Section 1:
Computing in context

Factors that impact gender balance in computing

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Raspberry Pi

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Abstract

The use of digital technology is pervasive in almost every part of our lives, and careers which require advanced computing skills are amongst the fastest-growing sectors globally. Learning computer science and digital skills offers young people the opportunity of a career in a flourishing sector, yet a lack of gender equity has been identified as a consistent and enduring issue which prevents girls from fully participating in these opportunities. In this short paper, I briefly review what we have learned to date from the literature on gender balance in computing education and outline some of the key barriers to full participation across genders: sense of belonging, relevance to self, and attitudes to technology. The use of collaborative teaching approaches to facilitate engagement and increase gender balance is also highlighted.

Introduction

A lack of gender equity in the uptake of both computing and wider STEM subjects has been identified as a consistent and enduring issue (Royal Society, 2017). There has been a considerable amount of literature published in the last twenty years that aims to explain why so few girls choose computing and then outline theories or interventions that could make a change to the current educational landscape. In this paper I reviewed the literature in this area to identify key factors that influence gender balance in computing.

The literature review was conducted with a search for terms relating to gender balance in computing to inform the implementation of the interventions with the most up-to-date evidence. In order to use robust and rigorous findings, only peer-reviewed journal papers or published conference proceedings were included. The ACM digital library (dl.acm.org) was selected as the primary database for the search. The scope of the literature survey was research published from January 1995 to June 2020, and included studies which showed the potential to transfer from STEM subjects to computing. Research conducted with university undergraduates as well as primary and secondary (K-12) pupils were included to identify any emerging findings in higher education which had the potential to be explored with younger cohorts.

Throughout this report, the term 'gender' is used as in the following definition: “either of the two sexes (male and female), especially when considered with reference to social and cultural differences rather than biological ones. The term is also used more broadly to denote a range of identities that do not correspond to established ideas of male and female” (Lexico, 2021, para 1).

Attitudes

Many studies have identified gender differences between learners in their attitudes towards computing. These attitudes include beliefs about the type of person who achieves well in computing, perceptions about the specialist nature of the subject content, and opinions about the potential for using computing skills in future careers. In this review, the connections between attitudes and subject choice will be explored first, followed by a more detailed consideration of the causes and impact of gender differences in attitudes towards computing.

Learners' attitudes are defined as the evaluative judgements which they hold about a curriculum subject, whether these be positive or negative, strong or weak, and formed from thoughts, feelings, or prior experiences (Maio & Haddock, 2009). There are a number of theoretical frameworks that can be used to understand students' attitudes towards computing and how likely they are to persist in the discipline (Denner & Campe, 2018). For example, expectancy-value theory (Eccles et al., 1998) suggests that subject choice and career goals are affected by the perceptions that an individual has of parents' and society's attitudes towards the subject. If a female student does not perceive the subject or career to be valued by others, she is less likely to value it herself and may focus time and energy on other subjects which are more highly valued. Both expectancy-value theory and social cognitive career theory (Lent et al., 2008) also highlight the role of a student's expectations of success or 'self-efficacy' (Bandura, 1999) on their persistence in computing: students are more likely to choose computing if they believe they will succeed and if they have a sense of support from those around them (Lent et al., 2008). The theories highlight the importance of interventions focusing on a range of individual, environmental, and societal factors to improve the gender balance in computing.

Attitudes towards a subject can be seen as a precursor to learners' motivation to succeed in them, and this has been notable in the work of Cheryan et al. (2009) who showed that when students held a positive attitude towards computing, they were more likely to be motivated to participate in further computing study. Wider research in STEM subjects has also shown that pupils' attitudes play an important part in shaping educational choices. Else-Quest et al. (2013) found significant gender differences in attitude towards mathematics which were also an accurate predictor of education-related choices. They suggested that the lower self-concept reported by girls in mathematics would reduce the chance of them choosing it for further study because they did not believe that they would achieve well. In the context of computing study, Goode et al. (2018) examined similar connections with high school computer science pupils (aged 14 to 18). Through the use of data drawn from qualitative case studies, they suggested that female students experienced an accumulation of negative experiences in computing classes. They cited examples such as lack of contextual information to link computing to the real world and pedagogy without a higher-order thinking focus which had affected girls' attitudes towards computing in an unfavourable way.

There is a clear need to examine more closely which factors influence female pupils when they form opinions about a subject and to identify possible interventions which will either augment existing positive connotations about computing or change attitudes towards the subject by illuminating new possibilities.

Do I belong?

Girls' interest and motivation in STEM subjects can be predicted by their sense of belonging in the subject. When students attend classes in subjects they have chosen to study, they create a group, or community, who are working towards a common goal to achieve a formal qualification in that subject. Evidence suggests that a sense of belonging develops from both the extent to which girls feel that they fit into the community and also how they perceive that they are valued and accepted by other members of the community (Good et al., 2012). In the workplace, women's sense of belonging to computing as a career is affected by the effort they perceive they need to exert in order to succeed. Smith et al. (2013) found that women who worked in STEM subjects thought that they would have to expend more effort than others to do well and suggested that this may affect the extent to which women feel that they belong in the STEM field of careers. Some girls face barriers to taking part in computing because they feel that they do not belong there and this can be improved.

Research into increasing girls' sense of belonging often draws on theories from the field of psychology. An example of this is self-determination theory (SDT), which suggests that students have three basic needs in order to sustain motivation and persistence in any given subject: competency, autonomy, and relatedness. Mishkin (2019) applied SDT to female high school computing students (aged 14 to 18) and found that of the three needs, the feeling of being related to others was the most important condition for girls' motivation to study computing, and that a sense of belonging was a significant predictor of their motivation. This reinforces the idea that although girls typically achieve well in computing, they do not choose to study it because they see themselves as isolated or unwelcome amongst other computing students.

This need for a sense of belonging can be problematic for gender balance in computing because it creates a repetitive cycle of female inequity. Girls and women do not see themselves represented in the field and are therefore not motivated to pursue it, which then perpetuates the lack of representation and means that future generations do not feel that they fit into the community either. One way of breaking this cycle is to explicitly call out existing representations of female computing students or women in computing careers as role models for the next generation. The term 'role model' is generally used to describe an individual who displays behaviour, attitudes, or achievements that can be emulated by others.

The literature survey revealed considerable variation amongst studies about the use of computing role models. Black et al. (2011) distributed a booklet containing the stories of successful women in computing to secondary school pupils in order to inspire and encourage female students to consider computing as a career. Role models in this study were presented as people with achievements that could be admired and followed. This approach contrasts markedly with research conducted by Townsend (1996), who created videos describing the journey of female undergraduates including how they had juggled childcare responsibilities and overcome fears or adversity to achieve success. In this way, the attitudes, behaviours, and achievements of the role models were presented together as a coherent whole. It is difficult to draw any conclusions on whether one approach was more effective than the other, as the studies lacked any commonality in measuring their outcomes. Black et al. (2011) used a mixed-methods approach based on qualitative access figures and quantitative teacher feedback, whereas Townsend (1996) used quantitative data sampled from undergraduate students to compare between a control and treatment group. The variety of evaluation methods used highlights the importance of careful trial design in order to effectively and confidently measure the impact of an intervention.

A variety of places to find role models was also highlighted in the literature. A common theme was to introduce a gender-balanced group of undergraduate students to primary and secondary pupils, either to teach computing lessons or to speak about their experiences. Such an approach was found to help pupils perceive computing as a subject that was equally difficult for girls as well as boys (Zaidi et al., 2017) and to increase girls' self-efficacy in computing (Lang, et al., 2010). This approach was tested on a small scale due to the logistical practicalities of matching students with classrooms in both studies. It contrasts with the larger-scale research conducted by Black et al. (2011) which drew on role models from history, workplaces, and classrooms, as well as first-person accounts to create a booklet for mass distribution. As mentioned previously, the variety of research design, tools, and instruments in these studies means it is difficult to draw any conclusions about whether any approach was more effective than another. Further research could provide insight into this through the use of a scalable trial design and a reliable, validated evaluation instrument.

Young people choose their own role models; teachers cannot choose role models for them. There is also a gender difference to take into account, wherein female students choose role models with a higher number of self-perceived likenesses to themselves than male students do (Wohlford et al., 2004). It was notable that self-esteem was also a predictor of female students' chosen role models. This suggests that some high-achieving role models may provide the opposite effect from that which was intended, and deter girls from emulating the individual because they feel that the achievements are too far out of reach. At the other extreme, if girls select role models based on perceived likeness, they may focus on the people around them, such as friends and family, and this may not provide them with any examples of women in computing at all.

There have been investigations in other STEM subjects relating to the influence of role models on girls' attitudes towards the subject. One very recent study looks at the effects of a role-model intervention in maths with girls aged 12 to 16 years old. It links to Eccles' (1998) expectancy-value theory to measure the effect that the intervention had on girls' personal enjoyment of maths and the importance they attached to maths. The intervention provided a significant increase in both enjoyment and importance, and the authors concluded that it was important to introduce such interventions at a relatively young age before pupils begin to make specialist academic choices (Gonzalez et al., 2020).

Children and young people are also influenced by parents and other family members when they make choices. Eccles' (1998) expectancy-value theory also states that young people's attitudes towards a subject are influenced by their perceptions of the values their parents have about that subject. Where parents are seen to support their children's choices in computing, girls are more likely to express interest in computing as a career (Creamer et al., 2004; Denner, 2011). Some parents may hold less traditional attitudes about gender roles and have daughters who are more likely to pursue nontraditional careers such as computing (Chhin et al., 2008). There is room to further explore the role that parental encouragement plays based on evidence which suggests that interventions based on positive messaging from parents show a positive influence on their children's attitudes (Kraft & Rogers, 2014).

There is still some ambiguity in the literature around the effects that role-model interventions and parental encouragement have on girls' attitudes towards computing. Although studies have provided evidence of their effectiveness on a small scale with innovative approaches, there are still questions to be addressed around both intervention design and trial methodology. Future research could explore the impact of parental encouragement and the impact of introducing role models on girls' sense of belonging in computing.

Relevance to me

The use of technology is pervasive in almost every aspect of our daily lives. This provides opportunities for educators to show how studying computing can be relevant for many jobs and careers and, specifically, how learning computer science skills can be applied to everyday situations. Learning to program then moves away from acquiring the skills to write code towards the ability to be able to create authentic applications such as games, stories, and mobile phone apps that can be used outside of the classroom in the real world (Kafai & Burke, 2013).

Computer science can be perceived as a very abstract subject, in which there is a great deal to learn about programming concepts in order to use them to efficiently write code. However, Fisher and Margolis (2003) identified that the contexts in which computer science skills can be used are important for female students. Through a series of longitudinal surveys, they observed gender differences in students' motivations for studying computer science at university. Female undergraduates were much more likely to identify links between their learning and other disciplines, whereas male students were more invested in the value of computer science as a subject in itself. Subsequent studies have drawn on this finding to explore a variety of different ways to introduce real-world contexts into computing lessons.

Four principles were proposed by Guzdial and Tew (2006) to contextualise computing so that students could connect their learning to their prior experiences and future expectations:

1. Learning activities were aligned with real-world scenarios
2. Topics were aligned with students' own interests
3. Assessments were aligned with the material which had been taught
4. The methods of inquiry used in the classroom were aligned with professional standards in the workplace

The first and second of these principles were applied to two introductory programming modules for undergraduates which situated learning to program in the contexts of media manipulation and computer-generated animation sequences. Guzdial and Tew (2006) hypothesised that students would perceive the course to be of value because of the explicit links to real-world scenarios. Although they did not specifically set out to create a learning experience which would appeal to female students, it is notable that when averaged out over several presentations of the modules, 51% of students were female, which reinforces the findings from Fisher and Margolis (2003).

Subsequent studies have explored further ways that computing can be made relevant by introducing the idea that computing is a tool for bringing societal benefits to others. Dewitt et al. (2017) built upon the links between programming and media generation in a project for boys and girls at a summer camp, where they were tasked with creating a piece of artwork to address a social issue. This led to a positive increase in attitudes towards computing amongst both boys and girls. This finding seems to contrast with a study that compared university student opinions about humanitarian contexts, practical contexts, and games-based contexts in computer science courses (Rader et al., 2011). When asked to rank assignments in order of preference, students preferred assignments using games-based contexts. However, the authors do acknowledge the very low number of female students amongst the respondents and so greater value may be found in Rader et al.'s (2011) finding that 79% of students expressed a positive opinion about programming assignments which showed how computer science could benefit society.

Finally, computing is not just relevant in social contexts. Franklin et al. (2011) explored how learning to program could be made culturally-relevant for middle school students in the US. Using the theme of Animal Tlatoque, they successfully recruited a group of students who were previously unengaged in computer science, and subsequently found that this small group (n=34) became more interested in computing as a career and were more likely to view computing as a subject for girls.

The variety of approaches taken within the literature towards defining relevant computing contexts is perhaps indicative of the lack of depth in computer science education research to date. It is entirely plausible that in order to situate learning about computing in a relevant way to interest girls, an approach which draws upon the deeper insights from research into other STEM subjects is needed. Lyons (2006) recommended that science curricula were more likely to interest girls if they provided opportunities for genuine inquiry, involved real-world experience and integrated social and scientific issues, as well as opportunities for experimentation, practice, reflection, and conceptualisation. Thinking about computing, the relevance of the subject in society and the opportunity to apply computing skills to solve real-world problems need to be carefully embedded within a curriculum so that girls can see that computer science has many potential applications in future study and careers.

Learning together

An emerging body of evidence suggests that collaborative teaching approaches can engage more girls with computing. This is of particular interest when learning to write computer programs, which can be seen as the most difficult section of the computing curriculum for learners (Kallia & Sentance, 2018). Introducing a shared, group approach requires a shift from traditional computing pedagogy. Learning to code changes from a series of tasks undertaken by individuals, to a sociocultural experience in which students work together to create and share digital content (Kafai & Burke, 2013). The initial inspection of the research and subsequent literature survey found evidence to support two collaborative teaching approaches in learning to program which merited further investigation: pair programming and peer instruction.

Pair programming

The idea of writing computer programs in pairs has been directly drawn from industry, where colleagues often work in partnership to write and review code in order to maximise the quality and design of a program (McDowell et al., 2006). Transferring a workplace practice into a classroom teaching approach offers pupils an authentic experience of real-world programming. The idea of paired work is commonly used in many other subjects, where pupils discuss ideas or contribute towards a shared piece of work. Pair programming differs from other paired work as it has a defined structure. In pair programming, one student takes the role of ‘driver’ and has control of the keyboard and mouse to write the code. The other student is the ‘navigator’ who reads out the instructions and monitors the code for errors (McDowell et al., 2006). The teacher’s role includes training the students in successful pair interactions and ensuring the pairs rotate after a given time so that each student experiences both roles. The success of pair interactions is actively managed by the teacher as well as being evaluated by the pairs themselves (Williams et al., 2008).

Werner et al. (2004) advocated for the use of pair programming in introductory university programming courses based on their findings that collaborative work had a positive impact on female students’ perceptions of computing as a subject for further study. Pair programming has been shown to improve student confidence and have a positive impact on student retention in computing and has also demonstrated that the quality of programs written in pairs is significantly higher than those written individually in an introductory undergraduate course (McDowell et al., 2006). Similar findings in K-12 (primary and secondary) environments demonstrated that pair programming generally increased pupil attitudes and confidence towards computing (Denner et al., 2014). This suggests that using pair programming has potential to be used as an inclusive pedagogy to benefit girls' perceptions of computing, whilst also supporting all learners to develop skills and knowledge of programming concepts.

Further research has explored different approaches to pairing pupils along with how those pairs might affect the interactions which take place between partners. A small-scale study from Tsan et al. (2016) suggested that by the age of 11, all-female pairings were producing significantly lower program quality than mixed or all-boy pairs. However, this study was limited in focus and only assessed the quality of the completed artefact rather than pedagogy required to promote high-quality outcomes. Ruvalcaba et al. (2016) noted that ethnicity of pairs may affect the types of interaction between pairs, with Latina/o students more likely to use non-verbal communication signals to interact with their partner whereas white and mixed student pairs relied more on verbal communication to check understanding. Both studies indicate that pair programming requires careful training of teachers to ensure that the whole pedagogy is understood and applied, without bias.

The use of pair programming as a teaching approach in schools is likely to appeal to girls, and make them more likely to both choose a subject and achieve well in it. Further research can help strengthen the evidence of how to effectively pair pupils, provide guidance to teachers on the characteristics of successful pairings, and demonstrate the value of this pedagogy within the specific context of the English school system.

Peer instruction

The idea of working together with peers to build knowledge has been explored in the literature relating to both computing and wider STEM subjects.

Peer instruction is an approach which was developed by Mazur (1997) through a series of studies conducted with physics undergraduates. In these studies, peer instruction was positioned as a pedagogy to help students understand difficult concepts through classroom interaction. Lessons were structured around a series of multiple choice questions (MCQs) which the teacher could devise to stimulate discussion around physics concepts. These concepts would be first of all introduced using an instructor-led presentation, followed by a series of MCQs which students could answer with electronic clickers or flashcards (Vickrey et al., 2015). The instructor assessed the understanding of the class through the MCQ scores and chose to briefly recap the answer if a large proportion of class understood, or else to initiate paired or group discussion of the question so that students could evaluate the options presented and work out which one was correct together (Watkins & Mazur, 2013).

Watkins and Mazur (2013) highlighted that the use of peer instruction in introductory STEM courses led to increased retention of students in STEM disciplines during subsequent intermediate and advanced courses. The authors proposed several reasons for this improvement. First, the pedagogy included inherent formative assessment and so instructors were better able to adapt their teaching to meet student needs. Secondly, students responded well to the opportunity to interact and discuss with their peers, and developed their fluency in explaining scientific concepts. Finally, an additional outcome was to increase student self-efficacy, which promoted a positive attitude towards further study of STEM courses. A separate study conducted in an introductory physics course at Harvard University investigated the effect of peer instruction on student achievement (Lorenzo et al., 2006). An intervention which used peer instruction was delivered to 1,048 physics students and was evaluated qualitatively using pre- and post-tests. A statistically significant gender gap in the pre-instruction test scores was reported following the intervention, and Lorenzo et al. (2006) attributed this to the interactive and collaborative nature of the teaching approach which helped to create a classroom environment that supported both genders.

Although research on collaborative teaching approaches and gender balance is as yet limited, the research to date signals this as a worthwhile area to explore further.

Discussion

The literature discussed here describes an accumulation of historical, social, and cultural barriers faced by girls in the computing classroom which have developed alongside the growth of computing as a subject in schools.

The concept of an incredible shrinking pipeline (Camp, 2002) has been used to describe the decreasing number of girls involved in each stage of computing education. However, it has been noted that there are too few girls entering the pipeline of computing qualifications initially, and so it would seem insufficient to direct efforts into research that aims to retain female students from GCSE through to A level and beyond. This report recommends building on research which presents computing as an equitable subject that is relevant, applicable, and achievable to all pupils, regardless of gender. Because pupils make subject choices in England at the relatively young age of 14, a range of interventions in both primary and secondary phases are suggested in order to present computing as a subject where girls can succeed.

This review has underlined the importance of girls' attitudes towards computing and their motivations for studying the subject. As with other STEM subjects, computing has acquired an image of being a subject which is taken by 'geeky' students to be used in a very specialist way in jobs and careers (Creamer et al., 2004). Whereas other sciences have had to unpick layers of inequity which have built up over decades, computing is a relatively young subject and this offers the opportunity to identify robust changes which can be made rapidly to alter the gender imbalance currently seen in the subject.

It has been highlighted that the sociocultural context of learning computing appears to play an important role in shaping girls' attitudes (Denner, 2011; Kafai & Burke, 2013). Underpinning research with learning science theories relating to attitudes, beliefs, and motivation can provide a rigorous approach to measuring changes in attitude. Much of the initial work to explore girls' attitudes towards computing and identify the obstacles which prevent them from participating in the field has been conducted in the US (e.g. Fisher & Margolis, 2003) where girls are similarly underrepresented in computing study and careers.

What next?

The Gender Balance in Computing project has been funded by the Department for Education in England from 2019 to 2022 to examine the key factors affecting pupil attitudes towards computing early in their education, and to identify promising approaches which have the potential to be delivered at scale in a wide variety of educational settings, through a series of randomised-controlled trials. More information can be found at https://teachcomputing.org/gender-balance. The results from this project promise to add to our understanding of what specific actions we can take to address the factors identified here.

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