Women's Sense of Belonging in Computer Science Education

Project Report for Advance HE
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Executive Summary

Computer Science is a highly male-dominated discipline in the UK, with women forming only 18% of undergraduate course cohorts in this domain in 2018 [6]. To address inequalities for underrepresented groups within academic subjects, such as gender inequality in Computer Science, there is a growing understanding that activities which simply focus on increasing numbers of underrepresented cohorts is not enough. Instead, Advance HE highlights the need for institutions, faculties and departments to foster a *sense of belonging* for all staff and students. Given this, our project aimed to **understand and envision a women's sense of belonging in Computer Science**, and uncover good practice initiatives for encouraging wider participation of underrepresented groups in the discipline.

To achieve this goal, our initial plans for the project involved conducting a one-day *cross-strata* workshop to bring together 50 A-level, undergraduate and postgraduate Computer Science students identifying as women, who would work together to co-create ideas and teaching resources that foster sense of belonging for women in the discipline. Unfortunately, due to the restrictions of the Covid-19 pandemic, we were unable to conduct any workshops face-to-face and diverted from the cross-strata element of including A-level students due to the difficulty of engaging schools in non essential activities during this challenging time. We instead engaged with A-level students through a survey, and re-focused our efforts on UG and PG students and research staff.

As a result, our insights for fostering a sense of belonging in Computer Science have been developed through the following:

1. a **survey** with female A-level Computer Science students, detailing their thoughts, experiences and interests in Computing;

2. a **survey** open to all staff and students at Lancaster University, uncovering perceived interests in Computer Science and project ideas that would encourage wide participation in the discipline; and, most predominantly,

3. innovative **focus groups** involving women undergraduate and postgraduate Computer Science students at Lancaster University as well as the project team, delving deeply into issues of belonging and opportunities for enhancing this within Computing education.

Stemming from our analysis of these studies, we provide **three sets of recommendations** for fostering a women's sense of belonging in Computer Science. In summary:

- For **educational materials**: Computer Science projects should link to the real-world; students must be given chance to choose projects relating to their interests and passions; students should be taught about the history of Computing; and language bias must be removed from teaching materials.

- For **inclusive education environments**: students should have access to mentoring opportunities; failure should be celebrated as a learning jour-

ney; and teaching or group settings should ensure respect of others, e.g. by increasing staff and students awareness of unconscious bias.

- For **educational practitioners**: staff should use inclusive language in the classroom and must be provided with the development opportunities to achieve this; and there should be an increased awareness of a 'responsibility to learn' about bias and equality.

While these recommendations focus on improving **gender inequality** in the field, we believe they provide useful insights for encouraging all underrepresented groups to pursue education in the field and create a sense of belonging for **all students** in Computer Science.

Drawing on content from the surveys and focus groups, we have produced two **Research in a Box** initiatives, as promised in the proposal, and developed the new website: `www.researchbox.org.uk`. Another three boxes are also in development due to a high interest among our colleagues to generously offer their time and skills as part of this eye-catching and inspiring work. These resources are designed for deployment and use in schools, aiming to encourage wider participation in Computer Science through creative, real-world projects.

We also documented the focus groups in a visual way through **sketchnotes**, offering a different format for engagement with the outcomes from these discussions. As a key next dissemination step, we plan to commission an **animated video** based on the project findings; this video will form additional creative impact and will be a valuable motivational resource.

Moving forward, we plan to use our outputs for marketing, engagement and outreach activities within the School of Computing and Communications (SCC) at Lancaster University and, more generally within SCC, ensuring the department is dedicated to enhancing the engagement of women students and improving gender equality in the discipline. We also aim to include our outputs within the institution's diversity awareness teaching and training. Members of the project team are already highly engaged with institutional and departmental Athena Swan agendas (Kathy New, Institutional Athena Swan Programme Manager; Lynne Blair, SCC Athena Swan Lead; Kelly Widdicks, SCC Athena Swan Research Lead), offering **clear opportunities for the dissemination and inclusion of our findings** at departmental and institutional levels. Beyond Lancaster University, we are excited for the resource outputs to be made available through Advance HE and our Research in a Box website.

We continue to collect responses to our Lancaster University survey (still open for a few more weeks), and will then write up the report findings into an academic publication. This publication will be open access (e.g. via Lancaster University's research repository).

Through this sharing strategy, we hope to **raise awareness of issues of gender inequality in Computer Science, and enable other institutions, departments and faculties to utilise, and build upon, our findings and resources**. For future work, we aim to conduct further studies with schools to bring in the cross-strata element originally envisioned for the project, and to gather evaluative data on the project outputs thus far.

Main report

1 Introduction

Computer Science is a **highly male-dominated discipline in the UK**, with women forming only 18% of undergraduate course cohorts in this domain in 2018 [6]. Vital work is being done across the Computing sector to address such gender inequalities, including events or communities that celebrate this underrepresented group (e.g. BCSWomen Lovelace Colloquium,[1] Grace Hopper Celebration,[2] the Association of Computing Machinery (ACM) Women in Computing[3]), the involvement of institutions and departments in the Athena Swan Charter,[4] and academic research uncovering mechanisms for equality, diversity and inclusion [e.g. 12, 3]. STEM (Science, Technology, Engineering and Mathematics) learning initiatives [9] also exist to address the gender balance in Computing, aligning with calls from the UK Government [4]. Yet, such ambitions do not seem to be having their desired effects, with **women's participation in computing even declining in Western countries** [16**? ?**]. As a result, there is more work to be done to ensure women, and other underrepresented groups, become truly interested, engaged and embedded in Computer Science.

In prior work, we have been investigating these issues alongside opportunities for driving equality in the Computing sector—particularly for women. In this, we have found that A-level students identifying as women have already developed elements of resilience in the Computer Science domain, establishing 'ways of being' that help them work within this male-dominated education environment. However, our participants unfortunately reflected on a **difficulty of determining their sense of purpose or belonging in the discipline**, especially with regards to resonating with Computing projects currently drawn upon in education settings. This highlights a need to foster a women's *sense of belonging* in Computer Science education.

Fostering a sense of belonging aligns with similar calls from Advance HE,[5] as well as the academic literature. In the latter, there have been calls for enhanced visibility of aspects of Computing (e.g. its histories, its related subjects, gender balances in non-western countries, women who enjoy Computing) to emphasise women's involvement [16], as well as to address stereotypes in Computing [10] and recognise the critical role of education faculties for fostering belonging [12]. Building on this literature and our prior work, we aimed to **understand and envision a women's sense of belonging in Computing**, and uncover good practice initiatives for encouraging wider participation in the discipline.

To achieve this goal, we conducted three studies utilising quantitative and

[1]BCSWomen Lovelace Colloquium: `https://bcswomenlovelace.bcs.org/`

[2]Grace Hopper Celebration: `https://ghc.anitab.org/`

[3]ACM Women: `https://women.acm.org/`

[4]Athena Swan Charter: `https://www.advance-he.ac.uk/equality-charters/athena-swan-charter`

[5]Advance HE Good Practice Grants 2020: `https://www.advance-he.ac.uk/reports-publications-and-resources/good-practice-grants-2020`

qualitative research methods. These consisted of:

1. a **survey with female A-level Computer Science students**, detailing their thoughts and experiences of how Computing could have been made more attractive to them;
2. a **survey open to all staff and students at Lancaster University**, uncovering perceived interests in Computer Science and project ideas that would encourage wide participation in the discipline; and
3. **innovative focus groups** involving women undergraduate and postgraduate Computer Science students at Lancaster University as well as the project team, delving deeply into issues of belonging and opportunities for enhancing this within Computing education.

We predominantly focus our report on the findings from the innovative focus groups due to their rich data sets, but draw upon the surveys for additional insights. Furthermore, we wish to note that we use 'female' and 'male' where the data explicitly refer to those terms. However, we have adopted the practice of many others within the research community of using 'woman' or 'man' (as nouns) to describe the gender identity of an individual (as opposed to biological aspects of an individual); the adjectives female and male may still used where precision is needed, e.g. female A-level students. We also note that our report only takes a gender binary view as none of our participants identified as a different gender identity.

In this report, we detail the study approaches as well as the main findings resulting from the data analysis. Section 2 focuses on the school survey, Section 3 details the Lancaster University survey, and Section 4 delves into the focus groups data. Finally, in Section 5, we summarise our main **recommendations for educational materials, inclusive education environments and educational practitioners**.

Building on our findings, we have developed two **Research in a Box** initiatives, briefly presented in Appendix A and available on our newly designed bespoke website: `www.researchbox.org.uk/`. An additional three boxes are currently under development, due to a number of our colleagues generously offering their time and skills to further enhance this valuable resource bank. These resources are designed for deployment and use in schools—aiming to encourage wider participation in Computer Science through creative, real-world projects.

We have also documented the focus groups in a visual way through **sketchnotes** [15] (Appendix B), offering a different format for engagement with the outcomes from these discussions.

Through this report while we have primarily focused on women in Computer Science as a distinct underrepresented group, our recommendations and outputs are more widely applicable across the education sector, and thus we envision that these resource approaches will be useful for other underrepresented groups in a given subject—particularly STEM disciplines. As a result, **we encourage the education community to use and build upon our resources for fostering a sense of belonging in education for all diversity groups**.

2 Secondary School survey

We conducted a survey with 52 female A-Level Computer Science students at five schools in the North West of England. The survey included questions about: what was important for participants in their future career; what participants thought was important for a Computer Science career; how they rated their confidence in different Computer Science skills; and their university plans. The survey also asked about participants' experience of Computer Science A-Level, including projects that participants liked and disliked. Finally, participants were asked about their perceptions of the Computer Science gender gap. The survey was disseminated through A-Level teachers and had ethical approval from Lancaster University's Faculty of Science and Technology's Ethics Committee.

2.1 Computer Science: likes and dislikes

When asked about their Computer Science likes and dislikes, our participants **most liked programming** (43 participants), **solving technical problems** (43), and **teamworking** (41). Participants had less experience of creative designing (15 participants said they had not done this) and using Computer Science to improve lives (19). In terms of Computer Science project likes and dislikes, the responses were highly varied. The kinds of projects that participants enjoyed varied widely, with no clear 'type' of project that was especially popular. Our participants' reasons for enjoying a specific project also varied highly. The three most common themes were **problem-solving** (10 participants), **learning new things** (10) and **creativity and design** (7). The most common reason for disliking a specific project was it being difficult, confusing or complicated (12 participants).

2.2 Pursuing Computer Science at university

Of the 52 participants, 25 (48.1%) rated Computer Science as their favourite A level subject and 22 participants wanted to continue Computer Science at university. The main reason given for *not* wanting to study Computer Science at university was being more interested in pursuing something else, or Computer Science not fitting in with their chosen career (12 participants). Within this category, **some participants did not see Computer Science as being sufficiently socially beneficial.** For example, one participant stated *"it isn't a caring career"*, whilst another responded *"I don't want to do* [Computer Science] *because I want to impact on people's lives (social action) and I don't think this can be done with* [Computer Science]*"*. This suggests that there are some **image problems with Computer Science**, with young women not necessarily being aware of the many societal applications of the discipline.

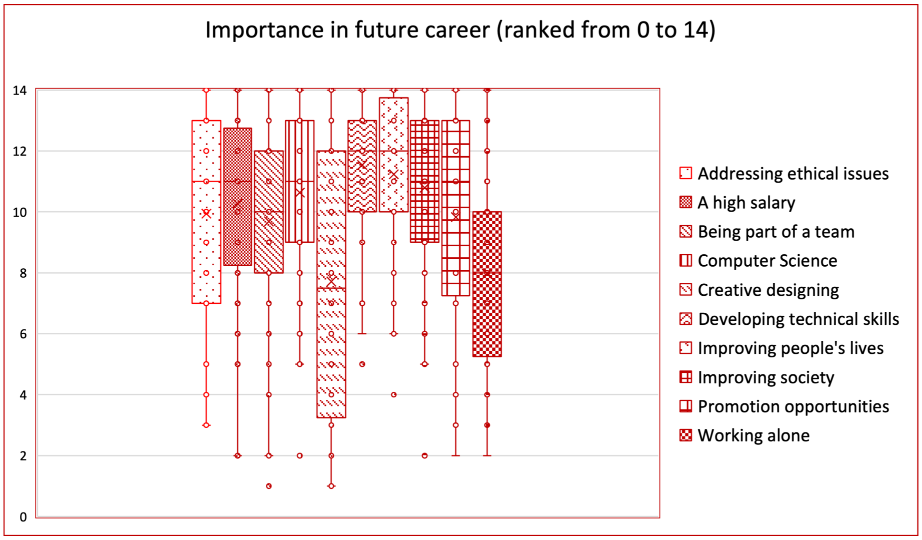


Figure 1: Boxplots of the importance of different aspects in the school survey participants' future careers. These boxplots depict the medium, lower and upper quartiles, and maximum and minimum importance rankings for the different aspects amongst the participants, as well as the ranking outliers. For example, for the aspect 'Being part of a team', the maximum importance ranking was 14, the upper quartile was 12, the medium was 10, the lower quartile was 8, the minimum was 2, and the point at 1 is an outlier.

2.3 Career aspirations

Participants were asked what was important for them in their future career, and were given a series of options to rank. The two most important aspects selected were developing technical skills and improving people's lives (Figure 1). Interestingly, our participants' confidence was higher in programming than in wider Computer Science skills to enable them to improve people's lives, such as addressing ethical issues and identifying social implications of computing (Figure 2). Participants were also less sure about the importance of these skills in a Computer Science career (Figure 3). This suggests that, **whilst improving people's lives was a key career aspiration for these young women, they are not necessarily being equipped with the Computing skills to do this** or being given an image of Computer Science that stresses these aspects as important. This further adds to discipline's image problem as noted in Section 2.2.

2.4 Reflections on Computing's gender inequality

When it came to their thoughts on the gender inequality present in Computer Science, the responses were complex. When asked how they felt about studying

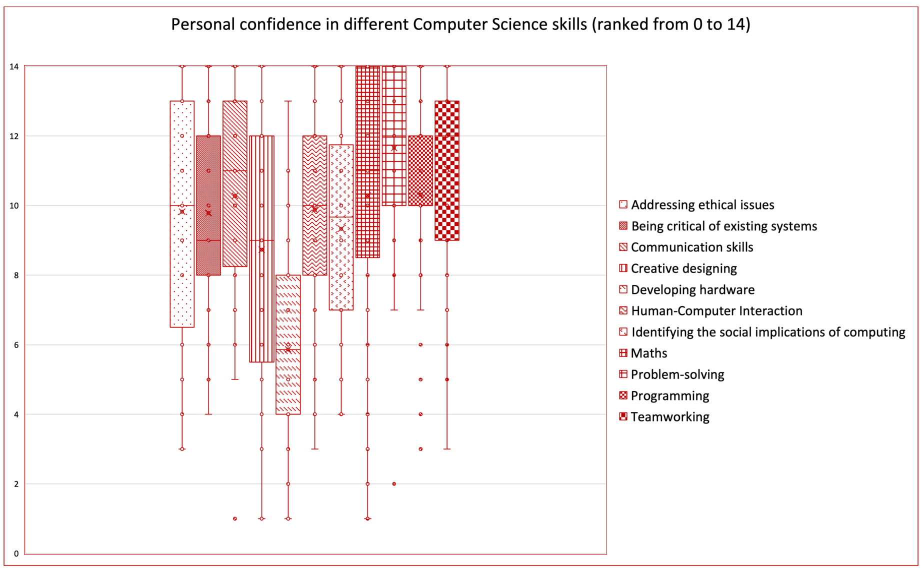


Figure 2: Boxplots of the school survey participants' confidence in different Computer Science skills. These boxplots depict the medium, lower and upper quartiles, and maximum and minimum confidence rankings for the different Computer Science skills amongst the participants, as well as the ranking outliers. For example, for 'Communication skills', the maximum importance ranking was 14, the upper quartile was 13, the medium was 11, the lower quartile was 8.3, the minimum was 2, and the point at 1 is an outlier.

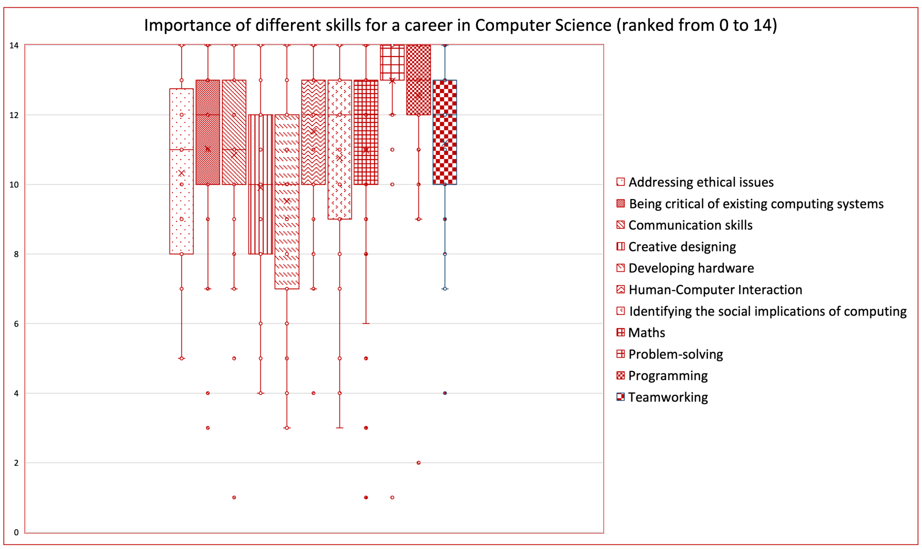


Figure 3: Boxplots of the school survey participants' perceived importance of different skills for a Computer Science career. These boxplots depict the medium, lower and upper quartiles, and maximum and minimum importance rankings for the different Computer Science career skills amongst the participants, as well as the ranking outliers. For example, for 'Communication skills', the maximum importance ranking was 14, the upper quartile was 13, the medium was 11, the lower quartile was 10, the minimum was 7, and the points at 5 and 1 are outliers.

Computing at university if there were not many female students in their class, **17 participants stated that it was 'fine' or 'ok'** and that they would not personally be discouraged. However, a small number of these did go on to say that they wished that the situation were different. One participant, for example, stated *"diversity would enhance the quality of learning and from a social perspective, it would be nice to have more people you can easily relate to"*, while another commented *"fine, but sad that some girls may be put off"*.

Several participants (8 in total) spoke of their **concerns about being in the minority**. Responses included: being *"intimated and somewhat scared"*; *"it's intimidating... You constantly have to work to earn* [men's] *respect in a way that their male peers do not"*; and *"I would feel out of place and if I was not supposed to be there"*. A further eight participants expressed concern, but then said that it would be ok: *"uncomfortable at first but would get used to it"*; *"I would feel a little out of place but would still enjoy it"*; *"somewhat uncomfortable but overall would not mind"*; and *"it might be disconcerting but it wouldn't put me off"*. These responses indicate determination in the face of an 'uncomfortable', 'isolated' and 'disconcerting' situation, but also hint at some concern and an uncertainty around belonging in Computer Science.

3 Lancaster University survey

The Lancaster University survey aimed to uncover perceived interests and knowledge in Computer Science, as well as gathering ideas for Computer Science projects. We were interested in collating different and creative ideas from a wide demographic, and all staff and students at the institution were able to participate. The survey included: demographic questions; questions on the use of Computer Science at work or in spare time, and ranking their interest and knowledge in the discipline; ideas for appealing Computer Science projects; and ideas for Computer Science projects that may appeal to underrepresented groups at school, if this differs to the previous answer. Participants were also asked to select if any (or none) of the following would appeal in a Computer Science project: creative design, problem solving, working in a team, working on social problems, working on environmental problems, working with real-world data.

The survey study was ethically approved by the Faculty of Science and Technology Ethics Committee at Lancaster University. Survey participants (incentivised by the chance to win a £50 voucher) were recruited by mailing lists across the institution (e.g. departmental/ study recruitment lists) and via snowballing methods, and were required to provide consent before participation. In total, we received 83 anonymous survey responses across institutional roles, gender identities and Lancaster University faculties. These survey responses were then analysed by members of the project team.

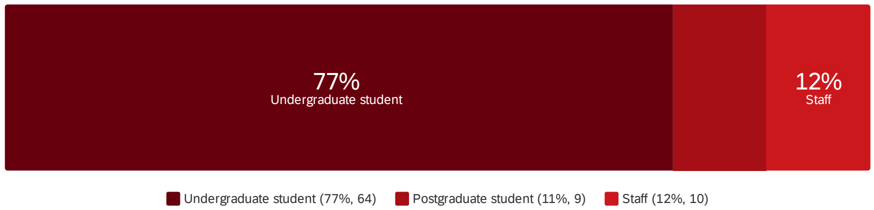
As shown in Figure 4, the majority of our participants (53%) are within the Faculty of Science and Technology of which Computer Science is a part, suggesting that people from a STEM background may have been more inclined to participate. Whilst we provided multiple options and a free form text entry for gathering the gender identity of our participants, responses were gender binary; hence our diagrams and analysis take a gender binary view.

The majority of our participants (77%) were undergraduate students, which may be due to more effective advertisement of the survey to students or higher demands on staff time due to Covid-19. The survey is still running for a few additional weeks, and we also aim to gather more staff responses in future work.

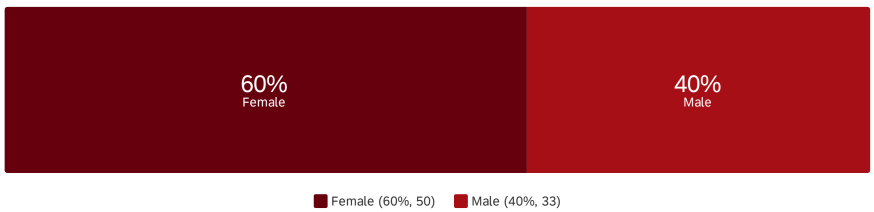
In the rest of this section, we provide an overview of the main findings from the survey: our participants' current involvement in Computer Science (Section 3.1), as well as their ideas for Computer Science projects (Section 3.2).

3.1 The participants' involvement in Computer Science

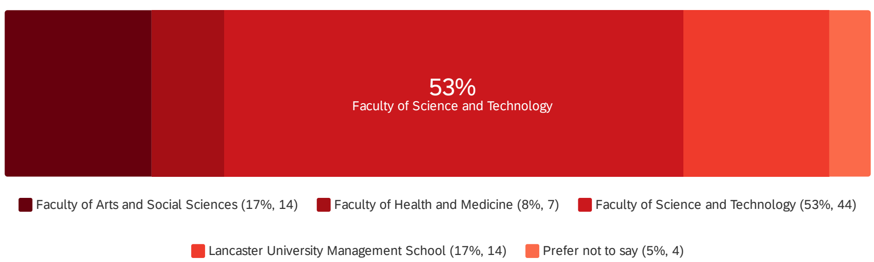
Figure 5 provides a breakdown of our participants' current experience in Computer Science. The majority of our participants had already used the discipline of Computer Science in some form at work (70% of participants), although less get involved in Computing projects during their spare time (37% of participants). Those identifying as men were more likely to use Computer Science in their job (88% of men, compared to 58% of women) and in their spare time (57% of men, compared to only 24% of women).



(a) Institutional roles



(b) Gender identities



(c) Faculties

Figure 4: An overview of the survey participants by their institutional roles, gender identities and faculties. Note that only the response data is shown here, not all options participants were provided (e.g. 'Prefer not to say' options).

Figure 6 provides a breakdown of our participants' self-rated knowledge and interest in Computer Science. The participants were provided with 5-point Likert scales with 1 being 'not at all knowledgeable' or 'not at all interested', and 5 being 'very knowledgeable' and 'very interested'. As shown in Figure 6a, **the majority of our participants class themselves as having at least some knowledge of Computer Science**, with only 18% of them classing themselves as having no knowledge at all.

Women generally rated their knowledge of Computer Science to be on the lower end of the scale (Likert scale points 1 or 2, 63% of women's responses) or neutral (point 3, 37%)—**not one woman selected 'very knowledgeable'**. Men generally rated their knowledge more evenly across the scale: 42% of men selecting points 4 and 5, 21% selecting neutral knowledge, 30% selecting point

2 and 6% selecting 'not at all knowledgeable'.[6]

Reasons for limited knowledge ratings included: not having many opportunities to engage with the discipline (e.g. courses, technology); only experiencing a part of Computing (e.g. for data analysis); not finding the subject interesting; finding it difficult to keep up with technological innovation; or only having peripheral knowledge from friends or family. For neutral responses (i.e. Likert scale point 3), participants reflected that they were not experts in Computing, or explained how they only had some knowledge of Computing—such as basic programming skills or an understanding of a particular topic in the field. For knowledgeable ratings, participants drew upon their experience of working in the field or their related qualifications; all explanations for a 'very knowledgeable' rating noted that they are studying, or have received, a degree or two in Computer Science or Software Engineering.

Figure 6b shows that **more than half of our participants are interested in Computer Science** (45% selecting Likert scale points 4 and 5), with 20% taking a neutral view to their interest (Likert scale point 3) and 24% less interested (Likert scale points 1 and 2). The majority of men's responses were neutral or interested in Computing (94%). Contrasting this, 35% of women's responses were less interested in the subject, and **only 12% of women were 'very interested' in Computing compared to 33% of men**.

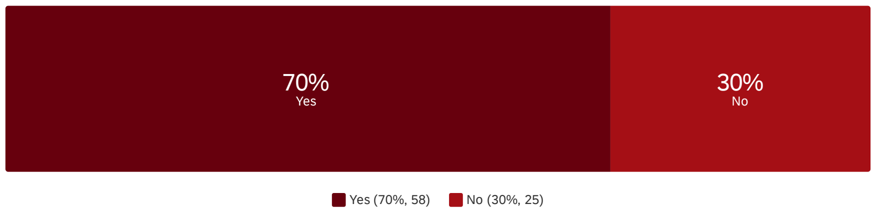
For those with less interest in the topic, explanations for this included: not finding it enjoyable generally or outside of work, not understanding the topic, or not having prior experience of learning, or chances to learn, Computing. The latter was also an explanation provided for the neutral responses, alongside concerns of barriers to the topic (e.g. time to learn, the subject seeming difficult) despite parts of Computer Science being attractive to them (e.g. the societal part of Computing, its benefits, its usefulness for data analysis). Those expressing interest in Computer Science explained that: they have to use it for their jobs; Computing makes tasks more efficient or simple (e.g. for data analysis); coding is fun and the field is creative; and that there are valuable skills to learn from the discipline, due to career prospects in the technology sector as well as the prominence of computing in our society. Such understandings of the applicability of the discipline contrast to those experienced by our school survey participants, who did not see Computing as being sufficiently socially beneficial as a field or for a career (Sections 2.2 and 2.3).

3.2 Ideas for Computer Science projects

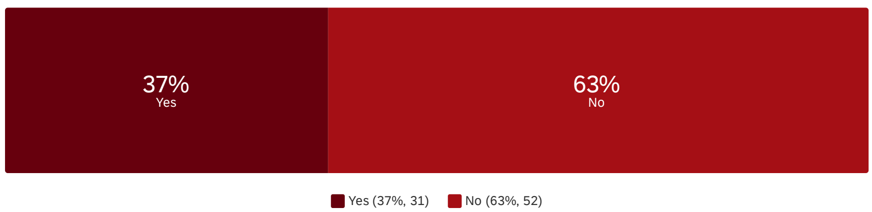
We asked our Lancaster University participants to select elements of Computer Science projects that would appeal to them, specifically: creative design, problem solving, working in a team, working on social problems, working on environmental problems, working with real-world data, and an option to select none of these elements.

In Figure 7, we break these responses down by the gender identities of our

[6] Note that percentages are rounded to the nearest whole number.

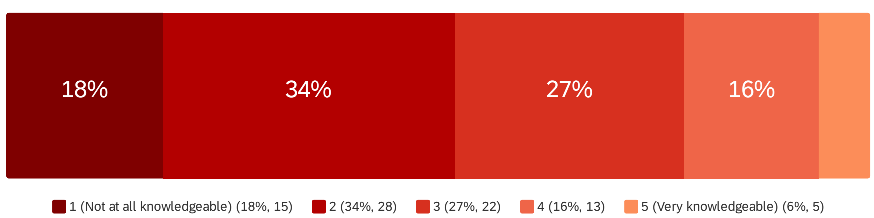


(a) At work

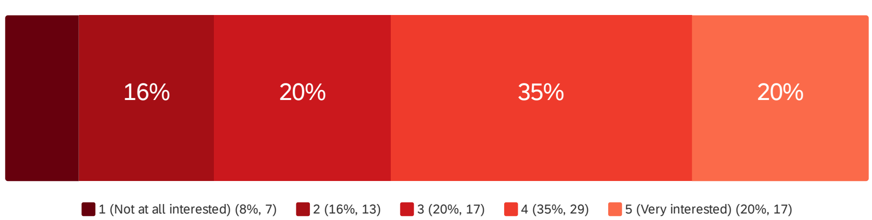


(b) In their spare time

Figure 5: The survey participants use of Computer Science at work or in their spare time.



(a) Knowledge



(b) Interest

Figure 6: The participants' knowledge of, and interest in, Computer Science.

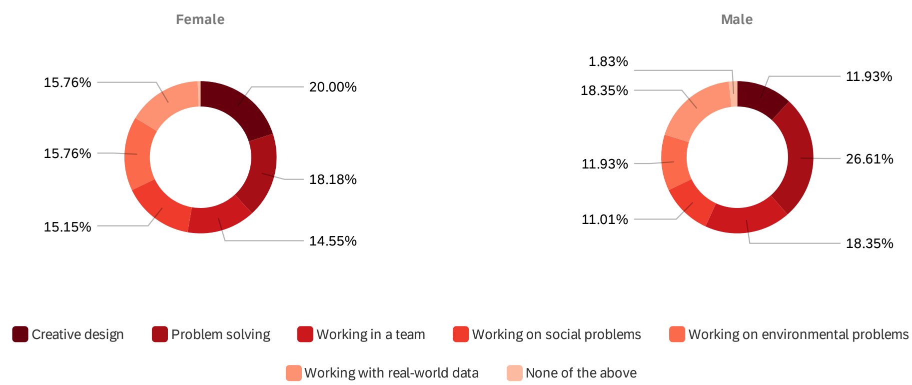


Figure 7: Elements of Computer Science projects that would appeal to our survey participants, broken down by the gender identities of our participants. Each chart represents the percentage of participants with that gender identity who found project aspects appealing; for example, 20% of women found creative design appealing.

participants, and note that there are similarities across these groups. Typically, all the noted elements would appeal to both women and men. For **men, problem solving** (27% men's responses), **working in a team** (18%) and **working with real-world data** (18%) were more popular elements. For **women, creative design** was the most popular (20% of women's responses) and **working on social or environmental problems** were more appealing than they were for those identifying as men.

To uncover more detail about the types of Computer Science projects that would appeal to the participants, we provided a free text form box allowing them to input their own ideas for introductory courses. 57 participants (32 women, 25 men) suggested **coding projects** as a way of introducing someone to Computer Science, with 43 of those 57 (22 women, 21 men) mentioning that the projects should hold some **real-world application**. For example, *"Ones with real-life applications – I can see a direct use for what I am doing and will inspire me to learn more about a career in that sector."*; and *"For me, maybe linking real-world problems to solutions that can be fixed with* [Computer Science] *e.g. an introductory on how to build apps or websites while people keep in mind how their vision can solve or improve something."*

Eight participants also mentioned that coding projects should **have a social good or an environmental application**, e.g.: *"Programming, data analysis and AI* (Artificial Intelligence) *with a link to improving society issues, whilst developing the skills that are transferable to future careers in order to contribute to improving society for all. Environmental/ Health and Social Care."*. Others (9 participants) drew upon creativity or gaming e.g.: *"Projects that act as a form of 'game' or provide interesting visual feedback are always more interesting, as you can more easily see how your changes to the code influence the project."*

Easy introductions and beginners' guides were also provided as suggestions (14 responses), possibly given we asked for project ideas for introductory courses e.g.: *"introductory coding; an overview of how the domain of* [Computer Science] *is composed."*, *"Starting off simple but step by step and comprehensive explanation of why we do such things"* and *"Anything that could be easy to follow for beginners whist showcasing a wide range of computer science."*

When asked if the participants would change their project ideas to explicitly engage underrepresented groups in Computer Science, **more than half of our participants (53/83) said that they wouldn't change their idea** or did not provide an example of a change to their idea. Some participants even used this free form text entry to provide more explanations of their ideas and emphasise why it would be interesting for underrepresented groups. Others suggested changes, for example: focusing on the **social benefits** of Computer Science; making projects more **creative** or linking them to **students' passions**; focusing more or less on gaming; or linking projects to those underrepresented groups (e.g. *"appealing to senses of injustice of these underrepresented communities"*).

Suggested changes also linked to **aspects of teaching Computer Science and perceptions of the field more generally**, for example providing more support for students who are not confident in maths, or emphasising the wide scope of Computing: *"Maybe something to show that coding skills are not enough to excel at a* [Computer Science] *job. Other, transferable skills are very much needed as an employer can teach you your hard skills. To encourage people passionate about technology but lacking needed skills to pursue their interest."* One participant noted that the **applicability of a project** should be emphasised in a detailed way, and suggesting role models in the field would be useful for underrepresented groups:

> *"Expanding on what I previously said, I think showing direct jobs/ careers which certain work can lead to can be inspiring (particularly if there is a famous female in this sector already, for example). They should be useful and fun and the diverse topic of computer science should be demonstrated – not just 'fixing computers' or 'working in an office' – more like 'developing and coding robots which can traverse nuclear wasteland and detect bombs where it would be too dangerous for humans' for example !! :)"* (Anonymous survey entry).

The need for an emphasis on the applicability of Computing to the real-world, as well as the suggestions for socially beneficial or creative projects, supports the findings from the school survey (Sections 2.1 and 2.2). Adapting teaching support and the perceptions of Computer Science could also help with the image problem in the discipline found in the school survey (Sections 2.2 and 2.3), as well as some noted uncertainty to belonging in Computing (Section 2.4).

4 Focus groups

To build on the insights from the surveys, we conducted four two-hour focus groups in January 2021 with a total of 13 participants (see Table 1 for a summary of the participant groups). These focus groups aimed to uncover some of the barriers to an inclusive environment, and utilised innovation and ideation methods to develop specific solutions for improving women's sense of belonging in Computer Science education. Participants had to identify as women and consider themselves within the discipline of Computer Science at Lancaster University. Since we, as project members, fit the recruitment criteria, we ran a pilot workshop (group G1) to reflect on our own experiences and solutions for creating a sense of belonging in the discipline.[7]

Participants for the other groups (incentivised by £10 vouchers) were recruited through relevant mailing lists for undergraduate and postgraduate students in the School of Computing and Communications at Lancaster University, as well as via snowballing methods and relevant Microsoft Teams groups (e.g. the departmental women's group). All participants were required to provide informed consent to partake in the study, and the study was ethically approved by the Faculty of Science and Technology Ethics Committee at Lancaster University. The workshops were framed around a combination of Adobe's KickBox practice [1], and Silverstein et al.'s concept trees and imaginary brainstorming [13]. This allowed the exploration of problems, and the categorisation of these, to be drawn upon in solutions—enabling the ideation of solutions from *beyond Computing* that could then be applied to the issue of gender inequality in the discipline. All focus groups were carried out online via Microsoft Teams and followed the schedule below, stepping through a process of understanding the participants' perceptions of belonging and how those can ultimately be fostered in Computer Science education:

1 Introductions. Participants were asked to introduce themselves to each other, alongside their background in Computer Science education.

2 Sense of belonging sentences. Participants were asked to write down what a sense of belonging meant to them in 1 minute. These were then shared amongst the group and summarised by the facilitator.

3 Sharing experiences: where they did not belong. Participants were given 10 minutes to note down as many experiences where they themselves, or a friend or colleague, have felt that they did not belong. These were then shared via the Teams chat and discussed as a group.

4 Sharing experiences: where they belonged. Similarly to the previous exercise, participants were given 10 minutes to note down as many experiences

[7] Note that we ran the pilot version of the focus group (group G1) in two separate hour-long sessions. Based on our own reflections on the study, we added the 'Sharing experiences: where they belonged' section to the schedule to ensure participants in groups G2–G4 could reflect on their positive experiences of belonging before moving onto the solutions-focused exercises.

where they themselves, or a friend or colleague, felt that they did belong. These were then shared via the Teams chat and discussed as a group.

5 Categorising experiences. Discussing amongst themselves, participants were asked to thematically categorise their identified experiences from the previous exercises of where they felt they did, and did not, belong.

6 Identifying solutions for improving a sense of belonging. Based on the categories developed from the previous exercise, participants were asked to individually note down and then discuss potential solutions for improving a sense of belonging.

7 Applying the solutions to Computer Science and schools. Drawing on their solutions to improve a sense of belonging, participants were asked to discuss how these solutions could specifically be applied to Computer Science education in schools.

8 Identifying the group's priority solutions. The group were asked to select their top 3 solutions, discussing why these should be prioritised.[8]

A facilitator, sketchnote taker, and note taker were present at each of the focus groups, and the focus group was also audio-recorded. All focus groups were fully transcribed and thematically coded for analysis. Sketchnotes from the focus groups are available in Appendix B. In the rest of this section, we detail the main findings from the focus groups based on our analysis.

Group	Participants	Group Type
G1	P1, P2, P3, P4, P5	Staff
G2	P6, P7	Students
G3	P8, P9, P10, P11	Students
G4	P12, P13	Students

Table 1: A summary of the participant groups. Note that the student group type includes undergraduate, postgraduate taught, and postgraduate research students; the staff group type includes postgraduate research associates, lecturers, and professional services staff.

4.1 Overview of the participants

Our participants had a **variety of routes into the field of Computer Science**. Only four participants referred to experience in the discipline at a young age, for example by learning to code as a hobby (P3), at school (P9), or through formal qualifications such as GCSEs and A-Levels (P1–2). To study Computing at this stage of life, some of these participants had to overcome barriers: P2

[8]Note that this exercise was done before the previous in G2. We changed the order for G3, G4 and the second part of G1 to provide more time in the focus group for the participants to discuss more solutions.

had to join a local college to study Computing, using programming magazines to feed her enthusiasm in debugging code; and P3 had to teach herself to program, utilising BASIC as she had access to this language. Other participants joined the field later in their careers as an undergraduate student (P6, P8) or as a postgraduate student or researcher (P3–5, P7, P10–13).

In terms of the subject material that captured our participants' interests in Computer Science, **interdisciplinary degree programmes** (P3, P6) and **applied areas of Computing** played an important part. These included Cyber Security and Cryptography (P2, P9, P11), Data Science (P10, P12–13), creating games (P2–3), and the societal factors linked to Computing (P3–6) such as social justice and sustainability (P5) or understanding how technology shapes society (P4). Experience in **related STEM subjects** were also common in our participants' journeys into Computing, such as past degrees or interests in Maths, Statistics and Engineering (P8–13). P8's interest in Maths led her to consider a Maths undergraduate degree, but she instead chose Computer Science as this seemed to her to be the obvious career path for a Maths graduate.

Beyond the subject itself, other factors affected the participants involvement in Computer Science. For P7 and P13, they were specifically **encouraged by others** to begin study in the field—similar to P9 whose father brought home the BBC micro:bit for her to engage in. Furthermore, while P3 programmed at a young age, she believed she got to a stage where she had to choose between her hobbies of Art and Computing: *"I felt like computing was something you had to give all of yourself to and I didn't have the time to have too many extra hobbies so it kind of went by the way side"*. While deciding to pursue Art as her hobby, it was in fact that subject that brought her back to Computing later in her life as she embarked on her interdisciplinary degree programme.

While all our participants work in the domain as staff or as a student, some of our participants indicated a **form of identity crisis with Computer Science** (P3–5, P7). These included, for example, questioning whether they are 'in' Computer Science (P3), classing themselves as an 'anomaly' in the field (P7), or reflecting on their routes into Computing (P4–5, P7). For the latter, P4 questioned how she ended up in her current Computing role due to previously studying more social science subjects than those traditionally classed as STEM, referring to the journey as *"a bit wild"* and still feeling somewhat uncomfortable in the domain given her skills lie outside of programming. Similarly, P5 described her route into the field as *"circuitous"*, and P7 even mentioned how there is a standing joke in her family that she is pursuing a PhD in Computer Science due to her short background in the field.

Despite such feelings, P3 positively reflected that it's *"nice being the odd one out sometimes"* as it led to her involvement in the focus group, as well as similar events more generally. This links to some of our participants **interests in equality or initiatives for improving gender equality in Computing** (e.g. BCS Lovelace), as P6, P7 and P9 all reflected on this issue as being the reason why they wanted to be involved in the focus group research.

Figure 8: A word cloud visualisation of our focus group participants' 'sense of belonging' definitions, where more common words used in definitions are depicted in larger text. Note that the participants' definitions were shortened to one or two sentences for this visualisation (i.e. further detailed descriptions were omitted); stop words (e.g. 'and') were also removed and lemmatisation processes were taken to reduce words to their base meaning (e.g. 'feeling' becomes 'feel').

4.2 Defining a 'sense of belonging'

In the first task of the focus group, participants were asked to define what a 'sense of belonging' meant to them. Figure 8 visualises the different words the participants used in these definitions, with particularly notable words and phrases including 'feel', 'part of', 'place' and 'community'. In fact, nine of the participants (P1–3, P5–7, P10–12) referred to their sense of belonging as **being or feeling part of a community**, place or space, i.e. a 'somewhere' or 'something' that was bigger than them as an individual. Within this, three participants drew upon having **shared values, interests or commonalities** with others that they can discuss, or having a common goal they can work towards together (P4, P8–9).

To feel a part of such communities, **acceptance for being who you are** was an important aspect to some of the participants, as P6 describes: *"I feel like I belong when I'm in a place where I'm loved and respected for who I am rather than who I have to conform"*. While some participants explicitly noted how belonging meant they would feel 'needed', 'appreciated' or 'valued' for their skills or for who they were themselves (P1–3, P8), others focused more on being accepted for their overall identities (P2, P6) and their feelings of safety or comfort with others in a community (P9, P13). For the latter, P9 reflected that it may only take one person to make you feel excluded or uncomfortable, and thus noted the fluidity of feeling part of particular community as it changes over time.

Beyond the community element, participants associated a sense of belonging to **applying their skills and achieving their career goals**, such as being useful or contributing to a space (P3, P7, P10), *"following my passion"* (P11) and *"to achieve my goals and dreams"* (P12). For P12's career goals, she also referred to belonging as having equal opportunities to others, or having the necessary mechanisms and guidance to achieve her dreams; this indicates feelings of being supported or encouraged by others, linking back to that important sense of community. Contrasting to P12, P11 explained her view of belonging to initially develop from *within*: finding your niche skills for a particular field, and *then* being known for that by everyone in the community.

4.3 Lived experiences of not belonging

In this section, we report on the experiences when our participants felt they did not belong. These formed four overarching themes detailed below, consisting of: being made to feel different as themselves (Section 4.3.1), the existence of expectations and norms (Section 4.3.2), being part of an underrepresented group (Section 4.3.3), and feeling ignored or excluded (Section 4.3.4).

4.3.1 Being different, being 'you'

Our participants expressed examples of not belonging within a space that linked to how they were different to others, and how that was perceived, accepted or treated—either by themselves or others. These included **physical differences** (e.g. wearing glasses, body shapes), **differing personality traits** (e.g. being quieter or less open than others), **varying values** or opinions (e.g. to materialism, religion), **cultural differences** (e.g. language barriers), and having **contrasting circumstances** to others (e.g. living elsewhere, having to work while studying). Our participants described moments of when they were specifically singled out for being themselves, referring to such experiences as 'unpleasant' and other people as 'horrible'. Yet sometimes these experiences were much more nuanced in that they linked to *assumptions* of what other people were thinking and how that made them feel; for example, feeling judged or misunderstood from others' actions and thus feeling 'alien' within a setting or group as P5 describes: *"people kind of look at you and go, 'what an earth are you doing here?' You know, 'you're not going to be able to do this sort of thing', and that feels sort of alien"*.

4.3.2 Existence of expectations and norms

Our participants described how the existence of expectations and norms made them feel like they didn't belong. These included what others personally perceived the participants to be and their **expectations of them**—linking somewhat to Section 4.3.1. For example, P8 described how people expected her to be perfect in every academic subject given her performance record, or would question why she wanted to try new hobbies that differ to those she currently excels at. Yet the majority of the participants' experiences of expectations and norms were formed at a societal level, making them feel like they shouldn't be part of a particular community or workplace. Examples given included **stereotypes** of what a Computer Scientist should be, as P4 describes: *"like a computer scientist is someone that programs in language A, language B, and language C kind of thing"*. Examples also linked to what roles women were expected to play—assuming they would be talented at design (P8) or sales (P9), or wish to be a housewife (P11)—and being questioned for taking a different path. P2 reflected that challenging such stereotypes can be tiring, describing them as a *"never ending uphill battle"* and having *"a constant sense of 'why bother'"*.

4.3.3 Being in an underrepresented group

Linked to the societal expectations and norms our participants discussed (Section 4.3.2), the participants provided experiences of where they felt they did not belong due to having a specific characteristic (e.g. age, gender) that was underrepresented within a space (e.g. a fitness class, a Computing course). Such experiences sparked feelings of self-consciousness (P2), alienation (P4–5), depression (P4) and loneliness (P5)—making it difficult for them to feel like they could belong or join in within a group, or questioning themselves for making a particular choice that brought them to that space. Alongside these **feelings of being the underrepresented group**, participants also spoke about experiences where they were **treated differently to the majority**. For example, being subject to sexism as a student, at work or as a tutor (P6, P9) such as people being shocked for the participants knowing about technology (P9, P11)—as P9 describes: *"I've been in presentations where I've been assumed to be the secretary, there's nothing wrong with being a secretary but I was there to do the technical speak, like just immediately isolates you"*.

4.3.4 Feeling ignored or excluded

Our participants also drew on experiences where they felt ignored, unacknowledged, or specifically excluded in a particular setting or group. For example, having your **contributions for a project or meeting overlooked** or ignored by others (P2, P7, P9), or having someone else take credit for your hard work and ideas (P7, P9)—as P7 describes: *"a kind of more senior person comes along and says 'oh yes, we've done this work' and doesn't acknowledge that you've done it"*. P9 expressed that her experiences of this were a result of the sexist actions from others—linking back to Section 4.3.3. Beyond work environments, our participants discussed social situations where they felt excluded as others knew each other or formed groups without them (P12–13). P8–9 and P12–13 all reflected on the importance of first impressions and that **initial sense of belonging** to an environment, referring to feelings of exclusion from *"a bad welcome"* (P13). P13 describes this feeling of being out of place from her experience of arriving late to a summer camp: *"everyone else knew each other already, and they all knew like silly songs and like all people's names and I'm bad at names anyway,* *and I was so jet lagged and so overwhelmed"*.

4.4 Lived experiences of belonging

Contrasting to the Section 4.3, here we report on the experiences when our participants felt they *did* belong. These formed four overarching themes detailed below: sharing commonalities with others (Section 4.4.1), feeling included and acknowledged (Section 4.4.2), being in a supportive environment (Section 4.4.3) and finding where the participants thrive (Section 4.4.4).

4.4.1 Sharing commonalities with others

Our participants reflected on how **having similar interests, values, identities** or other commonalities with people enables them to feel like they belong in a group—as shown in the definitions of a sense of belonging (Section 4.2). For P6, she discussed how simply hearing people talk in meetings or events about issues she cares about, such as sustainability or equality, can make her feel more connected to the group. This sense of a common goal was also highlighted by P9 and P13, with P9 reflecting on how taking a lead in **forming groups** that bring women together in Computer Science make her feel like she belongs in the field: *"I feel like I'm helping and I'm also getting back from the community as well, it's a two way thing, so I really feel at home there"*. Participants also brought up spending time with specific people–and in this case their **friends**–rather than just their shared interests or goals: they feel like they can 'connect' (P6) or 'be relaxed' (P7), with those people and 'never have to explain yourself' (P13) due to knowing so much about each other and your histories.

4.4.2 Feeling included and acknowledged

Opposing the feelings of being ignored or excluded as described in Section 4.3.4, participants discussed their experiences of when they were explicitly included or **acknowledged for their contributions and skills**—emphasising their sense of belonging. Examples included people asking you specifically for advice (P7, P9), people agreeing with your thoughts and ideas (P7), and your opinion or view is taken into consideration (P8, P12). For P11, she noted that it's important **to be heard and not judged**: *"when we have like a team when it's not judgemental of everything we do or say so I think that's when we feel we really belong"*. This links to similar views from P8, whom drawing on experience of group projects, acknowledged that while everyone's different opinions may not be the most applicable solution to the task they are undertaking, *"the things that you say, they still need to be like discussed"*. Feeling included despite differences was also raised by P6: she mentioned that while her family don't know her academic side, they still love and accept her for who she is.

4.4.3 Being in a supportive environment

Similar to the environments where our participants felt included (Section 4.4.2), our participants reflected on how being in a supportive space or **encouraged by others** made them feel like they belonged. These included: P9 having a support bubble with her neighbours during the Covid-19 pandemic, P11 being encouraged by close family and friends to pursue a master's degree, and P12 having a university tutor that would always check if the students had any questions or needed help in classes. P11 also gave a example of when she was giving a speech at a conference and all the other speakers were male, yet the conference organisers did an 'amazing' thing for her: *"the organisers were really supportive and they thought 'you have to be so much prouder that you're the only woman here, go on and rock the stage'"*. Learning from her own experience of feeling unwelcome at summer camp (Section 4.3.4), P13 returned to the camp in later years and began to create new traditions to **support newcomers** and make them feel like they belonged there. P10 also reflected that if she begins to feel comfortable in an environment by developing close relationships with others, she forms good memories—building her sense of belonging.

4.4.4 Finding where you thrive

Our participants described how **discovering where their skills are best placed**, and the development of those skills, made them feel like they belonged—such as being offered the opportunity to perform in competitions (P8), feeling like they are studying the correct course (P13), receiving awards for best student performance (P9), and **no longer having feelings of 'imposter syndrome'** (P6–9, P13). This was described by some participants as a form of journey to a place of belonging, with P9 finding her niche in the Software Engineering world and P13 recognising that her master's degree suits her more than her undergraduate. P10 describes this journey in her career, particularly as she left a job where she did not feel confident, where she felt she underperformed, and where her skills did not match the role: *"it was like asking the frog to fly"*. As she found a new technical role which utilised her expertise, she **developed more confidence** in herself and realised the issue lay with her previous working environment: *"I start to bloom... I understand that the problem was with something else that I didn't belong to that environment. I shouldn't force myself to get compatible with the environment which was not suitable for me"*.

4.5 Solutions for improving a sense of belonging

Drawing on their experiences of where the participants felt they did and did not belong, participants were asked to provide solutions for improving a sense of belonging. These did not have to be specific to Computer Science or gender equality, but rather for a more general view of enhancing belonging. Four overarching themes of solutions were discussed by the participants: daring to be yourself (Section 4.5.1), being aware you're not a barrier to belonging (Section 4.5.2), creating inclusive environments (Section 4.5.3), and engaging in training and development (Section 4.5.4).

4.5.1 Dare to be yourself

One solution participants discussed was this idea of 'daring to be yourself', and **building people's confidence in their achievements, interests and self identify** in order to share that individuality with others (P1–2, P7–11). Through this, some participants thought that people–and particularly those in underrepresented groups–can become more resilient to self doubt (P9) or help **challenge expectations and norms** (Section 4.3.2) by setting an example for others (P1–2, P6, P8, P10–11). P6 explains this theory, suggesting that people being open about who they are and being accepted for that would help create more diverse communities and thus more chances for people to feel like they belong: *"if people dared to do what, I don't know, show their quirks, then the world would be a little more colourful, erm, more interesting anyway... then if teams were more diverse, places were more diverse, like people would like feel less out of place because there's always someone who's a little bit like them"*. Linked to this, P11 described how she already tries to set an example for others by encouraging women in her community to get interested in studying: *"I assure them 'I did it girl, you can do it, it's fine to do it!'"*.

4.5.2 Be aware you are not a barrier to belonging

Despite the suggestions for building confidence and focusing on people as individuals (Section 4.5.1), some of the participants highlighted that it is important to know that you are not necessarily the issue, or a barrier, when it comes to feeling a sense of belonging. Rather some feelings of not belonging may be due to **systemic issues in society**, and there are **other people who also do not feel like they belong** in an environment. The participants suggested raising awareness of such issues and recognising that there is only so much you can control and change. Given this, some participants suggested people should leave a particular environment or job, or try new things to find where they belong (P7–8, P10–11); others suggested a course for action should be made beyond the individual (P2, P5, P9), as P5 describes: *"there is a need for bravery and being able to step out of your comfort zone but I think it is unfortunate that that is what's warranted because that's again almost saying 'this is what you need to do', 'you're the problem for not doing this'"*. P2 offered possible solutions to a more collective approach, for example by bringing underrepresented people together so they feel more represented in a space (i.e. sharing commonalities with others, Section 4.4.1), or by having 'friendly allies' that are in majority groups and are happy to help create a sense of belonging for everyone.

4.5.3 Create inclusive environments

To create a sense of belonging for everyone, participants discussed this idea of creating an inclusive and supportive environment—ensuring everyone's **needs**

are being met (P5, P12), that people are **treating each other with respect** regardless of differences (P5–6), and enabling **open and inclusive conversations** (P2–3, P8–10). Mechanisms for this included: noticing when others feel uncomfortable and reaching out to them (P5, P8); and establishing ground rules for interactions (P6), such as ensuring everyone has time to speak, be listened to, or get to know one another (P2, P6–7, P13). Given the issues P12 and P13 faced regarding their poor introduction to events or groups (Section 4.3.4), P13 described that there should be specific **roles or initiatives dedicated to answering your questions and making you feel included** in a space as you arrive (e.g. a buddy scheme)—emphasising that first impressions count when it comes to feelings of belonging: *"when you start a new job, like the first thing you do is sit and sign a thousand forms or like, you arrive to a desk and there's a laptop sitting there and like a key fob, and then you have to sit and do a whole load of induction stuff... think how much of a difference it would be if there were balloons on your desk or someone came and took you out for lunch"*.

4.5.4 Training and development

In order to enact solutions to enhance feelings of belonging, the participants discussed that people should have access to specific training and development opportunities. These included engaging people within a community to take **unconscious bias training** (P2, P4, P6), or join **mentorship initiatives** that can help you or others (P9)—similar to the buddy scheme suggested by P13 (Section 4.5.3). Part of the discussions around such training and development linked back to **taking responsibility for learning about differences**, as P4 describes: *"I know for me I feel like I've got a lot of learning to do when it comes to like understanding trans issues... I think just taking a bit of responsibility of like knowing these, we've got a sort of a journey to go on in terms of like learning"*. Through such learning journeys, P4 highlighted that we can recognise our own limitations in equality, diversity and inclusion and begin to address those—thus a potential first step to our participants' solutions of challenging stereotypes, embracing diversity, and not judging ourselves or others.

4.6 Belonging in Computer Science

In the final part of the workshop, participants were asked to discuss solutions for forming a sense of belonging in Computer Science education for women and girls. Similar to the more general solutions to belonging outlined in Section 4.5, our participants discussed: raising awareness of the issues regarding belonging and gender equality in Computing; building women's confidence to study Computing and challenge the norms or perceptions of the discipline; and focusing on changing the system rather than the individual for creating more diverse cohorts. These solutions applied to Computer Science would likely strengthen women's determination to study, and their belonging in, the discipline—issues which were present in the school survey (Section 2.4). Yet, in this section, we reveal other solutions that our focus group participants found most applicable to belonging in Computer Science. These included: capturing women's interests in Computing (Section 4.6.1), providing role models and mentors (Section 4.6.2), adapting teaching approaches (Section 4.6.3), adapting language (Section 4.6.4), and training and development (Section 4.6.5).

4.6.1 Capturing women's interests in Computing

Our participants emphasised the need to capture women's interest in Computing (P2, P4) and ensure that they do not lose this interest (P7). Mechanisms for this included **offering multiple topic options for projects** (P2, P13) that form commonalities between the student and the subject (as in Section 4.4.1). By offering multiple choices, students can follow a topic they are most interested in and avoid topics that may require an increased cognitive load or level of skill from a different discipline. For P4, she explained how a project put her off programming as it required an *"ability to like visualise space and directions and angles"*, and similarly P1 discussed a project that required decent Maths skills. Both examples created a negative perception of the topic, of which could've been avoided through projects capturing their interests and utilising their skills.

Moreover, our participants suggested linking Computing projects at school to **real-world or creative problems** (P2–7)—emphasising the applicability of Computer Science (P6–7), such as through project-based teaching methods (P4–5) or by ensuring projects lead to the creation of 'tangible' and 'visual' outputs as a measure of success (P2). By showing Computer Science's applicability to the real-world and the breadth of the discipline itself, P6 discussed how the Computing will become more attractive to women:

> *"When you realise what Computer Science is, at least what you didn't know before, then I think it's much easier to get kind of hooked because it's not that girls wouldn't be interested in it. I mean like Maths has almost 50/50 in terms of recruitment, I mean, a lot of girls like to do puzzles, and that's a lot of what Computer Science is but yeah I think if it was a purely technical subject I think lots of women including myself are just missing that how do you make a difference by just coding, or some technical thing"* (P6).

This finding relates to the school survey, where there is need to change the image associated with Computing to emphasise how the subject and careers in the domain can be socially beneficial (Sections 2.2 and 2.3). It also supports the Lancaster University survey, whereby women found working with real-world problems for society and the environment more appealing than men (Section 3.2).

4.6.2 Providing role models and mentors

Our participants discussed the importance of role models and mentors to create a sense of belonging for women in Computer Science education (P1, P8–9, P11, P13), reflecting on how they themselves are acting as role models or sharing stories of their own mentors. For example, P8 and P9 wondered whether their **parents engagement in Computing** influenced them to study the discipline; and P11 discussed how role models are one of the best solutions: *"cause we also as a woman have been inspired by so many people right, so that is the main thing which I really want to do, cause I do go to my schools and really, just have a chat with them and get it on with it"*. Similar to P11, P9 emphasised that the participants could **live by example** (as like Section 4.5.1), *"talking about the hurdles that we had, and showing* [the students] *how we overcame them"*. With this, P9 went onto discuss how becoming a role model can create a form of **domino effect**, as her involvement in local code clubs led the school students to run their own code club for younger years: *"it was really sweet when* [the student] *was like 'we do what you do'"*. For implementing a **mentorship scheme**, P12 suggested meeting people who have done a course you are considering; and P13 noted how mentors may only need to be one or two years ahead of you in terms of education progression, as long as the mentee can express their worries. However, P13 also emphasised that assigned tutors or mentors must be **fully engaged and care about the mentee**, as having someone who doesn't care can be more detrimental to belonging *"than not having anyone to start with"*.

4.6.3 Adapting teaching approaches

To ensure women feel like they belong in a Computing classroom, the participants drew upon the need for a supportive environment (Section 4.4.3) that enables them to learn and develop confidence in the subject. For this, they discussed adapting teaching approaches (P5) to ensure there is a **focus on learning outcomes** (P2), and that **students meet those outcomes** by checking in with them and addressing their questions (P12–13). To guarantee people feel comfortable asking questions in the first place, the participants emphasised the need for classroom environments to **praise questions and provide different ways to ask them** (P8–9, P11, P13), given asking questions in front of peers can require courage. P9 explains how they do this at her local code club: *"if someone asks a question we see if someone else can answer it rather than me giving the answer so then you understand why nobody else knows the answer and then the person asking the question doesn't feel quite as, well 'is it just me?'"*.

Moreover, our participants emphasised the need to **celebrate failure** in Computing (P2–5, P10)—removing the feeling of having to be perfect first time and instead learn by doing, as P5 describes: *"you don't learn by getting things right first time every time but you know, you've learned by getting things wrong"*. To celebrate failure, P5 suggested sharing stories of where scientists have gone wrong before their successes, and P4 loved the idea of reframing mistakes as a problem-solving learning tool: *"even being able to like see a mistake and be like 'oh, what a cool mistake!' like, 'there's so much to learn from this one!' 'Hey let's see what went wrong!'"*. For the latter, P2–4 suggested teachers could create an environment where the **individualisation of mistakes is removed**, such as focusing on 'bugs' rather than 'mistakes' or 'errors' in programming code that the student is facing. Our school survey participants highlighted that they most dislike projects that seem difficult or complicated (Section 2.1), and similarly the perceived difficulty of Computing was a noted barrier to the discipline for Lancaster University survey participants (Section 3.1); reframing failure and mistakes may help break these barriers and make challenging topics in Computer Science more enjoyable.

4.6.4 Adapting language

As a form of creating an inclusive environment and thus ensuring women's sense of belonging in Computer Science in schools, the focus group G1 participants discussed the important of adapting language—mostly from the teachers' perspective. This solution was two-fold: 1) **use gender neutral language**, and 2) **be aware of hidden bias in vocabulary**. For the gender neutral language, P1 mentioned how she is trying to avoid pro-nouns in emails and P3 is pursuing the same in the classroom: *"sometimes I'll say the wrong thing and panic, I'll go oh, whatever, this man, no woman, no non-binary, ahh! You can say all the things, and that sounds even more weird but I'm glad I tried"*. Yet P2 highlighted that this adapting language technique is more than just the pronouns, but also *"non-coded normal language"* that suggests hidden bias in vocabulary. While she explained that particular words are not always obviously biased–such as 'leadership'–once you learn the principles behind these words, the bias begins to make sense: *"how can leadership be a gender thing? And I'm going, oh yes it is* [laughs] *we like collaboration, or co-leadership, or part of a leadership team"*. To make such bias in vocabulary more widely known, P2 suggested there's a need for open conversations to share, discuss and learn; and P1 called for pronouns and vocabulary to be included in unconscious bias training, discussed next.

4.6.5 Training and development

To adapt and understand how to create a sense of belonging in Computer Science education, the participants focused a lot on the need for additional training and development—both **for staff and students**. As with the more general solutions in Section 4.5, participants discussed the need to not *"judge the others for their tastes, for their interests"* (P10) and *"not be judgemental when some people like comes and really ask for help"* (P11), and thus participants called for **training courses on unconscious bias** (P1–3). Yet G1 also highlighted the need for a *"two pronged education"* (P3) which focuses on current unconscious bias and inclusivity, as well as **education about the history and bias in Computing** (e.g. the history of women in Computer Science, and examples of discriminatory technology design). P4 discussed how this will help people change the way they look and emphasised the need for teaching resources on bias technology design: *"sometimes you just need these things pointing out to you to realise a broader perspective on things"*. Adding to these topic-focused training activities, the participants emphasised a need for additional **training on mediating or setting groups** in Computing education settings, to ensure different diversity groups are supported and feel comfortable (P2–5). For this, P12 discussed the importance of groups getting to know each other before they learn together, and P13 discussed making groups based on commonalities beyond diversities:

> *"If they had like different interests I suppose, like people who were maybe to do like gaming stuff or people who were maybe wanting to do like data science stuff... I don't even think it has to be subject related like, it could be more like something funny, like at camp we had silly things to make you sit on particular tables so it would be 'sit here if your favourite colour is blue'... it like mixed up the different groups and it meant that you were discussing with different people so I suppose if you were doing different breakout groups within the classroom and it could be like that because it makes you feel a bit more organic I think"* (P13).

5 Summary

In this report, we have analysed and detailed the findings from three studies: 1) a survey with female A-level Computer Science students (Section 2); 2) a survey open to all staff and students at Lancaster University (Section 3); and 3) innovative focus groups involving women undergraduate and postgraduate Computer Science students at Lancaster University as well as the project team (Section 4). From these, we have been able to uncover some of the issues women face regarding their belonging in Computer Science, as well as how Computing can be made more attractive for widening participation in the discipline.

From these findings, we are able to provide tangible **recommendations for Computer Science education that aim to foster a sense of belonging** for women, and envision that these recommendations will be useful for fostering a sense of belonging for other underrepresented groups in STEM subjects. Our recommendations can be broken down into three fundamental areas: educational materials (Section 5.1), inclusive educational environments (Section 5.2), and recommendations for educational practitioners (Section 5.3). These recommendations are described below, and also used as a basis for the infographic in Figure 9—providing an example of a **poster resource for educators** or memory aid for 'fostering a sense of belonging in Computer Science education'. We then end our report with a summary of future work in this research domain.

5.1 Recommendations for educational materials

One of the main recommendations this report poses is that projects should be made **real-world and tangible** to students, and learners should be given multiple project options so that they can that select **project topics which relate to their own interests and passions** (as recommended in the focus groups, Sections 4.6.1 and 4.5.3). Having freedom and independence, and capturing women's interests by offering projects that are creative and link to social or environmental problems is supported by the schools survey (Section 2) and the Lancaster University survey (Section 2). Our Research in a Box initiatives (`www.researchbox.org.uk/`) provide examples of such real-world projects that aim to encourage wider participation in Computer Science.

Computer Science education should also **teach students about the history of Computer Science**. Teaching all students about a range of diverse role models when it comes to gender, as well as other attributes such as race or sexual orientation, will enable students to see themselves reflected in both the history of technological innovation and potential careers (Section 4.6.4). This is equally important when it comes to language [8, 2] and the effect that unconscious use of biased vocabulary can have on students—whether it is spoken to students or written into teaching materials. **Guidance on removing bias from speech and teaching materials** should be provided.

5.2 Recommendations for inclusive educational environments

Creating an inclusive environment in any setting was raised repeatedly by participants in the workshops (Section 4), and this must be extrapolated to apply to educational environments [5]. One of the ways in which this can be implemented is through **mentoring schemes**, which was raised by participants on multiple occasions (Sections 4.5.4 and 4.6.2). Mentoring has shown to be an effective way of supporting underrepresented groups in fields [7], and can be seen as a vital way of supporting women in their Computer Science education.

When it comes to classroom or after school activities themselves, how they are carried out must also be considered. Ideas included **celebrating failure**, as failure in computer programming is often something which constrains women when it comes to development [11] and **removing the individualisation of mistakes** were raised as important opportunities to allow for an inclusive educational environment (Section 4.6.3). Such reframing of failure and mistakes may help overcome perceived difficulty or barriers to challenging topics in Computing, as raised by our surveys (Sections 2.1 and 3.1).

Alongside this, **ensuring respect** (Section 4.5.3) amongst peers and towards the students could be achieved by **providing training on unconscious bias and group mediation** (Section 4.6.5). Awareness of gender equality issues from such training may also help students understand that they are not the barrier to belonging in Computer Science (Sections 2.4 and 4.5.2).

5.3 Recommendations for educational practitioners

Similarly to the importance of gender neutral language when providing materials to students (Section 5.1), it is equally important to ensure that **inclusive language** is used when teaching Computer Science, as gender has a large impact in the 'science of talk' [14]. This could be achieved through **unconscious bias training** for educators which was continually raised throughout the focus groups (Sections 4.6.4, 4.5.4 and 4.5.4) and important for an inclusive educational environment (Section 5.2).

However, the education sector should emphasise the importance of educators to **take responsibility for one's own learning** in regards to principles of equality, diversity and inclusion (ED&I)—recognising any potential bias or gaps in their ED&I knowledge (Section 4.5.4). This may be supported through an understanding of **hidden language** [14, 2] (Section 4.6.4) and an **awareness of the history and bias** in Computer Science (Section 4.5.4). With additional training for educators in these domains, key principles could be passed onto students through the educational materials (Section 5.1) and by creating new norms for an inclusive educational environment (Section 5.2).

Figure 9: An example infographic based on our recommendations that could be used as a poster for educators.

5.4 Future work

In our research, we have investigated and envisioned women's sense of belonging in Computer Science, as well as provided good practice initiatives for encouraging wider participation in the discipline—both through our recommendations (Sections 5.1–5.3) and our Research in a Box initiatives (`www.researchbox.org.uk/`). What is important now is to **bring these recommendations and initiatives into action**, and evaluate whether they have a positive impact on gender equality in Computer Science or encourage other underrepresented groups into the discipline.

As key next steps for this, we aim to gather more representative samples for our university survey (Section 3)–both within Lancaster and at other universities–to gather more generalisable insights. We also aim to conduct further studies with schools, involving:

- running the innovative focus groups with school students to understand their sense of belonging, iterating and building upon our findings and recommendations; and
- evaluating the Research in a Box projects by deploying them in schools and gathering students' feedback.

This supports our original aim of a **cross-strata approach** to addressing the issues of equality in Computing, providing a strong foundation for widening participation in the discipline.

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Lucy Hunt
Chris Bull
Gordon Blair, Jess Davies, John Quinton, Daniel Evans, Peter Diggle, Sue Rennie and Michael Hollaway
and lastly, but definitely not least, Kirsty Blair

— thank you all.

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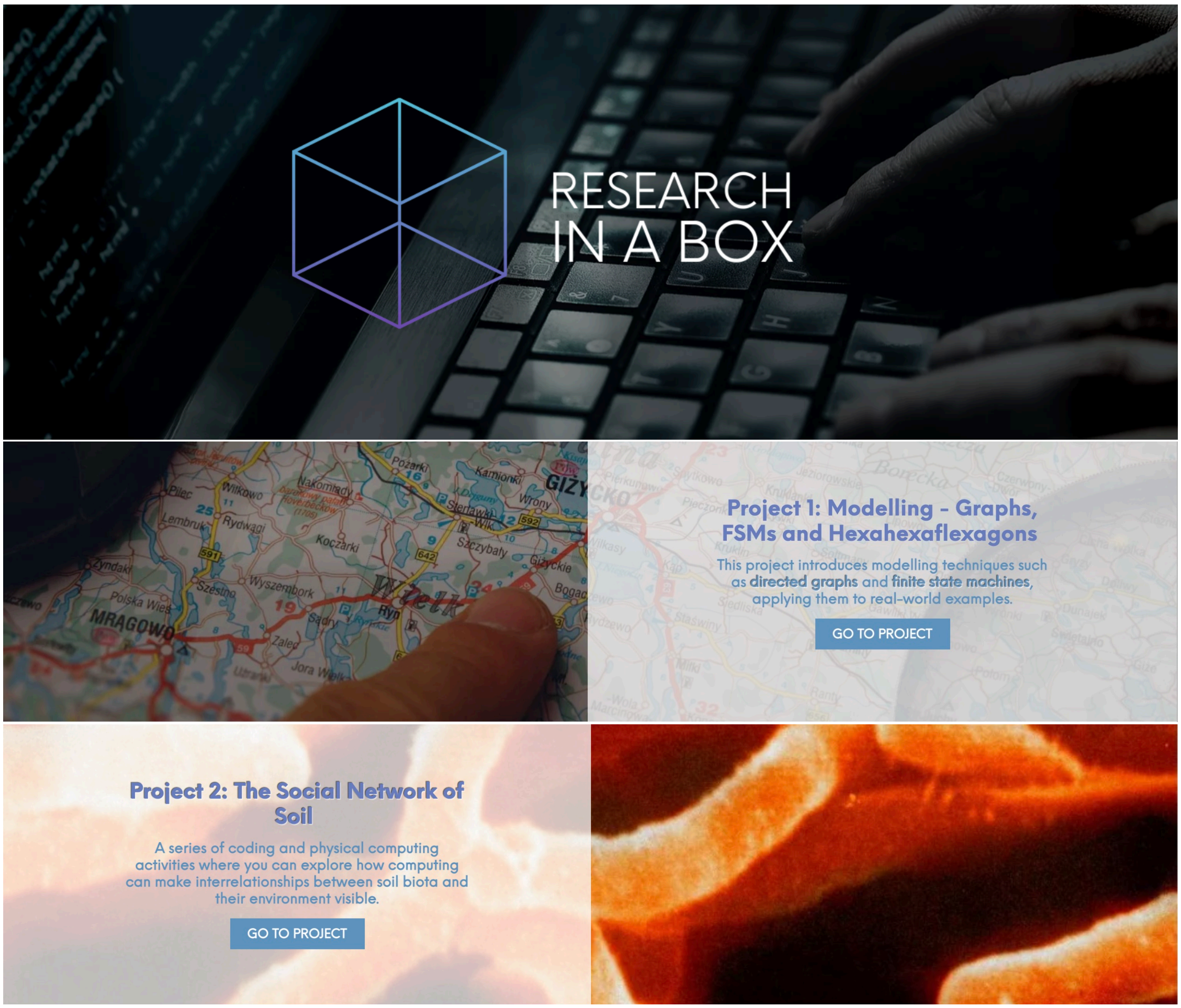
Appendix A Research in a Box

See www.researchbox.org.uk

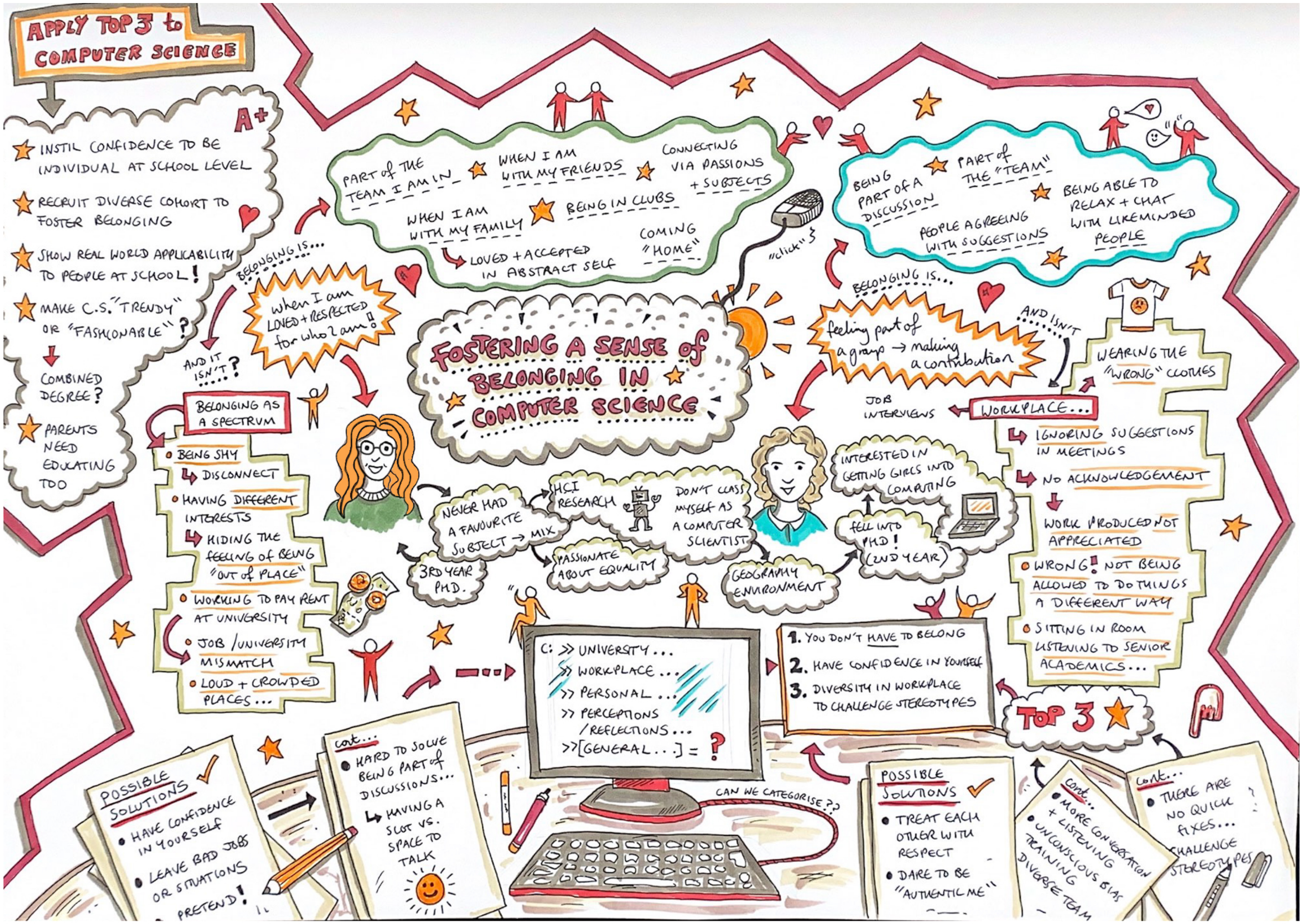



Project 3: Data Visualisation
In this project, we will study how data visualisation, an exciting new art-form, can bring data-sets alive and open doors of discovery to hidden meanings and patterns in data.
GO TO PROJECT
Project 4: Simulation - Agent Based Models & Flocks of Birds
This project introduces agent based models and an associated tool, applying them to behavioural simulations of more complex and interacting real-world examples and eco-systems.
COMING SOON
School of Computing & Communications
Lancaster University
AdvanceHE
© 2021 by Research in a Box

Appendix B Sketchnotes


MINORITY
QUANTITY OVER QUALITY
BEING PICKED ON...
CHARACTERISTIC DIFFERENCES + BEING YOU
DIFFERENCE IN VIEWS
BEING OVERLOOKED
FITTING INTO EXPECTATIONS
WHAT SKILLS ARE WELCOME?
↳ HIERARCHY OF USEFUL
LIVING ON EDGE...
LIVING UP TO EXPECTATIONS OF NORMS
PHYSICAL + CULTURAL + VALUE DIFFERENCES
CHANGE
TAKE ACTION!
● TURN CONVERSATION TO BE INCLUSIVE
● TAKE RESPONSIBILITY FOR LEARNING
● PROVIDE OPPORTUNITIES → NOTICE DISCOMFORT
● INFLUENCE THE PIPELINE TO CREATE DIVERSITY
● BRING DIVERSE GROUPS TOGETHER
● CHALLENGE THE NORMS → DEFY EXPECTATIONS
● BUILD CONFIDENCE → SPEAK OUT
MEDIATION TRAINING?
↳ find ways of making space for quiet people to contribute!
↳ Relates to confidence
FOCUS on full picture of software
↳ e.g. design + UX
↳ choice of build / personal int. / real world
↳ reduce cognitive load
↳ change the language
TURNING CONVERSATION TO BE MORE INCLUSIVE?
SDGs?

TAKING RESPONSIBILITY FOR LEARNING?
• TEACHING MORE ABOUT THE HISTORY of COMP-SCI.
↳ It is diverse! Plus links to UNCONSCIOUS BIAS.
↳ Awareness of PRONOUNS... + LANGUAGE!!
NOTICING DISCOMFORT?
• AVOID SINGLE MINORITY IN GROUPS...
↳ BEING AWARE of OTHER GROUP STRUCTURES
• CELEBRATE FAILURE as a learning process
↳ UNLEARN METRIC of "success at all costs"
• TRY NOT to SINGLE PEOPLE out – even with praise
• IT IS NOT OUR RESPONSIBILITY to cope alone
• BUGS NOT MISTAKES
TOP 3!
REALWORLD PROJECTS!
REFRAMING FAILURE...
EDUCATION
↳ HISTORY / CONTENT
↳ BIASES / BAD DESIGN
THE PIPELINE!!
weeee!



APPLY TOP 3 to COMPUTER SCIENCE
A+
INSTIL CONFIDENCE TO BE INDIVIDUAL AT SCHOOL LEVEL
RECRUIT DIVERSE COHORT TO FOSTER BELONGING
SHOW REAL WORLD APPLICABILITY TO PEOPLE AT SCHOOL!
MAKE C.S. "TRENDY" OR "FASHIONABLE"?
COMBINED DEGREE?
PARENTS NEED EDUCATING TOO
BELONGING IS...
When I am LOVED + RESPECTED for who I am!
PART OF THE TEAM I AM IN
WHEN I AM WITH MY FRIENDS
CONNECTING VIA PASSIONS + SUBJECTS
WHEN I AM WITH MY FAMILY
BEING IN CLUBS
LOVED + ACCEPTED IN ABSTRACT SELF
COMING "HOME"
"click"
AND IT ISN'T?
BELONGING AS A SPECTRUM
BEING SHY
DISCONNECT
HAVING DIFFERENT INTERESTS
HIDING THE FEELING OF BEING "OUT OF PLACE"
WORKING TO PAY RENT AT UNIVERSITY
JOB / UNIVERSITY MISMATCH
LOUD + CROWDED PLACES...
FOSTERING A SENSE of BELONGING IN COMPUTER SCIENCE
NEVER HAD A FAVOURITE SUBJECT → MIX
3RD YEAR PHD.
HCI RESEARCH
PASSIONATE ABOUT EQUALITY
DON'T CLASS MYSELF AS A COMPUTER SCIENTIST
GEOGRAPHY ENVIRONMENT
FELL INTO PHD! (2ND YEAR)
INTERESTED IN GETTING GIRLS INTO COMPUTING
BEING PART OF A DISCUSSION
PART of THE "TEAM"
PEOPLE AGREEING WITH SUGGESTIONS
BEING ABLE TO RELAX + CHAT WITH LIKEMINDED PEOPLE
BELONGING IS...
feeling part of a group → making a contribution
AND ISN'T
WEARING THE "WRONG" CLOTHES
JOB INTERVIEWS
WORKPLACE...
IGNORING SUGGESTIONS IN MEETINGS
NO ACKNOWLEDGEMENT
WORK PRODUCED NOT APPRECIATED
WRONG! NOT BEING ALLOWED TO DO THINGS A DIFFERENT WAY
SITTING IN ROOM LISTENING TO SENIOR ACADEMICS...
C: >> UNIVERSITY...
>> WORKPLACE...
>> PERSONAL...
>> PERCEPTIONS / REFLECTIONS...
>> [GENERAL...] = ?
CAN WE CATEGORISE??
1. YOU DON'T HAVE TO BELONG
2. HAVE CONFIDENCE IN YOURSELF
3. DIVERSITY IN WORKPLACE TO CHALLENGE STEREOTYPES
TOP 3
POSSIBLE SOLUTIONS
HAVE CONFIDENCE IN YOURSELF
LEAVE BAD JOBS OR SITUATIONS
PRETEND!
cont...
HARD TO SOLVE BEING PART OF DISCUSSIONS...
HAVING A SLOT VS. SPACE TO TALK
POSSIBLE SOLUTIONS
TREAT EACH OTHER WITH RESPECT
DARE TO BE "AUTHENTIC ME"
cont...
MORE CONVERSATION + LISTENING
UNCONSCIOUS BIAS TRAINING
DIVERSE TEAM
cont...
THERE ARE NO QUICK FIXES...
CHALLENGE STEREOTYPES


Fostering a Sense of Belonging in Computer Science
How did you get here?
2nd yr PhD ↳ Data Science + Engineering
What does a sense of belonging mean to YOU?
2YR UG → MATHS? ↳ COMPUTER SCIENCE!
3RD YR PHD ↳ WHISTLEBLOWING IN S.E. (USED TO BE SOFTWARE ENGINEER/ENGINEER)
PG. CYBERSECURITY ↳ INTERNATIONAL STUDENT
FOLLOWING MY PASSION ↳ SELF MADE BELONGING
FEELING USEFUL AND ABLE TO MAKE DIFFERENCE
FEELING SAFE, ABLE TO SHARE, + APPRECIATED ↳ GROUP IDENTITY...
BEING APPROVED AND APPRECIATED BY OTHERS ↳ SHARED GOALS
WHEN DIDN'T YOU BELONG?
GOING TO THE GYM + NOT BEING LIKE EVERYONE ELSE...
FEELING OUT OF PLACE IN "BUSINESS CLASS"
BEING OVERLOOKED AS A WOMAN...
PURSUING CAREER ABROAD AS WOMAN
PUSHED INTO UNSUITABLE ROLES...
FEELING INADEQUATE IN SOME SUBJECTS
LANGUAGE BARRIERS
EXPECTED NOT TO KNOW TECHNICAL INFORMATION
BEING INVOLVED IN UNCOMFORTABLE DISCUSSIONS
LOSING CONFIDENCE IN ABILITIES
WE DID BELONG WHEN...
• TRAINING WITH FRIENDS + COLLEAGUES
• HELPING WITH COMMUNITY
• BEING ASKED FOR ADVICE + RECOMMENDED
• OPINION BEING VALUED
• ACCEPTED INTO SPORTS TEAM
• FEELING KNOWLEDGEABLE IN COHORT
• BEING ENCOURAGED BY FAMILY + FRIENDS
• BEING SUPPORTED BY CONFERENCE ORGANISERS
• ENGAGING IN EFFECTIVE COMMUNICATION AT WORK
• CULTURAL EXPECTATIONS
• PHYSICAL CHALLENGE
• SELF CONFIDENCE / INVESTMENT
• CAREER ENVIRONMENT
• COMMUNITY + SHARED INTERESTS
CATEGORIES
SOLUTIONS
TOP THREE?
PICK YOUR BATTLES
START CONVERSATIONS ↳ LEAD BY EXAMPLE
CHANGE CULTURAL EXPECTATIONS
ENCOURAGE WOMEN TO FOLLOW INTERESTS!
FIND OR MAKE YOUR OWN GROUPS ↳ MENTORSHIP
TAKING THE FIRST STEPS
TRY NOT TO JUDGE YOURSELF OR OTHERS
TRUST YOUR INSTINCTS
QUESTION + CHALLENGE SITUATIONS
EMBRACE DIVERSITY
IMPROVE KNOWLEDGE
VALUE OTHERS' ACHIEVEMENTS
SELF CONFIDENCE / INVEST IN YOURSELF!
FOSTER SHARED INTERESTS
CREATE OR SEEK POSITIVE ENVIRONMENTS


FOSTERING a SENSE of BELONGING IN COMPUTER SCIENCE
HOW DID YOU GET HERE?
MSC DATA SCIENCE
loved maths at school
respected person suggested D.S.
MSC DATA SCIENCE
Economics / statistics
WHAT DOES 'BELONGING' MEAN TO YOU..?
HAVING EQUAL OPPORTUNITY TO BE PART OF SOMETHING BIGGER...
SUPPORT + ENCOURAGEMENT TO ACHIEVE
FEELING COMFORTABLE + SAFE TO BE MYSELF
WHEN DIDN'T YOU FEEL YOU BELONGED
ARRIVING LATE TO JOIN A COMMUNITY
JOINING THE WRONG GROUP
BEING THE ODD ONE OUT...
ATTENDING CONF. AS OUTSIDER
BEING 'LEFT BEHIND' ON CAMPUS
STARTING REMOTE LEARNING
WHEN DID YOU FEEL YOU BELONG?
SURPRISE PARTY PLANNED
BEING INCLUDED DESPITE BEING ONLY WOMAN
IN PERSON LAB SESSIONS WITH A GOOD TEACHER
FEELING LIKE I'M ON THE RIGHT COURSE
RETURNING TO CAMP + HELPING OTHERS BELONG
BEING WITH OLD FRIENDS
NO EXPLANATIONS
COMRADERIE IN TEAMS
CREATING CATEGORIES...
COMMONALITIES
SUPPORT + ENCOURAGEMENT
BEING OPEN
SENSE OF COMMON GOAL
WELCOMES
SOLUTIONS?
ENSURE A GOOD WELCOME!
MENTOR / BUDDY
GET CONVERSATION STARTED!
SHARING EXPERIENCE
Bonding activity
SUPPORT / ENCOURAGE
ASSIGN CARING PEOPLE TO HELP
CREATE ENVIRONMENT of SUPPORT
FEEDBACK!
STRUCTURED AND INFORMAL ACTIVITIES TO FIND COMMONALITIES
ENSURE ALL HUMAN NEEDS ARE MET + CREATE COMMUNITIES
FORM SYMPATHETIC SUB-GROUPS FROM LARGER ONES
1. SUPPORT + ENCOURAGEMENT
2. GOOD WELCOMES!
3. COMMONALITY
OUR TOP 3!