Exploring causal factors affecting (potential) female nuclear fusion Ph.D. candidates and their decisions

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Executive summary

The aim of this project was to conduct a scoping study into why lower numbers of female graduates choose nuclear fusion Ph.D.s relative to other physical sciences. This is a particularly nuanced study as we are considering the nuclear fusion research pathway in comparison to other STEM routes. As such, we might expect all females choosing physical sciences post-graduate study to be exposed to similar challenges and enablers, however, significantly fewer females are choosing a research career in fusion physics.

A survey was undertaken, with follow-up semi-structured interviews. The target population was the 21 female Ph.D. candidates who studied within the UK's Fusion Centre for Doctoral Training during the period 2012-2019, with a response rate of 7 and 3 for the survey and interviews respectively. Responses were analysed thematically, drawing out themes from the literature (identified during the literature review) and additional themes arising from responses.

Our findings identify three key enablers for potential female doctoral students in fusion:

> *The presence of role models* (both male and female, but particularly female) who demonstrate potential career progression routes and encourage certain 'ways of working' including: encouraging all types of questions; an openness to being wrong or uncertain; and thinking time not being seen as a weakness or lack of understanding. The importance of role models in demonstrating potential career progression has also been highlighted by Whitelegg et al. (2002).
>
> *Opportunities for work experience within mixed group doctoral labs* during undergraduate degrees. This is supported by the literature, with previous studies showing that women in male-dominated academic work environments experience lower feelings of belonging (Leaper, 2015) and rate their competence as lower than those in other environments (Ulku-Steiner et al., 2000).
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> *Evidence of mixed groups of students and staff* at open days and on courses, and *evidence of an open community* where the sorts of 'ways of working' listed above are encouraged, where gendered attitudes are discouraged, and where there are clear routes for dealing with any challenges that might arise

Our analysis also confirmed previous literature findings that a key barrier for women working in STEM subjects within academia is working within a potential hostile environment in which women may feel patronised, and experience higher expectations of them relative to their male colleagues (Donovan et al., 2005; Hodgson et al., 2000; Leaper, 2015; Whitelegg et al., 2002; Whitelegg, 2004). It is therefore key that in order to achieve the above, higher expectations are not placed on women. Our findings suggest that the challenges are a result of both unconscious and conscious bias, including specific incidents where gender appears to play a role in the negative treatment of students.

Our findings indicate that the majority of students chose to do a Ph.D. early in their undergraduate careers, but chose fusion as a focus either later in their undergraduate careers, or during their masters. This highlights the optimum timing for intervention to be mid-late undergraduate.

This research has been conducted in collaboration with the Fusion CDT through our colleague at the University of Liverpool. As such, findings will have immediate impact, as they will be reported back to CDT staff with the intention to enact changes to improve the gender balance of future CDT cohorts.

As a scoping study, this research will not be published elsewhere, but it is hoped that it may lead to further study within the area. Many potential further avenues for exploration have been highlighted in this report.

1. Introduction

The UK is home to the Fusion Centre for Doctoral Training, comprising five of the UK's top Universities and being almost the main provider of fusion doctoral graduates in recent years (Fusion CDT, 2022). However, only 21 of the 116 doctoral students (18%) in the period 2012 – 2019 were female, compared to the sector average for physical science postgraduate research of ~26% in 2017/18 (IoP, 2018).

Research council-funded CDTs are required to monitor and report the participation of underrepresented groups via an explicit ED&I strategy. The UK's Nuclear Sector Deal includes an ambition to achieve 40% female participation by 2030 (BEIS, 2018). This project aims to identify some of the barriers experienced by female candidates (considering) undertaking fusion doctoral research as well as their expectations. Through this, it is hoped that the project can identify causal factors relating to their choice of research area in the hope that it would be possible to improve female participation and experiences for present and future cohorts.

We begin by looking at the work that has taken place on gendered motivation in STEM subjects for those selecting undergraduate degrees. Eccles (2015) finds that influences include family-based beliefs and practices including parental influence on children's interest and perceived ability in maths. Parents are more likely to attribute good maths performance to effort in girls and natural talent in boys, and furthermore are more likely to consider girls to be more naturally talented at English, regardless of evidence of actual ability (Eccles, 2015).

Literature around experiences amongst women in postgraduate Physics has also identified the challenges experienced by women in particular career paths, with a greater number of female Institute of Physics members reporting career barriers over the age of 30 (45% of those over 30, vs 15% of those under 30) (Whitelegg et al., 2002) and only 25% of younger women choosing to remain in physics research after completing their Ph.D.'s, despite previously noting aspirations to work in this area (Whitelegg, 2004). Our research sits between these two stages, examining the motivations and choices of female graduate students when selecting Ph.D. research.

2. Aims

Project Aim: to conduct a scoping study into why lower numbers of female graduates choose fusion Ph.D.s relative to other physical sciences. The project aims to be a starting point to inform further research in this area.

This research sits within the broader area of female participation within STEM subjects. Despite over a decade of work to promote gender equality in STEM, women still only represent around 25% of the UK STEM workforce (STEMwomen, 2021). Furthermore, there seems to be a unique challenge in relation to nuclear fusion research, which has significantly lower female participation than physical science post-graduate research in other areas (FusionCDT, 2022; IoP, 2018). As such, this study aims to begin to draw out motivations, enablers and barriers experienced by females in this field, in order to inform further study into interventions that may improve the uptake of nuclear fusion research amongst female physical sciences graduates.

3. Activities and survey results

This study began with the gathering of information from current and former female Ph.D. students studying nuclear fusion through the UK's Fusion CDT. It was hoped that this could be used to inform further research to identify whether the motivations, constraints, enablers and barriers experienced by these students were common across all physical sciences subjects, or whether nuclear fusion presents a uniquely challenging research field for potential female Ph.D. researchers (and therefore future career researchers).

To examine this, a survey was constructed to understand the experiences of female students completing (or who have completed) Ph.D.'s as part of the UK's Fusion CDT. Questions were developed following a review of the literature. The aim of the questions was to draw out motivations, constraints, enablers and barriers. The results of this survey were then analysed thematically, cross referencing from themes drawn out from the literature (or, indeed, new themes).

In total, all 21 women who had in the past or are presently studying for a Ph.D. with the Fusion CDT were invited to participate. Of this pool, 7 responded. The survey offered insights into the academic experiences of these women prior to their decision to take up Ph.D.'s.

Most had studied Physics as undergraduates (with the exception of one mathematician), and 4/7 had studied nuclear fusion as part of that degree, with one being an optional module, however 6/7 were already aware of nuclear fusion before applying to university, mainly through Physics at school, but in one case as a result of a summer internship at JET.

Amongst the 7 respondents, there were a range of points at which they first considered doing a Ph.D.:

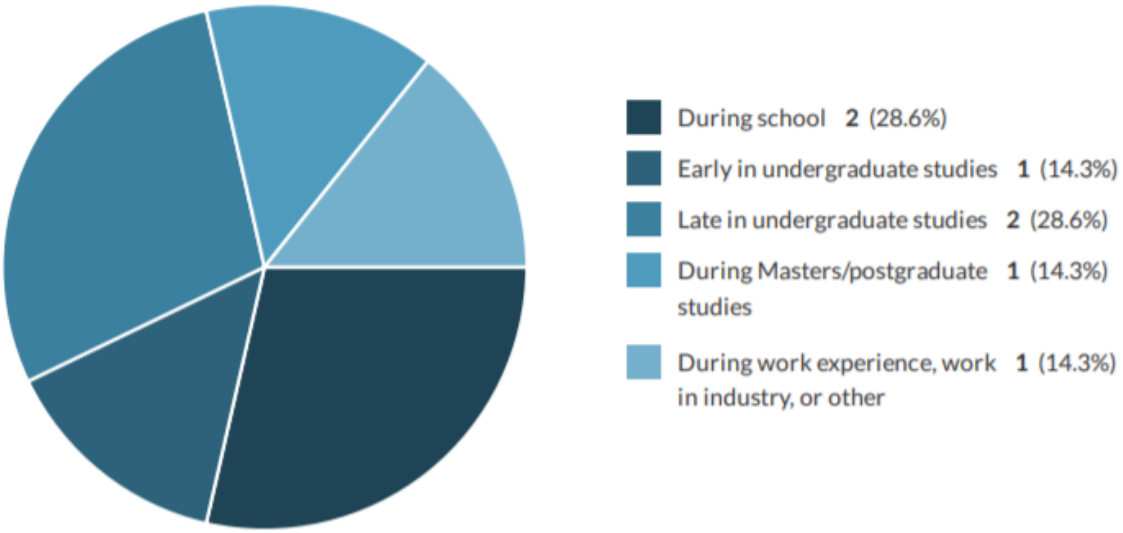

Figure 1 - point at which survey respondents first considered completing a Ph.D.

With the 'other' being during an industry internship where the respondent met other employees who had done and highly recommended doing a Ph.D.

The results are quite different when we consider at what point the respondents first considered nuclear fusion as a postgraduate study area:

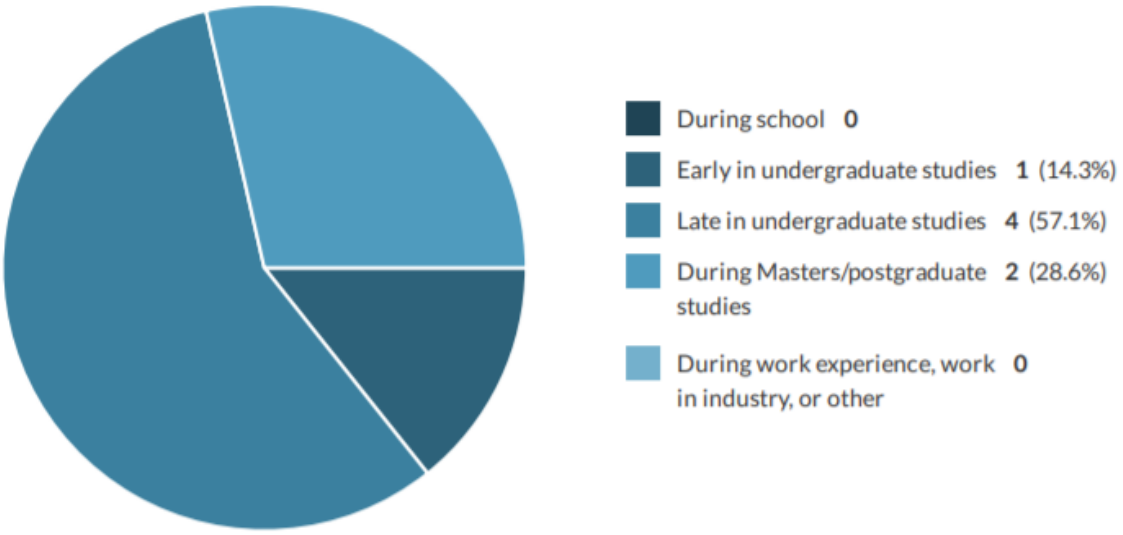

Figure 2 - point at which survey respondents first considered nuclear fusion as a Ph.D. topic

We see from these results that there is a window during undergraduate studies when students may have already considered doing a Ph.D. but have not chosen specific area in which to specialise. This suggests that interventions could be targeted at mid-late undergraduate students, to encourage them to consider nuclear fusion as a possible Ph.D. topic.

The results from the survey informed a further research stage where respondents were invited to be interviewed, with interview questions emerging from survey themes. Interviews were semi-structured, allowing for key areas to be covered whilst also enabling respondents to lead the conversation towards areas that they felt were important. Unexpected areas of interest were followed up with further questions to further explore respondents' experiences. Finally, each interview finished with an open-ended question about whether respondents felt that any of their experiences in their career so far had been impacted by their gender. A great deal of rich material and reflections emerged from these final questions.

Whilst the interviews generated rich data, the opportunity for comparison and generalisation has been limited by the low number of respondents willing to be interviewed, with only three interviews taking place. As such, interviews have been used in the analysis to illustrate themes drawn out from the survey and the literature review. Whilst the generalisability of these illustrative examples may be questioned, it is worth noting the extremely small population size from which these samples were taken. The total number of female Ph.D. students in the Fusion CDT in the 2012 – 2019 period was 21 (18% of overall total number of students). This means our survey response of 7 is a response rate of 33%, and our interviews represent 14% of the overall population of Ph.D. students on the fusion CDT. Due to the small population size, just one student's experience represents 4.8% of the population. With such small numbers, it is clear that every experience is relevant and important in identifying the specific motivations, constraints, enablers and barriers that may impact the general experiences of female researchers in the field.

4. Findings and Analysis

The following section contains analysis of the interviews with three respondents to our survey. These have been categorised as participant A, participant B and participant C. We deliberately omit any further information about the backgrounds of these respondents, in order to maintain their anonymity as much as possible within such a small study population. As noted above, despite the sample size being small, it represents 14% of the overall population that we are studying, and therefore every experience is important and could be reflective of wider barriers and enablers for female participation in postgraduate nuclear fusion research. We situate our findings within the literature, drawing on a number of studies into experiences and motivations of females within STEM research.

Within our findings, three key themes emerged that could be categorised as 'enablers', with multiple references to each from each of the three interviews. These themes were:

- role models (15 references across 3 interviews)
- work experience (10 references across 3 interviews)
- subject interest (8 references across 3 interviews)

Additional enablers included visits to the Culham open day (7 references across 3 interviews), the community (including gender balance) (6 references across 2 interviews), mentors (6 references across 2 interviews) and the presence of an early career goal (4 references across 2 interviews).

Themes that could be categorised as barriers were more diverse, possibly pointing to a greater range of potential barriers that may in themselves be less significant or pervasive, but when combined may become a significant challenge to progression. It's important to note that, as a scoping study, this research only draws on experiences of female Ph.D. nuclear fusion researchers. As such, there is a natural bias in that those who experienced fewer enablers, and more barriers, may have been discouraged to the point of choosing a different research route, or leaving academia entirely. A natural next stage for this work would be to complete a similar study with students from other physical science doctoral specialisms, particularly those with greater female participation, to compare and contrast the enablers and barriers experienced in different areas. A further potentially illuminating study, could seek to gain insight from students who had considered completing a Ph.D. but chose not to, or had been discouraged from considering it at all. Studies such as these may be more helpful for identifying significant barriers that result in the 'leaky pipeline', but were beyond the scope of this early research.

Key barriers that emerged with multiple references across more than one interview included:

- hostile environment / being patronised (10 references across 2 interviews)
- family wishes (3 references across 2 interviews)
- higher bar or expectations (3 references across 2 interviews)

An additional theme that was noted often in one respondent's interview, was the questioning of their own experiences. This was a recurring and emotive theme which is also noted in the literature; we therefore present and discuss our findings on this theme below.

The rest of this section will elaborate on these findings, highlighting quotes and situating them within the wider literature.

4.1 Enablers

4.1.1. Role models

All three participants highlighted key role models in their lives that had influenced their decisions (to do a Ph.D., to choose Physical sciences, to specialise in fusion). Interestingly, whilst we might have expected reference to female role models, male family members and young, enthusiastic male lecturers and researchers also had a big impact. The key point participants noted was whether they could relate to the role model: could they see themselves in this position in the near future? Did they feel encouraged that they could be their authentic selves and still succeed within this specialism?

> "*they were young and I think had just done a postdoc and it was first time they were teaching a module and I liked that because it was clear how I could progress into being a lecturer*" Participant A

> "*my dad was a physics teacher so when I was growing up I always spoke to him about physics, he basically made me interested … he is my main influence, inspiration … my passion for physics came from my dad*" Participant A

> "*They were male, quite a young lecturer, they had a very patient attitude, didn't mind what would seem like silly questions for us. They were really good at making us think in different ways*" Participant B

We can see from the quotes above that role models do not need to be female to have a big impact on female students. However, participants also noted significant female role models that made a difference to their career choices/progression:

> "*partly it was because the lecturer who taught me that was female and none of my other lecturers were female, she was one of maybe two during my degree. She was very passionate about it, and it came across that way*" Participant A

> "*I think one of the lecturers… was probably the reason I went to [University] to study physics, she was a very enthusiastic, normal person, she was very relatable, you could put yourself in that position. She was more of a role model, something you could aspire to be*" Participant B

> "*there was a female professor or assistant professor over at the University of Michigan that I worked with for eight weeks … when we were working together in the lab she had a very different approach… she was the one who was like: 'ok I don't actually know how to do this but we will figure it out', and it was really her who brought forward the whole 'you don't have to know everything' and yeah, made it ok to not know the answers… that you could just figure it out for yourself and that was ok too…she was quite a young professor as well, so she was someone you could see the career steps she had made*." Participant B

> "*she was a great lecturer, lots of fun demos and doing circus skills down the front type thing which was lots of fun, yeah that was certainly helpful in getting me interested*" Participant C

Finally, one participant noted that her sister had provided insight into the area:

> "*I think having a sister already doing a physics degree and starting to think about academia certainly gets you potentially thinking about it a bit more than you otherwise would have*" Participant C

However, we come back to this later as the participant also noted that this can be a hindrance.

When considering the participants' comments about female role models, it is interesting to note the references to different ways of working. This is also noted when referring to the young male lecturer who:

> "*had a very patient attitude, didn't mind what would seem like silly questions for us, they were really good at making us think in different ways" Participant B*

We come back to this idea (that there may be certain cultural norms associated with male-dominated working environments that can be difficult for female students to feel comfortable working within) later.

A key point that stands out from these quotes is that the participants were motivated by being able to see potential career progression in the short-to-medium-term, through role models who were relatable and had achieved what they hoped to. The world of academia has changed significantly over time, so older lecturers and professors may seem to be too removed, and students may have a hard time picturing themselves reaching this level of their career, as the steps taken may no longer be applicable. Younger lecturers or post-docs are evidence of the route through and can offer encouragement to students. This has also been shown in previous research, where Whitelegg et. al. (2002) found that respondents noted that older males (over 55) were sometimes considered to have stereotyped attitudes to younger female researchers, which were perceived as creating barriers to career progression.

Hodgson et al. (2000) briefly describe enablers, noting influence and support from parents, siblings, peers, senior colleagues and mentors. Whitelegg et al. (2002) did not discuss the impact of role models, but noted a key barrier for young female physicist in the UK being the challenge they could foresee in progressing in their future careers. This was exacerbated by seeing high workloads and a working culture in those of higher positions that was not compatible with raising a young family, but that coincided with optimum childbearing years (Whitelegg et al., 2002). One of Whitelegg et al.'s respondents noted that of the few women that they did see at the top of their research careers, they were almost always single and childless. Indeed, this is borne out in the data that shows that mothers are 29% less likely to hold permanent positions than equivalent women without children, and male professors are more likely to be married with children than female professors (Ivie & Tesfaye, 2012). This highlights the impact of a lack of clear role models demonstrating career progression in a way that is compatible with the lifestyle plans of students.

Whitelegg (2004) reports that female physics students cite a number of reasons for leaving physics, including the assumption that it would not be possible to attain a senior post, concerns around balancing raising a family with a research career, and anticipating geographical relocation related to a partner's career move. Indeed, Donovan et al. (2005) note that balancing career and family responsibilities is a key reason for women leaving STEM careers and struggling to re-gain access. These issues all relate to flexibility in the workplace and workplace culture or practices. This need not be exclusive to female role models – male postdocs and lecturers taking shared parental leave, leaving work in time to be home for childcare pick-up, avoiding unnecessary work travel and keeping their weekends free to spend time with their family could be equally beneficial.

The reasons cited for leaving physics in the literature appear to be a direct result of the working culture amongst academics, and may require deeper interventions into the working environment itself before improving the messaging received by female research physicists to reflect changes. Where changes have already taken place, more may need to be done to communicate these clearly to highlight new and improved working cultures. This is especially relevant where lecturers and professors who are

visible to students early in their undergraduate degrees are further on in their careers, and therefore progressed through previous working cultures and systems.

These issues overlap with the second most referenced enabler - **work experience or placement**.

4.1.2. Work experience or placement

Participants noted their experiences when working with others ahead of them in their careers.

> "*while I was doing my undergrad I did a couple of summer research projects where I was working within research groups where there were other Ph.D. students… the reason I had kind of chosen to do them was to think about what the day-to-day research life would actually be like and whether it was for me and so speaking to them and knowing their experience informed things*" Participant C

> "*I chose to do a Ph.D. in general because with my undergraduate degree I got to do a research placement, so each of my summers I spent eight weeks working in the lab or with a research group and I really enjoyed that*" Participant B (participant also noted there was a good mix of genders within these research groups).

All three participants also cited an open day at the Culham Centre for Fusion Energy as giving them an opportunity to learn about different options open to them for career progression and inspire them to consider fusion:

> "*I really enjoyed it, there was a good mix of people there as well, lots of people quite happy to talk about their research, quite enthusiastic about things and I think just seeing the facility as well was really impressive.*" Participant B

We can see from these quotes the importance of work experience to help students decide whether a Ph.D. is right for them, particularly for students to be able to talk to others in the roles they are considering for the future, and to see others like them represented in these groups (either postdoc labs or lecturers).

4.1.3. Community / Gender Balance

The gender balance, and the culture within the community of Ph.D. students were also noted to have an impact on participant's decisions:

> "*I remember on my first day… at that point the girls from [University] hadn't joined yet and I was the only girl on the course. I remember calling my mum after and saying 'I'm the only female on the Ph.D.'… it seems a little bit strange. I've never been that bothered, you know, I always kind of didn't realise I wanted females around me - I thought anybody is fine, I can work with anybody - but it does feel quite nice having other girls on the course. When I saw that they had arrived, I was relieved a bit because it's nice to have a community, and I think definitely doing a Ph.D. its quite isolating…we've spoken about problems that we're having that are similar in terms of being female*" Participant A

Group environment matters, and gender balance can make a difference within that:

"*the other thing that I really liked was that there was quite a balance of people at the admissions day in terms of male and female applicants... I went to [different University] and found there was only one other girl there, no female professor present at the open day and I was like, I can't come here, it doesn't appeal*" Participant B

"*I applied there [another university] but then didn't go there because it appeared that they had a lack of presence of female professors within their department… I wanted a research environment that was more sociable, and I have found that more sociable environments have come when you've got a mixture, a more diverse cohort…Even now when I'm applying for jobs, I like to see a balanced environment, I don't like to be the only female within a research group*" Participant B

Peer processes have been shown to have an important influence on individual female achievement within STEM; women experience lower feelings of belonging in academic work environments with significantly fewer women (Leaper, 2015). Women in male-dominated graduate programs have been found to rate their competence as lower throughout their graduate studies than those in other environments (Ulku-Steiner et al., 2000). This is particularly important when findings also show a strong relationship between how students rate their competence and their career commitment (Ulku-Steiner et al., 2000). This is further discussed below, when considering potential barriers.

"*especially because, there are some kind of gender stereotypes that come out when you're working on your own, people get a little more competitive or 'I'm trying to do the best research, I'm working harder than you are'*" Participant A

"*I think there's been a couple of weird things at the CDT… when we had been placed into groups there had kind of been this intentional splitting up of the girls to put us all in different groups. I found that quite weird because it was like our gender was being treated as equivalent to our discipline because it was like making sure there was a plasma physics person, a material person, and a woman in each group which felt a bit weird. I did mention that, and they said they were going to sort it out for next year. So that was kind of positive as well because they took it seriously and dealt with*" Participant C [may also belong in barriers]

All three participants highlighted subject interest as a key reason for choosing to pursue a doctorate in fusion. This is certainly a prerequisite for any Ph.D. and is beyond the scope of this study to assess how many students may have had this interest but been discouraged from pursuing a Ph.D. by other factors.

4.1.4. Summary of enablers

This study draws out two key enablers identified by participants that can be directly acted on by CDT staff to try to improve the gender balance of Ph.D. students:

1. Role models
2. Community culture (and gender balance)

Ensuring that female undergraduates are exposed to young, enthusiastic role models, who encourage mistake making, open-mindedness and thinking time within students. Ideally, these role models would also be female, but this is not a requirement. These role models may be present as lecturers, older students, Ph.D. students, postdoctoral researchers, or work placement leaders. Ideally, these role models would be present in a paid capacity as part of their day-to-day roles, as introducing voluntary

schemes where potential role models are encouraged to come forward can lead to further pressure on females within the sector (see barriers section).

Community culture is also key in attracting more females into fusion research. Participants noted the importance of females being present and gender balance within groups. It is acknowledged that this is a 'chicken and egg' situation, so initial steps that can be taken to gradually make improvements would be around cultural change within existing groups. There were several references to **the overall culture** amongst the community. The community included colleagues (fellow Ph.D. students), supervisors and undergraduate students. This highlights an opportunity for academic staff to encourage a more inclusive culture through words, actions and environments for students.

4.2. Barriers

Key barriers to success, progression or work satisfaction that emerged with multiple references across more than one interview included:

- hostile environment / being patronised (10 references across 2 interviews)
- family wishes (3 references across 2 interviews)
- higher bar or expectations (3 references across 2 interviews)

An additional theme that was noted often in one respondent's interview, was the questioning of their own experiences. This was a recurring and emotive theme which is also noted in the literature; we therefore present and discuss our findings on this theme below.

The rest of this section will elaborate on these findings, highlighting quotes and situating them within the wider literature.

4.2.1. Hostile environment / patronising

Closely linked to the enabler of 'community culture and gender balance' is the direct result of a lack of gender balance and unsupportive community culture: female students experiencing a hostile environment or feeling patronised by colleagues. This was the most referenced barrier across our interviews, noted many times by two of our participants.

Whitelegg highlights that female students may experience subtle discrimination through a prevalent male culture or atmosphere, or institutional employment practices (Whitelegg, 2004). Donovan et al. (2005) highlight a hostile environment as being a contributor to women leaving the workforce. Hodgson et al. (2000) found that women reported challenging attitudes from male colleagues and exclusion at all career stages including harassment (overt or covert public belittlement or bullying), isolation and unfavourable departmental cultures of competitive 'point scoring' rather than cooperation. This is mirrored in Whitelegg et al.'s findings that respondents felt there was a confrontational and self-confident male culture in the sciences, with greater proportions of women felt to reduce this male atmosphere (Whitelegg et al., 2002). Leaper (2015) notes that female students are at risk of not feeling they belong within STEM fields, due to the values they may associate with STEM subjects being in conflict with values reinforced within their peer groups.

The barriers experienced by women may include challenging or stressful experiences as a result of being within a male-dominated environment, and being exposed to deliberate, gender-motivated

behaviour or attitudes. The division here is noted to be loose and there are overlaps, what we want to stress is that whilst participants were in some cases nervous to refer to certain behaviours or experiences being a result of their gender, there appear to be clear incidents when this has been the case.

The challenge of the male-dominated environment may not always be possible for a participant to articulate:

> "*I have no personal problem with the people that I'm in the office with, I really like them, but I do think there is a bit of a vibe that I don't think would have been a thing if it was all girls… it's just an annoying part but I don't think it would put me off doing my Ph.D., it's just a stressful part of it*" Participant A

> "*I think a lot of it was around when I first started my research… I had asked for help from some of the Ph.D. students and they kind of insinuated that I would just google it*" Participant A

> "*Even during my undergrad all my friends on my course were male and they were quite competitive in some ways and patronising in a lot of ways to me… I think I'm kind of used to it by now in a horrible way*" Participant A

> "*I'm slightly more hesitant sometimes, whereas some of the guys I work with are like 'you just do it like this' and I'm like I'm never sure but never want to speak up necessarily, and it's interesting when I've worked with groups of girls in physics before, it's been a really nice mixture of, yeah you take more time over things and talk things through a bit more than necessarily you would in more of a mixed environment*" Participant B

Respondents also referred to cases where they felt their treatment was directly related to their gender.

> "*post docs or other Ph.D. students… they've doubted your leadership within the lab environment, and they've gone to someone else when you're in charge rather than to you… I've had Ph.D. students that when I've been leading experiments haven't listened to me because I'm a woman and will go to the next man in charge rather than talking to me." Participant B*

Concerningly, participants occasionally demonstrated self-blame for the lack of respect that they experienced, and highlighted how these experiences reduce self-confidence:

> *"I think it is the way I will sometimes approach the stuff and that I will be less sure of myself or sound less sure of myself and they will just go to someone who will give them the answer straight away whether it be right or wrong… you do get treated slightly differently sometimes and I guess that then has repercussions because it has a knock-on effect that you are not sure of yourself and then people don't listen to you so you are even more unsure of yourself and you don't get the confidence to build up, to be actually like, no it actually is this and these are my reasons, you don't really get the chance sometimes*" Participant B

> "*I've had people explaining my own project to me. I'm like yeah, yeah, I know that, I did study that for a long time*." Participant A

> "*I've got this specific instance that, there's a piece of equipment that I wanted to tie up because it was breaking and one of the guys made a comment that I just wanted to make it look pretty and he was like you don't need to make it look pretty as long as it works and I said that's the*

reason why I'm doing it because I want it to work not that I want it to look nice… I find it a bit patronizing" Participant A

And it is clear that a lot of headspace is dedicated to considering how best to overcome these issues, with a lack of options or defined routes for how to address challenges:

"*one of the things I spoke to my mum about when I was asking how to deal with the comments was about when I came in and out of the office like 'oh you're leaving already?' no, I got in really early this morning, managing my own time and getting questioned on it. It became a bit annoying at one point and in my office of four it was only me that was getting asked that. I would come in much earlier than any of them, they didn't know what time I was getting in but when I was leaving I would get questioned 'oh you're leaving already?' and I found that a bit patronizing and I would get 'ah you only come in 12 till 3' and I'm like I've never done that!*" Participant A

We note that the participant refers to this as **one** of the things she spoke to her mum about when considering how to deal with comment**s** (plural), and the significance that it is her mum she has spoken to, rather than a supervisor or mentor. This suggests that the participant has experienced multiple challenges that she sought advice on how to deal with, but did not find routes to seek out that advice within the work environment.

4.2.2. Higher bar or expectations

Our study demonstrates that some cultural challenges are pervasive and can be slow to overcome despite interventions. Participants noted that they felt expectations of female researchers were higher than their male counterparts, and there was a feeling of pressure to positively represent females within the workplace.

"*there was a presentation competition and there was one woman who had done a presentation that was just amazing she was super organised really confident, she did an amazing job and I was like 'well obviously she deserves it, all the other presentations were rubbish compared to hers' and a lot of the guys were like 'oh no I don't think she did a good job' and I don't know if there doing that because they genuinely don't think she did a good job or whether there's more involved.*" Participant A

This concern that women are judged more critically than their male colleagues was also highlighted in Whitelegg et al.'s study, where one respondent noted that they felt women had to be "three times as good as a man to be considered his equal" (Whitelegg et al., 2002, p. 4). A study by Donovan et al. (2005) also noted the higher expectations of women, with one respondent feeling that women needed to be better than men in order to compete with them with regard to academic respect or success.

Whilst we may question whether the perceptions of these women are accurate, it is still worthy of note that there is a perception of a higher bar or higher expectations. Regardless of whether or not these perceptions represent reality, the perception in itself may be enough to discourage women from entering or continuing within the field.

Respondents also noted additional pressure as they feel they are representing their gender in an environment where women are under-represented:

"*I always feel like there's a slight… a responsibility almost to be visible and to be representative when you're the only one there. I frequently get emails about doing outreach or this and that and you feel more pressure to do it, to show that there **are** woman there and things like that*

but and yeah, there's potentially more pressure to not mess up or say something silly because you don't want people thinking that's what woman in science are like" Participant C

This quote highlights extra work being done by successful women within underrepresented areas because they feel pressure to represent their gender either through their work ethic, standard of work, or through voluntary outreach. It is significant that this outreach is always voluntary and represents extra workload on top of the day-to-day research load. Whilst our interviews demonstrate the need for women to be represented at open days and as lecturers, it is a key point that this should not increase the workload of women already in the role, especially as they may already be burdened by overcoming inherent workplace challenges that may not apply to their male colleagues. This could be achieved through ensuring these opportunities are paid rather than voluntary, or ensuring that outreach activity is given equal weight to other desirable academic activities (such as teaching experience or publications) in workload planning, promotion cases and at job interviews.

4.2.3. Family wishes

Previous research has highlighted the impact of family-based beliefs and practices on outcomes (Eccles, 2015). Specifically, parents' perceptions of children's ability influence their own perceptions of their ability. Uniquely to girls, an increase in perceived talent in English leads to a reduction in perceived maths talent. The same study also found that parents are more likely to support maths interests in boys than girls, and to encourage STEM-related activities outside of school. This in turn was found to influence children's own self perceptions and interests (Eccles, 2015). Therefore, if family-based beliefs and practices have an influence, we might expect our female respondents to have had strong family support. We saw some evidence of this in one respondent (Participant A), who noted that their dad was a physics teacher and was therefore their main influence and inspiration.

However, unexpectedly, two respondents referenced family pressure as a barrier for them rather than an enabler. Particularly striking, was a respondent who noted:

"*my parents couldn't really understand why I was doing it, they wanted me to do maths, they didn't want me to do physics… they thought I was better at maths and didn't think I could get a career with physics… even choosing the Ph.D. was going against what they had ideally wanted me to do career trajectory wise*" Participant B

Whilst the family were encouraging within STEM subjects, it's notable that they were particularly against pursuing Physics. When asked about the strength of this feeling from her parents, the respondent noted "it was a strong feeling".

Another respondent noted that their older sister pursuing a Physics degree had encouraged them to start thinking about pursuing academia, but equally highlighted the downside to this:

"*in some ways it's almost a hinderance because you don't want to be seen to completely follow in the footsteps of your sibling*" Participant C

What this suggests is that, whilst family support can encourage females into STEM subjects, the lived experiences of individuals within these family networks can be complex, and encouragement within STEM may not be equal. Additionally, sibling career choice may have a negative impact even when STEM subjects are encouraged. Additionally, interventions aimed at increasing the number of females undertaking fusion Ph.D. research may benefit from finding ways of addressing family hesitancies around job opportunities for women, and career progression beyond the Ph.D.

4.2.4. Doubting experiences

A particularly prominent theme from one of the interviews was the participant doubting their own experiences and questioning whether what they were experiencing was linked to their gender.

> "*maybe they do to each other as well… maybe it's not just directed at me…but it is a bit difficult… a lot of it is frustrating because you don't know if it's a thing that everyone does to each other as a Ph.D. student or whether its directed more at me, or whether I'm just picking up on it more*" Participant A

> "*it is quite difficult to separate the two whether it is a gender-based issue or otherwise. It doesn't seem like the guys I've spoken to about having these problems have the same problems*" Participant A

This is closely linked to the idea from the literature that females may be aware of biases, but not attribute them to gender. However, this is more subtle in that it creates doubt and uncertainty which can lead to more anxiety around how to deal with these problems.

> "*...sometimes I know I'm feeling frustrated or sad about stuff but then if I mentioned it and said it as 'did you realise you were being a bit sexist there?' or something like that, made it out as if it was a gender issue, I think they would disagree I assume, I think they would be like 'well I say it to everyone'. I think it's difficult to find out what is*" Participant A

> "*I spoke to my parents about it because I don't really know how to deal with it and it was stressing me out and I don't want to be like 'hey can you just stop doing that?', obviously I didn't want to be confrontational or anything, but I did find it a little bit patronizing at that point… I just ignored it and it went away*" Participant A

> "*I think my problem is, it's difficult to say those kind of things and shut them down without coming across as a really strong confrontational feminist or something. I feel like maybe deep down I am that kind of person I just don't want to cause problems, you know personal problems*" Participant A

It's clear from this participant's personal reflections that she is struggling to find a way to address some of the issues she is experiencing as part of a male-dominated community. This is partly a result of not being able to clearly identify issues as being related to gender, but also not having processes in place for dealing with issues when they arise. We might question whether it is necessary to know whether these issues are gender-specific for them to be something in need of attention - do we want to create a 'no tolerance' environment for patronising colleagues or questioning their commitment or knowledge? And if so, how can we offer opportunities for training and culture change in order to prevent these issues, and processes for raising these problems when they arise?

4.3. Summary of findings

The research has identified three key enablers for potential female doctoral students in fusion:

- the presence of role models (both male and female, but particularly female) who demonstrate potential career progression routes and encourage certain 'ways of working' including:
    - encouraging all types of questions
    - an openness to being wrong, or not knowing something straight away

    - thinking time not being seen as a weakness or lack of understanding
- opportunities for work experience within mixed group doctoral labs during undergraduate degrees
- evidence of mixed groups of students and staff at open days and on courses, and evidence of an open community where the sorts of 'ways of working' listed above are encouraged, where gendered attitudes are discouraged, and where there are clear routes for dealing with any challenges that might arise

The research also points to a key barrier being a potential hostile environment in which women may feel patronised, and experience higher expectations of them relative to their male colleagues. It is therefore key that in order to achieve the above, higher expectations are not placed on women. We see this where women are encouraged to take on extra voluntary work such as outreach work, or where those who make judgements of attainment (e.g. competition judging panels) may have higher expectations of females. This is therefore something to consider when selecting judges for community competitions (a voting system amongst attendees, for example, may be particularly open to unconscious bias).

Our findings suggest that the challenges are a result of both unconscious and conscious bias, including specific incidents where gender appears to play a role in the deliberate negative treatment of students. However, we also note that regardless of intention, these experiences are real and therefore it is important that actions are taken to ensure that they are not allowed to continue, as they place unnecessary and unequal stress on female students (both through the experiences themselves, and in trying to understand how to deal with them without clear reporting structures and support in place).

Our findings indicate that the majority of students chose to do a Ph.D. early in their undergraduate careers but chose fusion as a focus either later in their undergraduate careers, or during their masters. This highlights the optimum timing for intervention to be mid-late undergraduate.

5. Impact

This research has been conducted in collaboration with the Fusion CDT through our colleague at the University of Liverpool. As such, the findings will be reported back to CDT staff, with the intention to enact changes to improve the gender balance of future CDT cohorts.

As a scoping study, this research will not be published elsewhere, but it is hoped that it may lead to further study within the area. Many potential further avenues for exploration have been highlighted, including conducting similar studies on other populations to compare and contrast experiences. Examples may include female non-fusion physical sciences doctoral students, female physical sciences undergraduate students who chose not to pursue doctoral study, and male physical sciences students.

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Figures and tables

University approval processes

If your project required specific approval from university committees, please provide the appropriate information below. This is a necessary requirement for future publication of outputs from your project.

- *Ethical review – An ethical review was obtained according to the Open University's code of practice and procedures before embarking on this project. Reference number* 5282 (see approval letter from University of Liverpool Ethics committee (Appendix 1) and Ethics application form (Appendix Y)

Appendices

Appendix A - Research Ethics Application Form - 5282

Appendix B – Ethics approval letter 5282