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Female computer science students: A qualitative exploration of women's experiences studying computer science at university in the UK

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Abstract
The under-representation of w omen in computer science education courses is well documented, and the social and commercial need to address this is widely recognised. Previous literature offers some explanation for this gender imbalance, but there has been limited qualitative data to provide an in-depth understanding of existing quantitative findings. This study explores the lived experiences of female computer science students and how they experience the male dominated learning environment. Female computer science students from eight universities were interviewed ($n=23$) and data were analysed using template analysis. Whilst these women have not been troubled by their sense of fit at university, a combination of stereotypical assumptions of male superiority in this field, and a masculine, agentic learning environment, has left them feeling less technologically capable and less motivated. The findings are discussed in terms of Cheryan et al.'s tripartite model for women's participation in STEM (2017) and we recommend that computer science departments should consider feminist pedagogy to ensure that all learners can be well supported.

Keywords Computer science students · Occupational fit · STEM gender imbalance · Agentic learners · Communal learners

1 Introduction

Women are in short supply in the computer science classroom. In the UK in 2017, women or girls made up 21% of secondary school pupils (aged 11- 16), 14.5% of college level students (aged 16–18), and 19% of university undergraduates studying computer science (Higher Education Statistics Agency, 2018; Joint Council for

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Qualifications, 2018). The trend continues beyond education and into the technology industry: only 12% of British software engineers are female (Office for National Statistics, 2019) and this proportion is in decline (WISE, 2017).

The topic has garnered widespread attention over the last decades, and efforts have been made within research, policy and practice to understand and solve the problem. There have been numerous attempts by the UK government, schools and the industry to improve the representation of women in STEM-related fields (science, technology, engineering and maths) more generally, but they have had limited success, particularly within the field of technology. The proportion of women studying and working in the field has not increased, and as Sinclair and Kalvala (2015) state, "large amounts of money are still being spent on getting it totally wrong" (p. 107).

Traditional arguments to explain the under-representation of women in the technology industry are that women lack the natural ability and the interest to pursue studies and jobs in this field (Ceci et al., 2009; Gelernter, 1999). Yet numerous studies call these assumptions into question. The difference in computer and maths ability between girls and boys, or women and men, has been shown to be minimal or non-existent (e.g., Else-Quest et al., 2010). In terms of attainment too, girls and women are more than holding their own, out-performing their male counterparts both at school (WISE, 2017) and university (Woodfield, 2012). Yet many of these mathematically adept women do not pursue careers in the most technical roles within the sector despite high salaries in these fields. Ceci et al. (2009) identified a lack of interest as the main barrier in their review of the reasons for the under-representation of women in maths-intensive fields. However, their review did not explore the reasons for women's lack of interest, and failed to consider the impact of wider society and structures (Cheryan et al., 2017; Sen, 1992).

The efforts made to understand and recalibrate the gender imbalance in the field of technology have not succeeded in making a significant or sustained change, and further research is needed to uncover the causes and identify solutions. The present study aims to make a contribution to this, investigating women's experiences of studying computer science at university in order to better understand the reasons behind some female computer scientists' disengagement with the field.

Explanatory frameworks which focus on the experiences of computer science students are scarce. In a review paper, Cheryan et al. (2017) examined women's participation in STEM fields and developed a model to explain why some STEM disciplines (biological or bSTEM fields such as medicine and biology) have a more equal gender balance than others (physical or pSTEM fields such as computer science and physics). Although it does not focus exclusively on technology, the framework is highly relevant to this research and therefore forms the theoretical foundation for this study.

2 Theoretical framework

Cheryan et al.'s model (Cheryan et al., 2017) has three elements, which combine and interact to make certain fields unattractive or inhospitable for women: a) the masculine culture of these fields, b) the lack of early exposure for women, and c) women's lack of belief in their ability to succeed. The model does not aim to offer a comprehensive overview of the experiences of women in these fields, and there are some aspects of women's experiences in STEM which are not given consideration in the framework. The framework for example does not cover the experiences of everyday sexism, micro aggressions and sexual harassment that women in STEM fields report (Ayre et al., 2013; Fouad et al., 2011), nor women's struggle to see how to best navigate their careers within STEM fields (Buse et al., 2013; Fouad et al., 2016; Yates & Skinner, 2021), all of which might be thought to contribute to an environment that is unwelcoming or hostile to women. The model nevertheless provides a useful structure to help to explore the topic and will be used here as a guideline for a review of the literature.

2.1 The masculine culture

The notion of a 'gendered organisation' (Acker, 1990) has made a contribution to our understanding of women's experiences in STEM organisations and the barriers they face to career progression (Yates & Skinner, 2021). The term refers to organisational cultures which purport to being fair and meritocratic, assuming that all employees are held to the same standards and given the same opportunities, but which, in reality, favour men, through standards which are easier for men to reach and opportunities which are better suited to men. A 'gendered classroom' (Dingel, 2006; Leyva et al., 2021) extends this idea, referring to a classroom which is assumed to be gender-neutral but which is in reality tailored towards male students. The idea of the gendered classroom has not been widely applied to computer science education, but existing literature suggests that this might be a useful lens through which to understand the experiences of female computer science students.

Women are shown to be more likely to be motivated by communal goals and men by agentic goals, so a pedagogical style or a learning environment which appeals to agentic learners and which is unappealing to communal learners, favours male students (Bakan, 1966; Eagly et al., 2000; Riegle-Crumb et al., 2019). Those motivated by communal goals are drawn to supportive relationships and collaboration and want to see a pro-social purpose to their endeavours. Those motivated by agentic goals are spurred on by competition, enjoy autonomy and independence, and are motivated to learn for the interest in the topic. Women and girls tend to prefer more communal learning environments (Brotman & Moore, 2008), characterised by supportive relationships (Meyers-Levy & Loken, 2015; Tamres et al., 2002), with clear guidance from tutors (Aylor, 2003; Frymier & Houser, 2000; Menekse et al., 2020), and where the curriculum is made explicitly meaningful (Giannakos et al., 2017).

These communal needs, more often desired by women, may not always be well met in the typical computer science classroom. STEM careers have been linked with more agentic goals (Diekman et al., 2010) and self-directed learning is a core skill that is desirable within the technology industry (Zander et al., 2012). Computer science courses therefore tend to foster agentic goals, with an explicit focus on autonomy, independence and self-directed learning (McCartney et al., 2016; Thomas, 2013). Competitiveness, another aspect of an agentic self, is prevalent in STEM classrooms, where individuals strive to demonstrate their superiority through intense work and long hours (Hirshfield, 2010, 2015; Sallee, 2011).

Research from the US which has explored the environment of the computer science classroom adds weight to the idea that computer science classrooms provide limited support for communal learners. Barker and Garvin-Doxas (2004) in a major observation study in a computer science classroom found evidence of an impersonal and guarded environment and the formation of informal hierarchies which led to competitive behaviour from the students (Barker & Garvin-Doxas, 2004; Barker et al., 2014; Garvin-Doxas & Barker, 2004; Östberg, 2003). They identified certain types of discourse which hindered the development of a supportive and collaborative culture within the classroom, and described a strongly defensive climate, in which trust was low, and students did not feel safe to make mistakes without risking humiliation.

One final factor that may contribute to an inhospitable environment for women in the computer science classroom comes from stereotypes: women and girls may feel that they are different from their own and others' perceptions of a typical computer scientist, and this can have an impact on their feelings of belonging and on their choices. Stereotypical computer scientists (which do, to some degree, reflect the reality; Beyer, 2014) are male, clever, and obsessed with coding (Cheryan et al., 2009; Margolis et al., 2000), and according to stereotypes, girls are not as good as boys at maths and technical subjects (Park et al., 2011). These stereotypes are held by girls, boys, parents, teachers and employers (Dickhäuser & Meyer, 2006; Vekiri, 2013), are entrenched from an early age (Master et al., 2017), and could make girls and women feel that they will not fit in with colleagues, or be successful in the field of technology. Stereotype threat has also been shown in this field to have a negative impact on performance (Kumar, 2012) and these stereotypes have been shown to have an impact on levels of interest in some STEM subjects (Cech et al., 2011 [engineering]; Cundiff et al., 2013 [science]) and on girls' choices to study computer science or not at high school in the US (Master et al., 2016).

2.2 Early exposure to computer science

The second element of Cheryan et al.'s (2017) model is the lack of early exposure to the field. Many children become familiar with computers through games they play as children, but with many games characterised by their repetitive shooting, loud noises and violent graphics, computer games are in large parts aimed at and played by boys (Hartmann & Klimmt, 2006; Lenhart et al., 2015; Ohannessian, 2015). Recent evidence indicates that boys and girls spend similar amounts of time on screens throughout their adolescence but the nature of their engagement with technology is different: boys spend significantly more time playing video games and girls spend more time interacting with their friends on social media sites (Mullan, 2018). These differences have been shown to have an impact on career decisions, as evidence suggests that computer gaming is a significant positive predictor of interest and confidence in studying computer science (Sevin & DeCamp, 2016).

This lack of early exposure has an impact. Girls who have been fortunate enough to have a greater degree of early exposure develop more computer self-efficacy (Correll, 2001; He & Freeman, 2010; Master et al., 2017), and have more positive stereotypes associated with technology jobs (Cheryan et al., 2013). There is evidence that countries which have more compulsory STEM coursework also have a better gender balance in STEM jobs (Charles & Bradley, 2009).

2.3 Gender differences in self-efficacy

Cheryan et al.'s final explanation for the under-representation of women in pSTEM fields is their lower levels of computer self-efficacy. This trait has been widely examined, and Gürer and Camp (2002) in their review of the evidence suggest that this lack of confidence in their ability to accomplish computer-related tasks is the single most influential factor in the under-representation of women in computer science. Despite evidence that men and women tend to perform equally well in computer courses (Beyer, 1999, 2008; Georgiou et al., 2007), women consistently rate their own computer ability as lower than men rate theirs (Lehman et al., 2016). This discrepancy is the result both of women underestimating their own ability (Beyer, 2008) and men overestimating theirs (Bench et al., 2015). Women's lack of belief in their abilities has been shown to have an impact on their career plans (Beyer, 2014; Dempsey et al., 2015; Rosson et al., 2011), expectations of success in the technology industry (Appianing & Van Eck, 2015), the development of occupational identity (Carlone & Johnson, 2007; Dempsey et al., 2015), intention to study IT (information technology) at school (Sáinz & Eccles, 2012), and interest in the field (Margolis et al., 2000).

3 Improving women's experiences in higher education

Many approaches have attempted to change the under-representation of women in computer science and other pSTEM fields, with mixed success. One successful strand of interventions has focused on relationships in the classroom. Encouragement from teachers (Dingel, 2006), lecturers (Beyer, 2014) and peers (Barker et al., 2009; Werner et al., 2013) increases both male and female students' likelihood to choose and persist with computer science courses. The pedagogical technique of 'peer programming', in which students are paired up, two students to one computer, taking turns at the keyboard, to collaborate on coding, has proved to be a positive experience for female students, and has produced higher standards of coding (Bowman et al., 2020; Ying et al., 2019). All women computer classes have been shown to lead to increased levels of comfort, connections and confidence for students (Ying et al., 2021). Other initiatives have focused on increasing the number of visible role models, although these have not always been wholly successful (Drury et al., 2011; Price, 2010). Opportunities, such as scholarships or internships which are open exclusively to women, have also not met with unqualified support as women often prefer to succeed on their own merit (Sinclair & Kalvala, 2015).

One positive case study comes from Carnegie Mellon University (CMU), in Pittsburgh, Pennsylvania in the US (Blum & Frieze, 2005; Frieze & Blum, 2002; Frieze & Quesenberry, 2019; Margolis & Fisher, 2002). The CMU computer science department has shifted to a more balanced culture (in terms of gender, breadth of student personalities and professional support for women) which encourages contributions from and a sense of belonging for women students. Their success began with a change in admissions policy as they broadened their selection criteria to focus on criteria that would select for future leaders which led to an increase in the number of women admitted, and men with a wider range of characteristics.

CMU were clear that they wanted to avoid developing a 'female-friendly curriculum' (Frieze et al., 2012, p.5) but elsewhere institutions have embraced the idea of feminist pedagogy (Shrewsbury, 1993; Weiler, 1991) which fuses feminist principles within the process of teaching. Whilst traditional patriarchal pedagogies rely on the paternal 'expert' model, feminists see that knowledge is never value-free and choices are made as to what to include in any curriculum. In contrast to the traditional model which suggests a single reality and therefore silences and disempowers many learners, feminist pedagogy focuses on the idea of working together in a collaborative community, within a respectful and reflective culture, underpinned by the three central concepts of community, empowerment and leadership.

Successful examples of feminist pedagogy include separate streams for experienced and inexperienced students, access to female teaching assistants and female peer networks (Hafner, 2012; Miller, 2015; Ramsey et al., 2013), but one of the most widely reported success stories comes from Harvey Mudd College (HMC) in California in the US, where significant changes were made to the way computer science was taught in the early 2000s (Barker et al., 2014). Before these changes to the curriculum were made, the culture in the computer science classroom at HMC had been described as one in which '*The outspoken ones [students] were framing the classroom environment as a competitive arena for demonstrating prowess rather than a laboratory for exploring ideas*' (2014, p.4). HMC introduced a Socratic dialogue-based approach to teaching in which students are expected to reach the answers themselves, supported by the faculty, who are described as laying out a trail of breadcrumbs to guide the students to the answers. The new approach aims to use questions as a chance for students to explore ideas and develop deep understanding, rather than as an opportunity for certain confident students to demonstrate previous learning, and the teaching staff welcome wrong answers in class as positive pedagogic opportunities. Staff also offer additional support for students through office hours and feedback from tests. Retention of women and satisfaction have increased significantly since the new style has been adopted.

The impact of this new pedagogical approach at HMC is impressive, but the nature of the college and the structure of the curriculum are quite different from those offered at most higher education institutions in the UK. HMC is an engineering, science and maths college, but students who take this transformed computer science class have not yet chosen a computer science major, nor have they been accepted onto one, and the computing class is compulsory for all students. Students on comparable programmes in the UK have already committed to and been selected for a specialist computer science degree, and have deliberately elected to do a computer science course. Another difference lies in the even gender balance at HMC, where women make up 49.8% of undergraduates (HMC, 2021). In the UK the proportion of women studying computer science is 19% (Stem Women, 2021). Their experiences are therefore not wholly comparable, and there remains a need for further qualitative exploration of the experiences of women studying on computer science courses in Higher Education in the UK.

4 The present study

Our understanding of the reasons behind women's under-representation in computer science has developed significantly over the past decades, but gaps still remain. The lack of sustained success from the initiatives aiming to redress the gender balance suggests that we still need to learn more, and research is needed from educational systems across the globe. Although Cheryan et al. (2017) offer a useful explanatory framework to account for the experiences of women in pSTEM fields, it does not focus specifically on women studying computer science. In a comprehensive review of the state of research on women in STEM in higher education in the US, Blackburn (2017) calls for more studies which focus on the holistic lived experiences of female students and this has been echoed elsewhere (Riegle-Crumb et al., 2019; Sinclair & Kalvala, 2015; Sinclair et al., 2015). In particular, there seems to be very little research that explores the culture of the computer science classroom in the UK.

The present study aims to address some of these gaps by delving deeper to investigate the lived experiences of female computer science students in the UK. Previous research in this field has tended to use quantitative methods, making use of data from surveys, underpinned by positivist assumptions. We argue that in addition to the insights from the measurable quantitative data, the experiences of the participants should be explored through qualitative methods, using qualitative data to complement existing quantitative data and generate new fruitful avenues for further enquiry.

Using Cheryan et al.'s model as an a priori coding template, this study aims to explore the lived experiences of female computer science students and find out how the three elements of the masculine culture, belonging and computer self-efficacy, are experienced by them. Specifically, we aim to answer the question: What are the experiences of female computer science students at university?

5 Method

5.1 Research design

This study is underpinned by interpretivism and phenomenology. Interpretative methodology assumes that reality and meaning are created within and through social interactions (Crotty, 1998). An interpretative researcher is interesting in exploring the ways that people make sense of their experiences – how they construct reality, how they interpret their experiences and make meaning out of them (Merriam & Grenier, 2019). The phenomenological position behind this study means it is concerned with lived experiences, in the case of this study with exploring the experiences of the female participants (Husserl, 1970).

5.2 Participants

Participants were recruited through purposeful sampling, and we sought to identify participants who were female, enrolled on computer science programmes and had been on their courses for at least one complete academic year. We contacted 24 programme directors across the UK, and directors from eight universities (UCL, Goldsmiths, City, St Andrews, Bristol, Glasgow, Queen Mary, and Sheffield) agreed to inform their students of our study; no incentives were offered. We were contacted by 23 students who met our criteria and who volunteered to be interviewed. Seven of the women were enrolled in an MSc programme and 16 in BSc courses. Of the undergraduate participants, five had finished their first year, four their second year and seven their final year (see list of participants, Table S1 in Supplementary Materials). The number of participants is within the recommended guidelines for template analysis (King, 2004) and for qualitative studies within work-related research more generally (Saunders & Townsend, 2016). The programmes were all based in well-established universities in the UK, six of which were prestigious, research-led institutions which attract high achieving students. The programmes attract a large number of applicants – most have over 200 students in a single year, and most offer a combination of learning environments, with traditional lectures most prominent.

5.3 Procedure

Ethical approval was obtained from [*blinded for review*] and an information sheet informed potential participants about the study. Informed consent was obtained from all participants. Interviews were semi-structured and lasted on average just under an hour. Interviews were conducted at [*blinded for review*] between July and September 2019 and were audio recorded and transcribed verbatim. The questions were kept deliberately open to ensure that we did not lead the participants, but allowed them to take the conversation in whichever direction they felt was most relevant. The interviewer (the first author) used open prompts to encourage the participants to give rich, full answers, such as *'Tell me more about that'*, *'how did that feel?'* and '*Is there anything else to add?*'. The participants were asked five main questions, intended to explore their experiences on the course generally and specifically in terms of the three themes from Cheryan et al.'s framework (2017): the masculine culture, early exposure and self-efficacy. To start the interview and to explore possible issues of early exposure, we asked '*What made you decide to study computer science?*'. Participants were invited to talk about their experiences in general terms with the question '*How has the course been for you so far?'*. We elicited data about the pedagogy and classroom environment asking *'How have you found the teaching and learning side of things?'* and *'How does it feel for you in the classroom?'*. To finish the interview and to give participants the opportunity to comment on their future plans we asked the participants '*What do you think you might do after you finish your course?'*. We did not ask explicitly about technological self-efficacy, but with prompts did invite the participants to comment on the impact of the experiences they described which often led to discussions about confidence. The data from 23 interviews fitted into the template themes developed in the final stages of analysis, so it was felt that the saturation point had been reached. The interviews were conducted and coded by the first author but the data and analyses were discussed in depth with the second author to strengthen reliability.

The data were analysed with a template analysis which is a form of thematic analysis (King, 2004). Thematic analysis is a set of procedures for analysing qualitative data, focused on identifying patterns of meaning. It is an umbrella term, incorporating a range of specific approaches. Template analysis emphasises hierarchical coding and its value lies in the way it balances a clear structure for the coding with flexibility, ensuring that it can offer a rigorous process which can best describe the data for each individual project. Template analysis, as with other forms of thematic analysis, is not wedded to a particular philosophical approach (Braun & Clarke, 2006; Brooks et al., 2015), but as a method of data analysis it can be used flexibly, in keeping with the particular epistemological stance of the researcher and the project. It is a flexible approach which allows the researcher to develop themes most extensively where the data is most rich allowing the analysis to capture details, and its use of a priori codes makes it particularly suitable for studies which are exploring existing theoretical concepts (Brooks et al., 2015). As such it was considered to be suitable for this study.

Within a template analysis, the researcher develops a template of codes based on a subset of the data or prior research. The codes are then revisited, refined and perhaps supplemented in the light of the analysis of the rest of the data set. The number of levels within the template hierarchy is not pre-set and the researcher is encouraged to develop a template of themes and sub-themes which fit the data.

The initial template was constructed based on the framework from Cheryan et al. (2017) and consisted of three a priori codes of the masculine environment, early exposure and self-efficacy. The first author then worked through the data, line by line, looking for text which could be relevant to each of the three codes. In accordance with King's suggested process for template analysis (King, 2004), the researcher examined words, phrases and ideas which could be helpful in understanding the women's experiences, and gave them codes. These codes were then grouped into meaningful clusters or themes and arranged within a hierarchy. Through this process, the template was refined. New codes were added, a priori codes deleted, labels were renamed, and hierarchical layers were inserted. Early exposure, for example, was one of the a priori codes, and there was plenty of new data to suggest that this theme made a contribution to explaining these women's experiences on computer science courses. Two lower order codes, linked to early exposure, were identified, as it became clear that early exposure to computers was useful both because it had allowed participants to see that studying computer science might be an option for them, and because it allowed them to see that coding might be fun. These two additional codes allowed for a richer description of the role and value of early exposure. A higher order code was then added, which positioned 'early exposure' alongside 'people who made it seem possible', as two sorts of experience that served as enablers, facilitating the women's choices to study computer science. No software package was used for data analysis as the data set was of a moderate size and we wanted to allow for a more flexible and creative coding process (John & Johnson, 2000). The template became clear and the questions saturated after three iterations.

A risk with template analysis is that researchers become somewhat attached to their initial template and may be less open to new themes and insights within the second part of the data analysis. Mindful of this risk, the researcher was meticulous in the detailed analysis of all interview transcripts. Lincoln and Guba (1990) offer suggestions for the researcher who is keen to ensure trustworthiness in their qualitative research. The first author kept a reflective journal throughout the research process, updated after each interview and throughout the process of data analysis. The data analysis was shared with the second author and with a colleague who had not been involved in the project for comment, and to check that the assumptions were reasonable, and the data analysis made sense.

6 Findings

In the final template, there were three top level themes: feeling stupid, identity fit is not problematic, and enablers. In the section below, the themes will be described and illustrated with quotes from pseudonymised participants. The final template of themes drawn from the qualitative interviews can be seen in Table S2 in the supplementary materials.

6.1 Feeling stupid

The first top level theme was *feeling stupid,* summed up by Antonia, who stated *'I do think I'm stupid'*. All participants had either experienced this feeling themselves or were acutely aware of it in other women. It was the theme which seemed to be recalled most vividly, and which most seemed to define the participants' university experience. The feeling seemed to have a number of antecedents, including some pre-existing, external 'conditions', assumptions of female inferiority, and the pedagogical environment which did not make the participants feel confident about their learning.

Pre-existing factors Most (16) of the participants identified factors which seemed to exist outside the participants' experiences of the course itself. First, that coding is hard; as Ornella said *'obviously, it's quite a tough thing'*. Computer science courses require high grades, coding takes time to grasp and there is an assumption that those who code are clever; as Anne summarised: *'you have to be amazingly, amazingly smart to even attempt it'*.

The women remarked on the different levels of experience they witnessed in their colleagues. The participants' perceptions were that the men on the course had been surrounded by computers, as Anne said, *'since they were in diapers'* and in particular had significant experience playing with computer games. Sophie said *'the boys have grown up gaming'* and Sonia that her male peers were *'so into their gaming from such a young age'*. The male students also appeared to have more experience coding, either through formal study, or just through *'tinkering around'* with computers. Caroline felt it was clear in her first computer science course in high school that the boys were better at coding than the girls because they *'did that at home'.*

Finally, as widely documented within computer science and in other STEM subjects, the male students appeared to be more confident than the female students, as Agnes said *'they always give the impression of, oh they know what they're doing'*. The participants particularly noticed this male confidence within the classroom, as Sophie noted *'They boys definitely look more confident in what they are doing and I think they are assuming that this is easy'.* Leila imitated their off-putting attitude as: *'oh yeah, I wrote this in ten minutes and it took me no effort at all and now I'm just going to sit here and be loud'.*

Some of the female participants were clear that the extra confidence was not always linked to additional expertise. Agnes recalled how a boy in her class at the age of 13 '*was bragging about how he could install Windows'* and remembered that he impressed her very much until she realised how simple this was. Alys recalls a male student colleague talking confidently about his prowess in an exam which, it emerged subsequently, he had failed. The women too noted that their own lack of confidence was not always grounded in a lack of ability. Ruth reflected '*I always felt like I was behind, and I think that was true in some cases and not true in others*.'

Assumptions of female inferiority Assumptions of female inferiority were reinforced implicitly and explicitly from all sides. Ornella summed this up saying *'ultimately, they [the men] just think you're dumb'.* Nearly every female participant (20) told stories of incidents where others had assumed that they would not be technically competent.

Leila recalled her sixth form teachers, who did not offer much support with her university application because *'it just didn't seem like really were very confident that I would get in, that I would be good at it'.* Ornella and Dua both felt that the lecturers at university shared this view and Sonia described an incident where a lecturer told her *'not to do that course'* because it would be too hard for her. The participants' male peers seemed to echo this view of inherent female technical inferiority described by Carolyn in this way: '*the mentality is that women are just not made for technology'* and Bianca explained that *'there were all of these issues with people just assuming I don't know what I'm doing'.* This seemed to be most evident in group work, where Ornella noticed that male peers did not expect her to be competent: *'when I succeeded it was kind of like a surprise, like, "Oh you did it."'.* For some participants, these assumptions had been made explicit. Caitlin's example was from an occasion where she offered to help some male colleagues who were struggling with a problem; one thanked her for the offer but said *'we couldn't solve it so you probably wouldn't be able to.'*

Finally, there were many examples of women's achievements being undervalued. Leila found out that her male colleagues assumed that she had been offered a place at the university with lower A level grades, *'because they let girls in with lower grades'.* Anne witnessed a female colleague who got a first in her degree being described as '*dumb as a rock*' on the grounds that her expertise lay in getting good grades and not in coding. Participants too had both experienced and observed male peers suggesting that they managed to get jobs or internships just because of their gender.

Women do not get the right support The courses seem to emphasise self-directed learning. Students are expected to '*just figure it out later*' or as Sonia put it *'we were just told to go off and solve a problem'* and the participants described a culture in which students would lock themselves in their bedrooms, use YouTube, and stay up all night to work out how to solve a particular problem, and where students' direct requests for help were not encouraged and not always answered. Bianca noted that the girls in her class would often '*get stuck and the tutors are busy with someone else, and they just look lost*' and Caroline spoke about standing and waiting in vain to ask the tutors a question because *'they were so engrossed in these really interesting problems with people who knew what they were doing'.* As well as being a clear message from the tutors, this focus on independent learning was noted in fellow students. Leila felt that her male colleagues *'weren't interested in helping'* and wished she could have worked in groups where the students would support each other and *'would be able to, like, work with me and we'd be able to build each other up'* and Antonia felt that the peers she sought help from implied *'don't waste my time'* with their responses. For some of the female participants, the self-directed approach to learning presented no problem, and they were happy to work in this way – Sophie explained *'I mean I get stuck as well, but I'm not worried about it […] I'll figure it out later'*. For others though, it proved more of a challenge, and they wanted either an alternative way to look at the problem, or tutors who would *'hold my hand a bit more'.*

The women involved in this study did not seem to be falling short academically. There is no evidence that their lack of comfort with the pedagogical style caused them to learn less well. Even Thalia, a student who described herself as *'failing, failing, failing, failing, failing, failing'* during her coding class, went on to achieve a merit in that module. But where there was an incongruence between the teaching style on offer and the learning style of the participants, it seemed to take its toll on their confidence and their enjoyment.

The women frequently mentioned the lack of female contributions in class. Leila, for example, said that during her whole three-year degree course, *'I do not think I ever heard a girl ask a question in class'.* The women explicitly linked their unwillingness to speak in lectures to their lack of confidence and talked about the reaction they believed they would get from the men if they did ask a question. Vicky said that she felt that '*any question I asked would be a stupid question*' and Antonia linked it explicitly to confidence explaining *'you are completely lost – that's why you are scared to ask a question'.*

Impact on motivation The women thus started the course feeling less experienced and less confident than the men, they were met with teachers and peers who assumed a low level of competence, and the teaching approach did not always suit them. Perhaps inevitably, this had an impact on their motivation towards the course and their future careers.

Some of the women were positively motivated by their experiences to work harder, to prove their worth to the men around them, or to themselves. Caitlin wanted to *'just show them that I'm good and can do the same things'*. Others found the assumptions of their low ability '*demotivating'* and the women talked about their lowered confidence causing them to expend less effort in their studies as Lizzy thought *'this is too hard, so I can't do it',* or leading to a decreased interest in the subject, as Precious explained *'it just meant that I was less, like, curious'*. Thalia found that as the term progressed she lost confidence, noting *'I was kinda sitting further and further at the back'*.

The participants talked too about the impact that their lower confidence has had on their attitudes and behaviour towards career-related opportunities. Svetlana had observed that although there were a lot of opportunities and events that the university laid on, lower confidence meant that *'the girls never attend'*. Alys decided to apply for an internship rather than the more senior permanent job which a male peer applied for because she felt *'I'm much happier doing the internship because […] it's less out of my depth'*. Caitlin identified a link between confidence and salary negotiations, suggesting that men are paid more in industry because their self-belief helps them with their salary negotiations, putting it down to *'the fact that I do not believe in myself as much as a guy does',* and both Anna and Vicky who had applied for jobs they were eminently equipped to do, '*walked out'* of assessment centres when they realised they were going to assess their coding skills because, as Anna said *'I just didn't know how to start'*.

6.2 Identity Fit is not Problematic

The participants in this study were asked about their perceptions of fitting in on their course. Their responses were mixed with some identifying strongly with their peers, and others reporting that they did not fit in on the course. More consistent across participants was the message that fitting in was not a cause for concern.

Many participants do fit in on their course Some of the participants (8) did feel as though they fitted in: Lucy went as far as to describe herself as *'ingrained'* in the computer science community. Some felt that they had similar interests to the other students. Alys felt *'we all have the same interests, so I would say I do fit in',* and some felt that although they were in the minority in terms of gender, they found it easier to get on with men than women. Some felt that the students on their course were so diverse that this made it easy to fit in; Thalia observed '*we were all from different places, we all valued our differences'* and Anne felt that the *'expectation of people being a little bit odd in computer science'* meant that *'I don't stand out at* *all'.* Others found that it was a question of overall numbers: with so many students on the course, it was easy to find people they connected with.

Not fitting in on the course does not matter Other participants (12) did not feel that they fit in on their courses, but for them this did not seem to be problematic. Some felt that they could just focus on learning in lectures, and could find their social life elsewhere. Mariam's social circle revolved around her halls of residence and she enjoyed the company of friends from *'different courses, different unis'.* Svetlana too talked about having many interests outside her course explaining that she was *'busy doing other things'* which meant that it mattered less that she did not identify with her colleagues, explaining *'I don't feel I need to fit in here'*. Others found that standing out was not without its advantages. Ornella felt different from her fellow students but saw a benefit in this: *'everything about me is different and yeah it obviously works quite well for me because in interviews I stand out, they're never going to forget me!'.*

6.3 Enablers

The final top level theme was enablers. These participants had clearly all decided to study computer science at university, and revealed a number of experiences which had enabled them to make this choice, and which had helped to make it a more positive experience. There were two main sub-themes, with the participants talking first about people who made their entry and progress in the field seem possible, and then about early exposure.

People who made it seem possible Nearly all the participants spoke about influential individuals who introduced them to computer science. For many these were family members, usually male, older brothers, cousins or parents, but teachers were also cited as important influences. Ornella described the organic way this happened for her, explaining that her cousin *'had always been really into computers […] and I found that as I was around him a lot, I tried my hand at that'* and both of Hillary's senior high school computing teachers were women, which she said *'was brilliant and made me think it was something I could really do'.* Some of the women talked about the importance of male champions – people who believed in them and could advocate on their behalf. Mariam described how empowering it was to have a line manager during her internship who encouraged her to voice her own views and put her ideas into practice. Leila believes that men are pivotal to changing the culture: '*in almost every case they will listen to other men before they'll listen to women.'* and suggested, *'It's men's responsibility to give women a voice'.*

Early exposure The second group of enablers all involved early exposure to computers. Most participants (14) had had some degree of involvement with computers as children. For some, their introduction to computing happened through video games. Sophie explained *'I would spend my entire summer playing those early games',* Hillary said *'I definitely played a lot of computer games'* and Precious said that as a child she was *'always into gaming'*. For others, the exposure had been the result of a fortunate coincidence, whether it was through a family member who had a particular interest (such as Lucy's brother or Ornella's cousin), or the chance that their family happened to have a home computer – Bianca explained that '*My dad worked in computing so me and my sister had computers from quite young*'. Participants who had not had access to computers at a young age were conscious of the disadvantage. Many of the participants had attended all-girls' schools and they commented on the lack of facilities in their schools. Anne explained that for those who have had limited exposure to computers as children, the choice to study computer science involves a level of risk which may dissuade women from making this choice: *'it's a big gamble if you're 18 and you've never coded a line in your life'*.

7 Discussion

Previous research exploring the reasons for women's under-representation in the technology sector has uncovered valuable findings, but literature which focuses on student experiences in computer science within a broader theoretical framework is limited. This study contributes to the literature, offering an exploration of the experiences of computer science university students in the UK. Cheryan et al.'s (2017) framework explaining the reasons for the under-representation of women in pSTEM fields (including but not limited to technology) identified three themes: a masculine culture leading to a lack of identity fit, a lack of early exposure to the subject, and the lower self-efficacy of women. The results of the present study suggest that the three themes all resonated with women studying computer science in the UK, and in addition, the study uncovered nuances which have not been previously identified and which could suggest possible new directions for further exploration.

Identity fit, one of the key aspects of the masculine culture, as Cheryan's model holds, has been shown to impact on career decision making in pSTEM fields; yet in this study, the participants reported that identity fit on their courses, was not important to them. In the findings of this study, the two factors of the masculine culture and lower levels of self-efficacy, conceptualised as distinct factors in Cheryan et al.'s model, are entwined. The students in this study reported that aspects of the masculine culture (specifically the agentic approach to pedagogy, which has received limited attention in previous literature) contributed to their lower levels of self-efficacy. Early exposure, the third aspect of Cheryan et al.'s framework, was noted in the participant narratives as a factor that allowed them to consider studying computer science, but two additional enablers were identified: role models (which has been noted in previous literature) and male champions, which has not been widely reported. The findings will now be discussed in more detail within the context of the existing literature.

7.1 Technology Self-Efficacy

The findings suggest that a number of different factors conspire to lead women to feel less technically competent than their male counterparts. Previous research has identified that women tend to underestimate their own technical abilities whilst their male colleagues are more likely to overestimate theirs (Bench et al., 2015; Beyer, 2008). This reflects the experiences of the participants in this study, and these women offered some possible reasons for the differences. They discussed the stereotypical sexist assumptions that women are not naturally suited to technical jobs and would inevitably be less competent in these roles. The participants gave examples of these societal stereotypes being internalised and promoted by them themselves, by their male colleagues and by their teachers both at school and at university. These stereotypes have been identified widely in previous research (Cheryan et al., 2009) and have been shown to have an impact on girls' career interests (Master et al., 2016). It was powerful in this study to note that the women faced a panorama of negative messages, with each participant offering story after story illustrating the pervasive and deep rooted nature of the assumption, across society, that women are, as Carolyn said '*just not made for technology*'. Early exposure to computers was identified by the participants as another factor which had an impact on the relative technology self-efficacy of the women and men. The women noted that their male counterparts were far more likely to have been exposed to computers at a young age, often through gaming, and that this early exposure contributed to men's increased levels of technology self-efficacy. These findings are reflected in previous literature (Barker & Aspray, 2006; Master et al., 2017).

A further and less widely examined reason cited for lower technology self-efficacy in this group of women seems to stem from the pedagogical style experienced in the computer science courses. The participants described a self-directed approach to learning, promoted by faculty and embraced by their male peers, a competitive culture both on the course and in group projects, and a lack of response from both faculty and male peers to their direct pleas for help. This culture was not problematic for all the participants but many found that it eroded their confidence and caused them to withdraw either from participating in class, from engaging in the course or from taking advantages of career-related opportunities. We discussed in the introduction the agentic social cognition, more often valued by men and shown to predict attraction to scientific careers, which favours competition, mastery and independence. This contrasts with the communal orientation, more often valued by women, which prioritises relationships and collaboration (Bakan, 1966). Existing literature suggests that these different social cognitions can offer an explanation for the underrepresentation of women in highly technical fields (Diekman et al., 2010; Tellhed et al., 2018), but where previous studies have linked the perceptions of STEM careers as agentic with levels of career interest, this study may be the first to suggest that an agentic pedagogical style within the computer science university classroom could have negative consequences for some students, eroding some participants' belief in their ability to pursue a technical career path, and decreasing their interest in the field.

It may sound as though this points to an easy solution for those aiming to make the university environment more hospitable for women: universities must make their learning environments more communal. Feminist pedagogy has been a way to design courses that challenge structures, assumptions and the status quo in society (although typically in more social courses). The computer science courses depicted by the participants in this study appear to erode women's confidence, and feminist pedagogy might offer a way to allow students to challenge social structures that are oppressive and develop critical thinking skills to aid in logical problem-solving. These types of pedagogies are starting to be considered and the example of Harvey Mudd College, given in the introduction, shows the impact that these approaches can have.

But the answer may not be so simple. The technology industry needs self-directed software engineers to accommodate the fast pace of technological change, and as a result employers encourage computer science programme directors in the UK to make their courses self-directed, in order to develop graduates with the right skill-set to make the industry more competitive (Zander et al., 2012). Whilst a less self-directed pedagogical culture might suit some students, it could be detrimental to the employability levels of all computer science graduates and could do a disservice to the industry. But perhaps there is another way. Perhaps computer science faculty could teach self-directed learning as a skill which needs to be developed, rather than assuming that students are naturally self-directed. Students could be offered more encouragement to develop their self-directed learning skills and be given more support if they need it as they go along. One approach that may be useful to consider is autonomy-supported learning (Reeve, 2016), a pedagogical approach based on Ryan and Deci's self-determination theory (e.g., Ryan & Deci, 2000), which aims to develop autonomous learning in students. It has been shown to foster motivation in students within computer science teaching in schools (Reynolds & Leeder, 2017), and there is some evidence of its value within higher education (McLachlan & Hagger, 2010). It has been shown to be at its most effective when teachers offer high levels of support (Reeve & Jang, 2006), and could be incorporated as a high-support approach to encouraging self-directed learning in computer science students at university. Another pedagogical approach that may hold some promise for communal learners is peer programming, in which pairs of students work collaboratively, sharing one computer and taking turns in front of the keyboard. Female computer science undergraduates have reported that this approach has made them feel less stupid and more supported than traditional approaches. Highlighting the value of a communal approach to results as well as to experience, peer programming seems to result in the production of better quality coding (Ying et al., 2019), which could indicate that this approach could add value to the industry as well as to individual learners. A further consideration is whether industry too could be encouraged to reconsider the value it places on agentic learning. Their assertion that the fast pace of technological development means that they need self-directed learners may be worth questioning. An acknowledgement within the technology industry that some software engineers would be more satisfied working in a more communal environment could lead to the development of an environment which is more hospitable for women and other communally orientated programmers.

Before leaving this point, we should highlight the importance of not overstating differences between men and women (Barker & Aspray, 2006). This study has focused on the experiences of women, and as such our participants have been women, and the findings have been described in gendered terms. There are group differences between genders, but of course, many more within-group differences, and whilst communal goals are more likely to be valued by women, they appeal to many men too. There is a risk in using such gendered terms, that we reinforce differences, which may not be helpful to our cause. The language of communion and agency may be a more fruitful and indeed, more accurate, way to describe the differences, rather than men and women. Future research could usefully pursue this.

7.2 Identity fit

Previous literature has highlighted that women can find it hard to fit in within male-dominated workplaces and stresses the importance of identify fit for career decision making (Peters et al., 2012), but the findings of this study suggest that identity fit is just not an issue with the women at university. Many of them do feel that they fit in, and those who do not, do not appear to be concerned by this.

Most participants said that their university courses had been so populous and diverse that they were able to find like-minded friends; those who did not, felt that they could find companionship elsewhere, and did not feel that the lack of friendships on the course itself had an impact on their learning or enjoyment. This insight to the experiences of these university students highlights the importance of examining the experiences of women at different stages: the issues which beset women at work are not necessarily the same as those which challenge them whilst studying. One notable theme from the data, is that the students discussed 'fit' in the light of friendships: those who reported feeling that they fitted were those who had developed friendships on the course; those who did not fit in on their courses had found friendships elsewhere. The construct of identity fit within the literature acknowledges that personal connections are a part of fitting in, but also focuses on the degree to which they feel their skills are valued and valuable (Peters et al., 2012). The student participants in this study did not include the value of their skills in their interpretations of fitting in, restricting themselves to the more personal interactions. This perhaps reflects the contrast between the individual nature of university studies and the more team-orientated nature of most workplaces. The centrality of professional identity in students could offer another possible explanation. Profession identity takes time to develop and it is likely that the professional identities of our student participants were not as yet fully developed, or fully integrated with their personal identities (Schepens et al., 2009). This could explain why fitting in on the course could be less important to them as students, than it might be later on, once they are actually working as programmers or software engineers: perhaps as professional identity develops, so does the desire to feel a sense of belonging.

These findings could indicate that fitting in in the workplace is more important than fitting in at university, and the strategies needed to support women's career development in the workplace may be different from those which could make a difference in the classroom. The suggestion that identity fit at university is not a cause for concern for these women has two possible implications. First, in terms of channelling resources, this information could imply that the university environment, in this regard, may be good enough as it stands. Second, there may be lessons that industry can learn from the students who found a large and diverse cohort enabled them to feel that they belonged.

Much of the traditional literature has pointed to recommendations which aim to fix women although more recently, the focus has shifted towards effecting a change in culture to make the environment more hospitable for women (Barker et al., 2014; Riegle-Crumb et al., 2019). The findings here point to a less discussed problem, the pedagogical approach, which, with its emphasis on competition and self-directed learning, may be more likely to suit men than women, to the degree that men are more often agentic learners. The implications of this line of argument go further than the need for the overall culture of the faculty to change, indicating that the male students too should be encouraged to understand the impact that their attitude and behaviour may have on others, and to appreciate a wider range of approaches to learning or pathways to success. Our findings indicate that the typical computer science classroom in the UK may be gendered: in theory, all students have the same support, access to the same resources and the same demands, but in practice, this approach seems to agentic learners (more often men) than communal learners (more often women).

7.3 Early exposure

The women's narratives touched on a number of themes which have been well-rehearsed in the existing literature. The women in this study were aware of the value of gaming as an entry point for their male peers, but a self-perpetuating cycle in which games are, more often, developed by, aimed at and played by men and boys (Hartmann & Klimmt, 2006; Lenhart et al., 2015; Ohannessian, 2015), excludes women from taking advantage of this possible point of entry. The value of role models too has been widely explored elsewhere (Drury et al., 2011; Price, 2010).

One theme which has not been as well covered in previous literature and which may offer a fresh perspective for the discipline was the importance of male champions, highlighted by a number of the participants as offering particularly valuable support. This is a topic that has been discussed in the business and popular press but has received very little attention to-date in the academic literature (DuBow & Ashcraft, 2016; Madsen et al., 2019). Yet it is one that could make a significant difference, helping to shift the debate away from being about a 'women's issue' and reframing it as part of a mainstream conversation, which places diversity and social justice at the heart of the discipline. In the scant literature that has been published on this topic, evidence suggests that men, as members of the dominant group can draw on social capital that women cannot access and are more likely to be taken seriously, thus having more impact (Madsen et al., 2019). Arguments have been made in the literature that men may not want to promote gender parity because that will inevitably cause them to lose their privileged status (Joshi et al., 2015; Leslie et al., 2013) but it seems that increasingly men increasingly understand the importance of equality (Donnelly et al., 2016). Some authors offer an alternative explanation for men's lack of proactive support for women, suggesting that men's lack of participation could be linked to a perception of their low psychological standing as far as gender inclusivity is concerned—a sense that it is not their place to get involved (Miller et al., 2009; Sherf et al., 2017). Further research exploring this as an issue within computer science departments, and within the industry as a whole could be of value.

8 Limitations and Directions for Future Research

As with all studies, there are limitations to this research which should be born in mind when interpreting these findings and which could be addressed in future studies. All participants self-selected and may have been motivated to participate in the study as a consequence of particular experiences during their courses. As such their narratives may not reflect the experiences of other students. This study sought to explore the experiences of female students, so participants were all women, but an exploration of the experiences of a more representative sample, including male students would add to our understanding of the phenomenon. The study was exclusively UK oriented, exploring the experiences of students studying at institutions in the UK, so an exploration of the computer science culture elsewhere would be of value. A larger-scale quantitative study could examine the generalisability of these findings. Limited information about participants was collected during the study, but it is plausible that particular aspects of the participants' backgrounds may have impacted on the themes produced and a more detailed understanding of the participants' backgrounds could have allowed further insights to their experiences.

We highlighted in the introduction, that a qualitative study could make a timely contribution to this field to broaden the parameters of the existing quantitative approaches. To this end, our findings have identified a number of possible factors that have not been widely included in previous studies, and which could be worthy of further investigation. The study has raised the possibility that the typical pedagogical culture seen in computer science classrooms is a gendered one which may fail to nurture students, often women, who have a communal orientation to learning. Further studies that examine the pedagogical culture of computer science courses and explore the learning experiences of agentic and communally-orientated students could usefully build on these findings. Finally, the importance of male champions, revealed in the participants' narratives could be further explored.

9 Conclusion

This study employed a qualitative approach to better understand the experiences of female computer science students in the UK. As such, it complements the existing literature which is heavily weighted towards quantitative studies. This study offers support for the tripartite model developed by Cheryan et al. (2017) to explain the under-representation of women in pSTEM fields, and it highlights the impact that technology self-efficacy, early exposure to computers and the culture have on the participants' career aspirations. One aspect of the culture which has perhaps been under-explored in previous literature is the agentic approach to pedagogy. A focus on competition, mastery and self-directed learning does not always appeal to communal learners and the evidence from this study suggests that for some of the women in this study, it had a negative impact on their confidence and engagement. University computer science departments will want to continue to instil skills of self-directed learning in students, as this is vital for maintaining a competitive edge in the industry, but it may be that universities can find a way to develop this skill in their students without alienating those to whom it does not come naturally, and embracing the inclusive principles of feminist pedagogy may serve the student body and the industry well. It seems regrettable that women who are interested, able and ambitious are not sure that they want to pursue careers in the technology industry. Further exploration of the pedagogical culture may allow universities to offer a more hospitable environment that builds confidence and interest for all students.

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Declarations

Ethics approval Obtained from City, University of London.

Consent to participate All participants signed consent forms agreeing to participation.

Consent for publication All participants signed consent forms agreeing to their data being used for publication.

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