What elements of a community help undergraduates gain confidence?

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Women’s underrepresentation in the field of physics continues to be an issue, in part because of the perceptions women may have about their abilities to study physics. In this paper, we will study undergraduate students’ perceptions about the required level of competence for studying physics, and how these perceptions may change due to participation in spaces that support competence building. We use a mixed methods approach to look at survey responses collected from students on the Foundations of Physics course at University College Dublin, and interviews with physics undergraduate facilitators of an informal learning programme for primary school children, that explores the overlaps of physics and music. We hypothesise, that female students perceive the required level of competence to study physics to be higher than male students. We propose that providing formal and informal spaces that support competence building will improve undergraduate students’ perceptions of their competence to study physics.
I. INTRODUCTION

Averaging only at about 20% in 2019, the proportion of women across all degree levels in all the physical sciences was the lowest in physics [1]. The lack of representation and diversity in science is a problem, because a group’s efficiency can be increased by letting the individuals express their unique characteristics [2]. This is one of the many reasons why diversity is needed in scientific fields. Drawing our motivation from this, we study some of the possible reasons for the low proportion of women in physics.

Furthermore, research has shown that there is a disparity between female and male performances when it comes to physics courses [3]. In this study, we look at students’ attitudes toward physics by looking at surveys collected from undergraduate students taking the Foundations of Physics course at the University College Dublin. Furthermore, we analyse interviews conducted with undergraduate physics students who took part in informal environments. We consider the difficulties both female and male students have had while pursuing physics.

Additionally, it was shown in Fracchiolla’s et al [4], that participation in an informal environment increased the facilitators’ competence. Following this, we aim to find similar themes in the interviews. We begin by defining the framework used as the basis for this study and outline our methodology. We continue with an overview of the key results which demonstrate differences between female and male perceptions finish with our conclusions.

II. THEORETICAL FRAMEWORK

An individual’s membership in a community is determined by their competence, which is defined by the community and its values through engagement and participation. The basis of this study relies on the community of practice (CoP) framework described in [5]. A CoP is defined by three attributes: domain, that includes the goals and values shared by the members, who by helping each other achieve these goals form a community. Practice defines the set of skills or repertoire needed to achieve the domain.

Consequently, we define the three dimensions of competence which describe the individual’s membership within the CoP: accountability to the enterprise (AE) describing the individual’s understanding of the domain, mutuality of engagement (ME) that focuses on the interactions within the community, and negotiability of the repertoire (NR) relating to the individual’s ability and confidence to perform the practices. Together with the dimensions of competence, we also determine ‘sub-codes’, that describe the movement in the CoP, or a lack thereof. These are ‘insider’, ‘peripheral’, ‘neutral’, ‘inbound’ and ‘outbound’, which define, respectively, central, peripheral and neutral memberships, or inward and outward movements.

III. METHODOLOGY

As we used a mixed methods approach, the methodology is divided into two parts: III.A. Quantitative data: Formal environment, which outlines the style, participants and analysis of the surveys, and III.B. Qualitative data: Informal environment, where we introduce the five facilitators and describe the semi-structured interviews.

A. Quantitative data: Formal learning environment

Surveys were collected from undergraduate students taking the Foundations of Physics module specially aimed at students who are new to physics. A ‘Pre’ survey was completed after the first few weeks of lectures and a ‘Post’ survey after ten weeks, before the final examinations. In the Pre surveys, there were 59 self-identified male and 86 self-identified female answers and, in the Post surveys 46 and 60, respectively. There were also a small number of students who identified ‘other’ as their gender, but there were not enough of them to run a separate analysis.

The Pre surveys included questions about the students’ secondary school backgrounds and their experiences with learning physics and science at secondary school. Both of the surveys ask for the students’ motivation for taking the module as well as whether they would choose it again. The main focus of the study were the 25 Likert-style statements ranging from ’5: Strongly agree’ to ’1: Do not agree’. The 25 statements were then coded using the CoP framework to determine which dimension of competence they belonged to. The main themes of the statements were centred around the students’ belonging and perception of competence in physics. After coding all of the statements, we found that the statements regarding competence were mainly coded with AE and NR. Thus, we chose nine statements coded with either AE or NR. Four selected statements were coded with AE:

6. Having strong maths and physics skills is important to me.
7. It is important to me to perform well on physics and maths tests.
11. I’m not certain I fit in intellectually in physics.
21. It is important to me that I am good at maths and physics.

Five chosen statements were coded with NR:
3. I am confident I can complete the module with a B- or better grade.
10. I am confident I can complete homework assignments by myself.
14. I am confident I can perform well on physics exams.
15. I am confident I can learn physics concepts.
16. I sometimes feel like other students in physics have skills I don’t have.

Two sets of data were analysed: ‘pairwise’ and ‘overall’. The pairwise set was chosen by finding the students who took both the Pre and Post surveys. There were 89 students in total
in the pairwise set. The overall set had 145 answers from the Pre, and 106 from the Post surveys.

The answers to each of the nine statements from Pre and Post surveys were plotted to determine whether the distributions of answers followed a normal distribution. One such plot is shown in Fig. 1.

![Bar graphs plotted with a Python code for statement 15: 'I am confident I can learn physics concepts'. The Pre answers are coloured in yellow and the Post answers in grey.](image)

FIG. 1. Bar graphs plotted with a Python code for statement 15: 'I am confident I can learn physics concepts'. The Pre answers are coloured in yellow and the Post answers in grey.

After the normalisation of each statement was verified, an analysis of the variance (ANOVA) statistical test was run, with a confidence level of $\alpha = 0.05$. We looked to determine whether there were statistically significant differences between Pre and Post answers as a whole, just female answers and just male answers. We also compared female answers to male answers for Pre and Post surveys separately.

In addition to the ANOVA test, a $\chi^2$ test was run between two clusters of survey statements to determine if the statements in these clusters followed similar distributions. **Cluster one** comprised of statements 3, 10 and 14. **Cluster two** consisted of statements 6, 7 and 21. The motivation for this was to increase the statistical power for the pairwise data set.

### B. Qualitative data: Informal environment

Using the above framework, we identified multiple CoPs in the interviews, but mainly focused on **Discipline** and **Informal interest**. As all of our interviewees are physics undergraduates, the **Discipline** community is strictly related to their physics degree. The **Informal interest** community was assigned to comments in which the interviewees talk about informal environments in general.

The qualitative data comprised of semi-structured interviews conducted with five undergraduate physics students taking part in informal environments as facilitators. Four of them, Leia, Luke, Han and Padmé, are facilitators in the music and physics programme. Rey has taken part in other informal environments in both mathematics and physics. Luke was interviewed once before his first time volunteering and once after. Padmé was also interviewed twice: the first interview took place before her second time as a facilitator, and the second interview was conducted after her third time. All of the other volunteers were only interviewed once.

The interviews consisted of questions about their expectations and hesitations regarding volunteering as well as how the students identified themselves regarding their degree and music interests.

The interviews were then coded using the CoP framework individually by two researchers. After they were coded, the researchers came together to discuss any differences until they were in agreement. For the purposes of this paper, we concentrated on the AE and NR codes that coincided with either the informal interest or discipline communities, as this helped us support the data collected from the surveys.

### IV. FINDINGS

Here we provide an overview of the key findings from the ANOVA tests of the pairwise (Section IV.A.) and overall (Section IV.B.) data sets. Finally, in Section IV.C. we discuss the findings obtained from the interviews.

#### A. ANOVA for the pairwise data set

None of the comparisons done for the pairwise data set showed statistically significant differences. The means of female and male answers in Pre compared to Post surveys were slightly different, but since the sample was limited due to fewer students taking part in the post survey, the standard deviations were quite large. The differences in the Pre to Post comparison for the whole sample were also not statistically significant, which was to be expected as the Foundations of physics programme did not include any additional interventions focused on students’ belonging and confidence in physics. An intervention like this is being designed currently and will hopefully be implemented in the future. A similar analysis of the data would then show whether the intervention is effective.

As was mentioned in the previous section, a $\chi^2$ test was also run for two clusters. The p-values for these were all less than the $\alpha = 0.05$ level, and thus we reject the null hypothesis that the distributions are similar. Furthermore, we were not able to combine the answers for the statements in the two clusters to increase the power. A larger number of students taking both surveys would be needed to study this further.

#### B. ANOVA for the overall data set

The Pre to Post comparison of the whole sample did not show any statistically significant differences which supports the ideas of the previous section. Moreover, the results from both the pairwise and overall data sets suggest that a specially
designed intervention is needed, for a statistically significant positive change in the means of the answers.

Similarly, when comparing Pre to Post answers of just females we did not find the differences to be statistically significant. In the same comparison for the male data, only the means of answers to statement 11 were significantly different. In this case, the Pre-mean was $2.3 \pm 1.0$ and the Post-mean $2.8 \pm 1.2$. As the statement is negative, the increase in these means is interpreted as the males not fitting in intellectually as well as they thought they did before the start of the programme. This could be due to them underestimating the level of difficulty in the beginning, but further study would be needed to determine the actual cause of this decline.

For the female to male comparison of the Pre and Post surveys, the means along with their standard deviations and $p$-values are plotted in Fig. 2. From the figure it can be seen that the means for statements 3, 10, 14 and 15 are significantly different with females’ means lower than males’. This supports the hypothesis that on average, female students have a more negative perception of their competence in physics than male students.

For statements 6, 11 and 21, there was a significant difference in the Pre surveys but not in the Post surveys. This can mainly be explained by the two means moving in opposite directions in the Post surveys. For example, the mean answers to statement 21 in Pre surveys were $3.5 \pm 1.0$ and $4.0 \pm 0.9$ for females and males respectively, whereas in the Post surveys these numbers were $3.7 \pm 0.9$ and $3.6 \pm 1.1$ respectively. More analysis of these questions is necessary to explain the motivations and causes for these changes.

For this data set, the only statements for which there were no differences in either Pre or Post surveys were 7 and 16. This would suggest that female and male students found performing well on physics and maths tests equally as important. In addition, both genders thought their peers had skills they did not have.

C. Interviews

To support the results from the quantitative data, we first look at interview questions that focused on the difficulties the students may have had while pursuing physics. Following that, we consider the impact participating in informal environments has had on the students.

1. Difficulties

All of the students were asked the question ‘Have you faced any difficulties while pursuing physics?’ Out of the three female students, Leia and Padmé mentioned that the gender divide in physics has had somewhat a negative effect on them. Leia mentioned the lack of women in her course and how this affects her confidence, but also managed to look past that:

[I] think it’s like 80 percent boys or something. So there’s definitely you kind of notice a divide. I’ve also as you know none of my lecturers are women either, in the last two years [ME-outbound]. So that’s kind of a bit daunting to kind of think "Oh God" you know, "I am smart enough?", "are all these people smarter than me?" and "Should I be in this course?" [NR-outbound]. But I guess it’s just kind of pushing yourself through that, going "Yes! Of course I’m fine!" You know you have to kind of look past the, you know if somebody did better than you in the test, so what? you can still be successful and you know, get good grades and everything, but I think that would probably be the biggest one for me, just having confidence in kind of my scientific abilities and stuff [NR-inbound].

Similarly, when asked whether she thinks other people see her as a physicist, Padmé replied:

I don’t know. I mean, in my course probably not as smart, well like for yeah, really you know, people kind of look at the girls and like most people wouldn’t think that they’re up on the same level which is kind of ridiculous. I’m kind of average in my course, but– [NR-outbound].

Later on in the same interview, she was asked about any difficulties she might have faced in course. She first mentioned the level of difficulty, especially of the examinations. She was then asked whether she thought the gender divide in her course made it more difficult for her, and she said that ‘we’re not actually very close as a year...’ and that they started a STEM society for women because ‘...someone in our course was saying like genetically women are worse than us...’ Both quotes were coded as ME-outbound.

Conversely, Rey described her difficulties to come from the course itself, saying ‘The only difficulty I could think of is just it’s a tough course, a tough degree...’ [NR-outbound], and said she has been lucky not to experience obstacles due to her gender: ‘...there has never been any barriers with gender or anything well not personally. I have been really lucky not to experience that...’ [ME-insider]. In addition, Han said that he found his first year in physics difficult and that he ended up failing the year as it was in the Netherlands where the system was different, but he ended with ‘You know like a lot ups and downs but like I’ve made it this far so...’ [AE-inbound]. Luke has also found the course difficult but was optimistic: ‘I’m going to find some topics harder than others, that’s just how life is’ [NR-neutral].

These quotes support the earlier results obtained from the quantitative data. They highlight some of the differences female and male students experience while studying physics at undergraduate level and also reinforce the notion that physics is a difficult subject to both females and males.
2. Impact of informal environments

The students were also asked how important they think outreach programmes are and whether facilitating an outreach programme has had an impact on them. Leia was asked if public engagement had helped her confidence and if it helped her cope with difficulties of her course. She replied: ‘Yeah. Definitely I think that’s why I was kind of drawn to it in the first place...’ [AE-insider]. This shows how informal environments can offer some additional support for undergraduates’ confidence and can be used as a coping mechanism for a difficult course. This idea is further supported by Luke who discussed the importance of informal programmes:

[S]ort of it helps establish a foundation to build upon, which is important. If you want to delve into the more rigorous technical studies that you can then, you know where you’re–where it begins...I’d say that’s, just that communication in a language you understand, in some form you understand more in-depth is very important and that’s, I mean that’s, that’s what outreach is there for I guess [AE-insider].

Similarly, Han also mentioned how facilitating informal programmes can further his own understanding of the more difficult concepts on the course: ‘Yeah because when you’re teaching it you’re kind of learning it more yourself... So my understanding is even better. I learned a few things myself’ [NR-insider].

Furthermore, Rey was asked if there should be a module that teaches undergraduates about public engagement, to which she replied: ‘Yeah I think that would be really good for some people. Especially for people who wouldn’t be inclined to volunteer or sign themselves up for something like this’ [AE-insider]. Clearly, all of the interviewees valued their experiences in the informal programme, as well as the communication skills and improved understanding of physics they gained, which improved their confidence.

V. CONCLUSIONS

In conclusion, the pairwise and overall survey sets showed no differences between Pre and Post surveys and an additional intervention is being designed to support competence building and belonging in physics. Female to male comparison of the overall data set demonstrated differences, which further highlights the need for additional support from the formal intervention. The interview analysis showed that nearly all of the interviewees saw an improvement in their communication skills and how the informal intervention has furthered their understanding of their course. To help improve confidence, we suggest that the new intervention include an informal intervention together with the formal. More data as well as survey validation and alterations are needed to answer the additional questions that arose during our research.

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