resource library of programmes offered by leading providers such as academia, industry, and government. Furthermore, organisations should share publicly available evaluation data to provide meaningful evidence of the programme and initiative's long-term impact. Finally, cross-referencing these initiatives to the literature in this review will aid in determining their efficacy and ensuring that the most effective initiatives to increase the participation of girls and women in computing education are chosen.
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