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Gender inequality in science, technology, engineering and mathematics: gendered time disparities in perceived and actual time spent in practical laboratory-based activities

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Lab-based activities provide essential skills for students within STEM disciplines, as lab activities provide students with research skills and science knowledge. Therefore, it is critical to note that female students have reported feeling less confident in conducting lab-based activities and report a lower sense of belonging in the lab. In two studies (*N*=544) we examined gender differences in the time that students spent, and perceived they spent, on various laboratory-based activities. We predicted that female (vs. male) students in science, technology, engineering and mathematics (STEM) would both perceive, and actually spend, less time in practical, science-specific activities, such as using equipment, compared to observing or note-taking. Study 1a (*N*=227) was an online, cross-sectional survey where university STEM students reported their perceptions of time spent during lab-based practical activities, and how satisfied they were with their time spent in these activities. Study 1b (*N*=318) was an observational study of university practical lab sessions in STEM disciplines. Our findings demonstrated that female (vs. male) students (1) spent more time recording and taking notes during lab sessions, (2) did not perceive, yet actually spent, less time in the lab using equipment, and (3) were equally satisfied with their time in the lab using equipment. Together, these results suggest that women occupy stereotypically gendered roles in the STEM lab, spending less time on activities that are key for their professional development. Furthermore, the fact that students from disciplines with more female participation were more satisfied with their time spent in lab activities can promote the insidious effects of assessing gender participation and equality in STEM through numbers only. The differences in time spent in lab activities-yet the lack of acknowledge of these differences-opens the discussion about how women might be receiving reduced utility from their programmes, and that universities may not be delivering on their obligations to ensure equal access to teaching resource and opportunities.

KEYWORDS

gender, STEM, higher education, laboratories, practicals

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Introduction

Gender inequality science, technology, engineering and mathematics (STEM) disciplines is a well-documented problem and, despite educational institutions' efforts to improve women's participation in STEM disciplines, in terms of numbers (e.g., uptake in enrolment of STEM classes) and experiences (e.g., sense of belonging), gender inequalities remain. Women's participation in science, technology, engineering and mathematics disciplines (STEM) remains a challenge in higher education (Prieto-Rodriguez et al., 2020). Although women outnumber men in some of these areas (e.g., biosciences; Vincent-Lancrin, 2008; Cheryan et al., 2011a,b), they remain underrepresented in many STEM disciplines, such as computer sciences and engineering (Liben and Coyle, 2014). Indeed, in the United Kingdom, while women's enrolment in STEM disciplines is increasing, under-representation persists: (a) compared to male students, female students are still less likely to take qualifying STEM subjects in high school (Department for Education and Behavioural Insights Team, 2020); (b) only one in three STEM university majors and one in four STEM professionals are women (STEM Women, 2022); and (c) only 9% of STEM professors are women (Kirkup et al., 2010).

Research suggests that this continued under-representation of women in STEM is multiply determined. The lack of role models in STEM can lead female students to perceive that they do not "fit" into the field (Cheryan et al., 2011a,b). Moreover, if those examples of female success in STEM are portrayed as being distant from students (Leslie et al., 2015), students will not perceive the role models as attainable, thus affecting their motivation to persist in STEM (Gladstone and Cimpian, 2021). Research also demonstrates that even for those women in STEM, perceiving a lack of fit with the prototype can facilitate feelings of marginalisation from the broader STEM group (Kim et al., 2018).

In addition to these issues of role models and fitting in, women's under-representation in STEM can be, at least in part, explained by *gendered expectations* in STEM disciplines (Heilman, 2012). Stereotypes about women's abilities (or lack of them) in STEM subjects, have been shown to create stigma and affects women's STEM motivation (Pronin et al., 2004; Casad et al., 2017). Similarly, beliefs about the perceived competitive nature of STEM fields influences women's career choices (Buser et al., 2012), and as such, ideas that men are more talented and interested in sciences than women (Boston and Cimpian, 2018); while women are seen as more talented and interested in humanities/social disciplines (Trusz, 2020). Indeed, the stereotype of masculinity as "effortlessly successful" (Jones and Myhill, 2004; Jackson and Dempster, 2009; Jackson and Nyström, 2015) can lead to beliefs about women's lack of ability, and lack of fit, in STEM. In contrast, stereotypes of women as warmer, kinder and focused on communal goals are the opposite of representations of STEM disciplines as inherently competitive, independent and analytical (Carli et al., 2016; Boucher et al., 2017).

These gendered expectations are also part of STEM students' everyday experiences in their education. Indeed, as STEM associated degrees and modules are seen as an individual choice of students (Burkam et al., 1997), research has focused on understanding how classrooms and lecture hall dynamics might explain gender differences in academic experiences. For example, the perceived similarity and sense of belonging of female students in computer science increased when stereotypically masculine items were removed from the classrooms (Cheryan et al., 2011a,b). Moreover, women's experiences in STEM classrooms are likely to be shaped by explicit and subtle cues regarding their lack of ability to succeed in their degree (Pronin et al., 2004), bias in the evaluation of their performance (Andrus et al., 2018) and, overall, a "chilly" climate (Walton et al., 2015; Wilkins-Yel et al., 2022). These environmental characteristics can affect female students' participation in the classroom. Indeed, research using students' self-reported answers about their interactions and participation in the classroom showed that male students, compared to female students, were more likely to perceive higher levels of participation, in terms of their (a) participation engaging in discussions, (b) answering the instructor's questions and (c) taking a leader role in small group work (Eddy et al., 2015). For a review on gender disparities in classrooms see Eddy and Brownell (2016).

However, a less explored context where gender inequalities emerge in STEM education is the laboratory (lab). Lab-based activities are indeed a central aspect of most of STEM disciplines curricula (Velasco et al., 2016; Arnado et al., 2022). Lab-based activities provide essential skills for students within STEM disciplines, as lab activities provide students with research skills (Lopatto, 2004), and focus on inquiry-based and active learning (Wan et al., 2020), managing scientific equipment, and developing skills associated with team work (Batty and Reilly, 2022). Therefore, it is critical to note that female students have reported feeling less confident in conducting lab-based activities and report a lower sense of belonging in the lab (Batty and Reilly, 2022).

The disparities in how female and male students approach lab-based activities have been described not only through students' self-reports, but also through observation of lab groups. Ethnographic and qualitative research on pairs of physics students has demonstrated that there are disparities in task division in lab groups within physics classes between women and men. For instance, interviews and ethnographic observations showed that groups within lab sessions are likely to adopt a model of work that disadvantages women, whom are relegated to the Secretary and Hermione archetype, with men taking the task-related roles to use equipment (Doucette et al., 2020). Hence, gendered roles within mixed gender groups were also found to be more likely to occur, with women either undertaking the "Hermione" role, that is, taking on a disproportionate amount of the work compared to their male lab partners, or assuming the secretary role which involved female partners mainly taking notes and recording data whilst male partners interacted directly with the lab equipment (Doucette et al., 2020). Further research has focused on understanding different behaviours within the lab sessions, and how they might be different according to gender. For example, research has shown how in lab sessions where experimental work is emphasised, women are less likely to use equipment, compared to men (Quinn et al., 2018).

The use of observational data in STEM educational practices research has provided important insights about the persistence of gender inequalities and stereotyping roles in STEM lab-based activities (e.g., Lucht, 2015). However, the limited research we are able to find suggests observing labs in STEM is critical for two key reasons. First, a lesser interaction with lab equipment could contribute to women perceiving themselves to be incongruent with the role of a scientist (Doucette et al., 2020). As one of the first exposures to the practical aspects of their discipline, such activities shape students' identities as scientists (Gonsalves et al., 2016) and as participants in a wider scientific community (Quinn et al., 2018). Indeed, as individuals see themselves being part of the STEM community, they identify and feel that they belong to this group (Kim et al., 2018), which contributes to individuals' motivation and wellbeing. Second, lab practical activities are important for students to see STEM knowledge as less abstract and more connected with their everyday lives, leading to higher engagement, motivation, and interest in these disciplines (Holmes et al., 2022). Similarly, previous research with secondary students demonstrated that higher hands-on making attitude-this is, the preference towards objects-was associated with higher curiosity and, in turn, with higher STEM career interest (Cui et al., 2022). Hence, the fact that women's participation is restricted to certain roles in lab practices might constrain their experiences and, therefore, motivation and engagement towards STEM disciplines.

Therefore, these initial findings are particularly concerning as laboratory-based practical activities are a key aspect of STEM studies. Despite the fact that there is an increased interest on addressing gender inequalities in STEM (Holmes et al., 2022), research looking at lab practices is-from our knowledge-limited. Moreover, the existing evidence has shown that students from different genders approach lab activities differently. However, this previous research has reported these activities focusing on (a) counting behaviours, (b) only observations of lab activities, without including other data, such as students' perceptions about their roles in lab activities, and (c) qualitative techniques that allow us to understand differences in how lab activities are performed by students, but with less clarity about how much time students spend in different lab activities.

Considering the importance of lab activities in STEM disciplines, we argue that it is key to look at how students approach lab activities and how these approaches might be different according to their gender. Furthermore, we also argue that it is important to focus not only on observations, but also in how students perceive they navigate lab practical sessions, in terms of the activities they conduct and the time spent on those activities. Indeed, an important aspect to understand students' learning experiences is how they monitor their actual task performance, as well as their assessment of the actual performance. This process, also known as calibration (Alexander, 2013), provides evidence to understand the importance of forming sound judgement about one's abilities, which might impact on individuals' meta-cognitive skills and strategic behaviour (Alexander, 2013). Hence, research about lab practicals and gender distributed activities can be of benefit when it takes into account students' perceptions and actual time spent in activities, as both elements inform us about students' judgments and potential future strategic behaviour when they participate in lab activities in STEM contexts.

In this study, we aim to contribute to this previous research, by now integrating two dimensions of analysis regarding lab practical activities: students perceived and actual time spent on activities. Moreover, we aim to analyse potential gender differences in both categories.

The current research

The present research builds on this work by (a) comparing lab equipment time use by female and male students across multiple STEM disciplines in a United Kingdom university, with larger mixed gender groups, through video recordings of lab activities and (b) asking students directly about their perceived time spent on specific tasks in lab groups, and their satisfaction with this time. Thus, enabling a direct comparison between university students' perceptions of their involvement in lab group activities, to their actual amount of time spent on these activities through time stamped data, within a particular university.

Following this, our research aims to explore how students perceive their peers in lab-based practical activities, as well as how students experience their participation in terms of time spent doing specific activities. Within these experiences, lab-based activities provide a first approach to practical STEM work and are fundamental to the process of becoming a scientist. However, as it was discussed, female students are likely to keep facing inequalities in terms of how these tasks are distributed, with women undertaking more "administrative" and passive work in the lab (e.g., taking notes or observing), and men undertaking more active and stereotypically "scientific" work (e.g., using equipment). The present research aims to provide further evidence on this issue, now taking into account gender differences in the time that students spend in different lab-based activities, considering students self-reports and time measured at the lab. Indeed, despite the benefits of observing gender bias in educational settings, this methodology has faced criticism due to the potential researcher bias (Blickenstaff, 2005). Hence, our study measured the time for the activities observed.

We report the results of one study including two phases with undergraduate students from STEM disciplines in a United Kingdom university. We included two dimensions described in the research on gender equality in STEM education: (a) self-reports on the perception of time spent and (b) the actual time spent on different tasks in STEM disciplines (through the analysis of recorded lab sessions). We asked a group of students from different STEM disciplines about the time they spent in different lab-based activities, such as using equipment, recording and taking notes, and observing. We also asked them about their satisfaction with their time spent on these activities (Study 1a). Afterwards, we conducted a separate study where we recorded different lab sessions where students from different STEM disciplines participated, and measured the time that students spent in the lab-based activities described (Study 1b). We predicted that (a) female students, compared to male students, would perceive spending less time using equipment, more time recording and observing data (H1); (b) female students, compared to male students, would be less satisfied with the time that they spent on these activities (H2); and (c) within practical lab-based settings, female students, compared to male students, would spend less time using equipment, and more time recording and observing data (H3).

Study 1a

In the first phase of our study, we examined female and male students' perceptions of their lab-based practical experiences, with an emphasis on the perceived time they spent on specific lab activities

TABLE 1 Descriptive statistics and bivariate correlations (Study 1a).

	Women	Men	Bivariate correlations				
	M (SD)	*M (SD)*	2	3	4	5	6
1. Relative time spent using equipment	3.05 (0.44)	3.17 (0.48)	0.18***	−0.11	−0.03	−0.35***	−0.09
2. Satisfaction with time spent using equipment	3.40 (0.85)	3.20 (0.95)	—	−0.05	0.28***	−0.11	0.36***
3. Relative time spent recording/taking notes	3.16 (0.54)	3.02 (0.56)	—	—	0.27***	−0.04	0.09
4. Satisfaction time spent recoding/taking notes	3.16 (0.84)	3.02 (0.83)	—	—	—	−0.03	0.40***
5. Relative time spent observing	2.95 (0.51)	2.82 (0.56)	—	—	—	—	0.12
6. Satisfaction with time spent observing	3.13 (0.88)	2.90 (0.91)	—	—	—	—	—

***$p < 0.001$.

and their satisfaction with that time. Undergraduate students were recruited by staff in STEM-facing colleges.

Participants

We recruited 370 STEM undergraduate students from three STEM-facing Colleges within a United Kingdom university who volunteered to participate in the study. We also recruited participants from the College of Medicine and Health, but we decided to focus on disciplines traditionally associated with STEM. Analysis results including the College of Medicine and Health can be found in Supplementary materials. We excluded participants who (a) had not participated in lab-based practical activities, (b) had not fully completed the survey, and (c) did not identify as women or men, leaving useable data for 227 participants (56.8% women, 43.2% men). Students were in their first (54.2%) or second (47.6%) years of study (third students were excluded from participating to avoid a conflict with a nation-wide survey of third year students). *A priori* G*Power analysis (v.3.1, Faul et al., 2007) revealed that a sample of 200 was needed to reach an 80% power to detect a small effect size ($f = 0.20$). Students participated in Spring 2020.

Procedure

This study was part of wider research about students' perceptions about their lab-practical based experiences. During the recruitment process, we contacted participants via email inviting them to take part in the survey. Participants first received an email providing brief details of the survey, following a link to access the project information sheet explaining the study and the consent form. Consenting participants were then directed to the survey. Participants answered questions on both group and individual lab-based work. Following the survey, participants were debriefed in full and provided with the opportunity to be entered into a prize draw for a £75 gift voucher.

Measures

After completing demographic questions (gender, year of study, college, and discipline of study), students were asked whether they had undertaken any lab-based practical work during their course at the university, and whether this practical work was mainly carried out in groups or individually. Students that (a) had not undertaken any lab-based practical work during their course and (b) mainly carried out this practical work individually, were excluded from the study.

To measure students' perceived relative time (a) using equipment, (b) recording or taking notes, and (c) observing, we used a single-item Likert scale type from 1 ("much less than other people") to 5 ("much more than other people"), with one item for activity with the following question: "relative to other people you work with, how much time do you spend (a) using equipment, (b) recoding/taking notes and (c) observing."

We also asked to students to assess their satisfaction with the amount of time that they were currently spending (a) using equipment, (b) recording or taking notes, and (c) observing ("how satisfied are you with the amount of time spent in the data recording/note-taking role?"). We used a single-item Likert scale type from 1 ("not at all satisfied") to 5 ("extremely satisfied"). Finally, as a covariate, we included female participation by discipline, following Athena Swan datasets and administrative information. We developed a ranking for 11 disciplines (1 meaning low numbers of women participating and 11 meaning higher numbers of women participating see Supplementary material). For descriptive and correlations see Table 1.

Results

Gender differences in lab experiences

To test H1, we conducted an ANOVA test (gender: female vs. male) female participation by discipline as the covariate. Female participation by discipline was indeed positively associated with students' satisfaction in terms of their time spent using equipment, and recording and taking notes. However, students from disciplines with lower female participation, perceived to spend more time observing and were less satisfied with their time observing[1] (Table 2). Results showed that students in disciplines with higher female participation were more satisfied with their time spent on these activities. There were gender differences in how students perceived their time spent on different practical lab-based work. However, these

1 We conducted exploratory analysis to know whether students' gender had an interaction with the levels of female participation on their perceived time and time satisfaction. However, results were not significant.

TABLE 2 Effect of participation by discipline on time perceived and satisfaction with time in lab based practical activities.

	Type III sum of squares	F(1, 224)	Sig.	η^2p
Relative time spent using equipment	0.45	2.18	0.14	0.01
Satisfaction with time spent using equipment	6.62	8.51	0.00	0.04
Relative time spent recording/taking notes	3.46	12.15	<0.00	0.05
Satisfaction with time spent recoding/taking notes	1.48	2.14	0.15	0.01
Relative time spent observing	1.68	6.10	0.01	0.03
Satisfaction with time spent observing	4.82	6.17	0.01	0.01

differences were focused on perceptions of time recording and taking notes, and not in terms of time using equipment and observing. Thus, female students-compared to male students-perceived to spend more time recording and taking notes, $F(1, 224) = 8.86$, $p = 0.00$, $\eta^2p = 0.04$. There were no reported gender differences for perceived time spent using equipment, $F(1, 224) = 1.96$, $p = 0.16$, $\eta^2p = 0.01$; and observing, $F(1, 224) = 0.954$, $p = 0.33$, $\eta^2p = 0.01$.

Furthermore, both women and men were equally satisfied with their time spent on lab activities, in terms of satisfaction with time spent using equipment, $F(1, 224) = 0.39$, $p = 0.53$, $\eta^2p = 0.00$, satisfaction with time spent taking and recording notes, $F(1, 224) = 2.57$, $p = 0.11$, $\eta^2p = 0.01$, or satisfaction with time spent observing, $F(1, 224) = 0.02$, $p = 0.27$, $\eta^2p = 0.01$. In other words, women reported spending more time on recording notes than men did (Supplementary Figure S1), but women and men were equally satisfied with the amount of time they spent on this task (Supplementary Figure S2).

Discussion

In Study 1a, we found partial support for our hypotheses, regarding differences in how male and female students perceived the time spent on specific activities in practical lab-based settings. As we predicted, female students perceived they spent more time than other students recording and taking notes during lab-based activities. However, no differences were reported regarding students' perceived time using equipment and observing, nor their satisfaction with the time spent on these activities. That is to say, despite perceiving different amounts of time recording, female and male students reported similar levels of satisfaction with the time they reported spending conducting these activities. This may be related to the positive effect of levels of female participation within the discipline on students' satisfaction, as female participation was positively associated with levels of satisfaction. As female students tended to participate in predominantly female disciplines, this might have boosted their satisfaction with their time spent.

In Study 1a we examined gender differences in how students perceived their time in different practical lab-based activities. Although our exploratory results partially supported H1, showing differences in how students perceived their time in different practical lab-based activities, particularly in the ones considered as less "scientific" (e.g., taking notes), results are based on students' perceptions. Following this, our next study explored whether there were gender differences in the *actual* time that students spent in different practical lab-based activities. Hence, in Study 1b, we examined gender differences in actual practical lab participation, via recorded practical lab sessions.

Study 1b

In Study 1b, we aimed to explore H3 in a realistic setting: practical lab-based activities. Hence, instead of focusing on students' perceptions about their time in different lab-based activities-as it was analysed in Study 1a-we decided to look at the actual time that students spent on these activities, and analysed whether gender differences could be identified. Although previous research has used observation in educational settings to explore learning practices in STEM (e.g., Velasco et al., 2016; Stains et al., 2018; Wan et al., 2020), from our knowledge, this method has not been used to analyse gender differences in participation in lab-based settings. Therefore, in this study, we explored a lesser known aspect of gender inequality in STEM, that is, practical lab-based settings. For this aim, we recorded different sessions of practical lab-based activities and measured the time (in seconds) that students spent using equipment, recording/taking notes and observing. We then tested potential gender differences in the time measures. We hypothesised that, during lab-based practical activities, female students would spend more time recording, taking notes, and observing, and less time using equipment than male students (H3).

Participants

We recruited 335 university students enrolled in STEM disciplines, at the same University as Study 1a (including Engineering and Chemistry). Students participated in one of their programme lab classes. Of those, we excluded 8 participants as their gender was not clear in the recording and could not be coded, leaving a total of 327 participants (20.5% women, 79.5% men). A sensitivity G*Power analysis (v.3.1, Faul et al., 2007) revealed that this sample gave us an 80% power to detect a medium effect size ($d = 0.37$).

Procedure

At the start of each lab session, we requested permission to film each group of students in the class. Students, lab academics and PhD lab supervisors were advised that we were filming with the aim of improving the quality of lab teaching. We provided a consent to film form for each student, a number of whom declined consent and they were not filmed. We took care that these students would not show up in the background of other videos, and confirmed for those that did consent, that the video would not be seen by the tutors marking any assessed element of the labs. For details regarding the number of sessions recorded and length of each session see Supplementary material.

We filmed lab sessions between 7 November 2019 and 9 March 2020 (pre-COVID). There were four cameras at each location. Where possible, the majority of sessions were filmed by a researcher with some distance from the student classes being filmed. The researchers taking consent and setting up cameras were also briefed that the work was to improve lab quality (rather than specifically to look at gender). We targeted mixed gender groups where possible in order to get a wider sample, as single gender groups were in the large majority, even where there was a rough gender balance in overall student numbers. The students either self-assigned their working groups in the lab or were assigned by us to ensure a gender split, yet not mentioning the study aims to the group. For disciplines with a smaller number of women than men in the labs, we worked with the lecturing staff to set up the lab groups to ensure that the groups were mixed where possible, and to avoid all-male and all-female groups.

With filming complete, three undergraduate interns were given access to the recordings to code them. The interns completed a timing template of all participants' involvement in the activities (using the headings: equipment, observing, recording data, group instruction, group write up, other actively engaged, and other-disengaged see Supplementary material). The timings were recorded in hours, minutes and seconds. After each video recording had been coded, the researchers transformed the time to seconds, and checked for data accuracy with regards to the initial coding. A check was run between 10% of the raw coded data and the converted SPSS file to check for conversion accuracy, which found 84% accuracy.

Results

Preliminary analyses showed that the data was not normally distributed (Shapiro–Wilk Test of Normality for all variables, $p < 0.001$). Hence, we conducted an independent samples Mann–Whitney *U* test (gender: female vs. male) on each of the lab activities. As we partially predicted, women spent less time using equipment in lab activities compared to male students, $U = 7021.5$, $p = 0.01$. There were no differences between men and women in the time that students spent recording data, $U = 7529$, $p = 0.08$, or observing in lab sessions, $U = 7820.5$, $p = 0.20$. For means according to gender, see Table 3.

Discussion

As we expected, when the time in lab based practical activities was measured, gender differences emerged. Following H3, female students spent less time using equipment during lab based practical activities than male students.

General discussion

Across one study including two phases, a cross-sectional survey of perceived time spent and an observational study of actual time spent, we analysed how the time spent in lab-based STEM practicals might be gendered. In line with our predictions, female students actually spent less time using equipment, compared to male students. Previous research has shown that using equipment is a key aspect of students' experiences at lab, as it is associated with students' engagement with their discipline (Keskin-Geçer and Zengin, 2015). Furthermore, specific activities within the lab-such as using equipment-have shown to be critical in understanding students' development of their identity as scientists (Doucette et al., 2020), which is associated with their sense of belonging to their discipline (Chen et al., 2020). For instance, engaging in practical activities in the lab (e.g., using equipment) contributes to students' perceptions of competence (perceived abilities to participate in lab based practical activities), performance (perceived practical work at the lab) and recognition (being recognised by others as part of the science group). All are key elements of Science and STEM identity (Carlone and Johnson, 2007). Hence, the fact that women actually spent less time using equipment might be detrimental not only for their academic engagement and motivation, but also for their career motivation and sense of belonging to the science community.

Unexpectedly, female students did not perceive spending less time using equipment, and were equally satisfied with their time in different lab activities, compared to male students. Self-reports did not support gender differences in these areas. Hence, although the students that participated in Study 1a and 1b were not the same (see Limitations and future research section), it is concerning that students perceived to spend the same amount of time using equipment than the rest of their peers, and were satisfied with this time. These results might be explained due to the environments where female students conduct lab activities: if female students are more likely to participate in disciplines where they are the majority, then they will perceive to spend similar time as their peers on activities (as their peers are also women), or perceive that the higher levels of women are a sign of more equality in their labs. However, previous research has shown that numbers are not enough, and even in STEM disciplines where women outnumber men (e.g., veterinary, life sciences), inequalities persist (Begeny et al., 2020; Bloodhart et al., 2020). Indeed, women participate in STEM more than previously, but they tend to participate in "female" disciplines congruent with gender stereotypical roles (Garcia-Retamero and López-Zafra, 2006). Our study (including both 1a and 1b) results can provide further support to this idea, demonstrating that although female students in STEM might perceive to spend equal time in lab activities compared to male students, they actually do not. This dissonance could be problematic, as a perception of equality—despite the differences with the actual time in this activity—may lead to a false sense of equality in the lab, and in turn, reproduce traditional

TABLE 3 Time spent in practical lab-based settings by gender (in seconds).

	Women *M* (SD)	Men *M* (SD)	Total *M* (SD)
1. Time using equipment	215.45 (273.52)	382.80 (483.92)	348.51 (453.62)
2. Time recording data/taking notes	284.93 (395.56)	221.36 (370.35)	234.39 (375.91)
3. Time observing	410.16 (492.34)	326.07 (457.84)	343.30 (465.58)

gender roles in STEM. Hence, while these results clearly demonstrate that gender inequality in practical STEM activities do persist, the magnitude of this inequality may be masked by a perceived sense of equality that flows from the higher numbers of women enrolled in the disciplines.

Furthermore, our study results contribute to previous research looking at inequalities in STEM settings in laboratories (Batty and Reilly, 2022); classrooms (Wieselmann et al., 2019), and online learning (Nurramadhani et al., 2021) with a novel approach to explore gender inequalities in STEM, looking at lab practical activities and the time that students perceive and spend on them. Our results provide evidence of the importance in analysing STEM educational settings, and considering their particularities in terms of learning contribution and group dynamics.

Theoretical and practical implications

Our findings contribute to the understanding of gender differences in the practical delivery of STEM education. In particular, within the context of practical laboratory activities and the persistence of gender inequality in the distribution of lab-based tasks. The novel approach of assessing data from multiple perspectives (e.g., self-reports in Study 1a, observation in Study 1b) provided a more rounded understanding of the extent of gender inequality in STEM, as well as how students perceived these inequalities. This is important given the incongruencies we found between perceptions and reality. The disparity between perceptions and reality regarding access to resources has also been demonstrated elsewhere, namely in the field of mentoring, potentially to the detriment of women's career advancement. Previous experimental research by Welsh and Diehn (2018) on the mentoring relationship found that women perceived that they were receiving more mentoring than men, even when provided with the same descriptions of the mentoring relationship. This potentially leaves women at risk of missing opportunities for introductions and career progress, as they do not fully experience the benefits of mentoring, such as developing a network and learning informal knowledge to navigate one's career. Moreover, our research can contribute further to the calibration literature (Alexander, 2013), providing initial evidence supporting the theory that the potential mismatch between students' actual task performance and their judgement about the same performance can also be expanded to other settings and measures. In this case, lab practical sessions and time. Considering the implications discussed early about the importance of lab activities for students' learning, academic and identity processes, calibration might inform how lab activities and gender differences also have an impact on students' meta-cognitive skills and strategic behaviour towards scientific participation.

Our research explores a distinctive setting (lab practical activities) where perceived/actual time differences can also lead to detrimental consequences for women equally access to educational opportunities and development of skills in their field. Indeed, the disparities in the results, in terms of perception of time spent and actual time spent using equipment showed that to analyse the effectiveness of gender equality interventions in STEM, different settings need to be considered (such as equipment use in lab-based practicals), as well as different sources of analysis to evaluate how organisations are working to improve gender equality in STEM.

Practical lab-based work is important not only in terms of students learning experiences, but also to help them develop their identities as scientists (Doucette et al., 2020). Our findings contribute to understanding further factors that may shape differences in perception between genders and what it means to identify with being a scientist (e.g., Starr, 2018; Chen et al., 2020), in this case, the time that students spend in different lab activities. Indeed, measuring time in lab activities, from our knowledge, has not been explored in gender equality research in STEM and, following our study results, it might be an important factor to consider when students identification with their discipline (e.g., "being a scientist") is analysed.

Our study showed that gender proportions in discipline participation was associated with students' time satisfaction with lab activities. Although this observation can have positive outcomes, for example that more equal settings are beneficial for all students, it can also mean that the increase in the enrolment of women in STEM disciplines might lead students to perceive a false sense of gender equality in educational settings. Our study provides initial evidence that numbers are not enough, and that multiple sources of evidence (e.g., surveys, observations) need to be included when gender equality is discussed.

These results also have practical implications. Most interventions aimed at improving gender equality in STEM higher education settings have focused their efforts on motivating women to apply and enrol in STEM disciplines (e.g., National Academies of Science, Engineering, and Medicine, 2020). Although this is a critical first step, organisations also need to promote diligence to ensure equal learning opportunities continue within the setting after women have enrolled in these disciplines.

Additionally, our study has implications for how gender equality interventions are conceived and implemented. To be fully effective, these interventions must be conceived considering not only students self-report, but also group settings. Furthermore, interventions must be implemented in different STEM educational settings beyond classrooms, where students can also learn different skills and develop a sense of their identity as scientists (Doucette et al., 2020).

Limitations and future research

Both phases of our study have a number of limitations that need to be acknowledged. Firstly, Study1b showed a non-normal distribution, and despite having a sample higher than 300 participants, we decided to conduct a non parametric test. Hence, these results need to be interpreted cautiously and more follow up studies need to be conducted to establish time differences in lab activities. Moreover, the samples from both phases were different, that is, the students that participated in the self-report study were not the same ones participating in the lab observation study. Hence, although students were part of the same college and department, we cannot follow up on whether the same students that perceived spending equal time using equipment, for example, were the same students that actually spent less/more time using equipment. Future studies could compare not only students' time perception and satisfaction between groups (e.g., women and men), but also within the groups, looking at differences in how students perceive and spend time in the lab. Similarly, Study 1a and 1b focused on gender differences, without taking into account discipline differences (comparing disciplines recognised with higher female participation to disciplines with lower female participation). Future studies need to acknowledge this aspect, creating studies that compare gender and discipline differences, as well as the interaction of both groups (e.g., how women in certain disciplines perceive their participation versus their actual participation). Moreover, our samples in both phases were unequal in terms of gender and discipline distribution (Study 1a included a majority of women, and Study 1b a majority of men). Future studies should better balance the proportion of participants.

Thirdly, our study focused on gender without considering other contextual factors. For example, in Study 1a we measured "perception" of time without including how level of perceptions might interact with other socio-cognitive variables, such as gender stereotypes (see McKinnon and O'Connell, 2020). Indeed, observational data alone do not allow us to determine whether gender differences are indeed explained only by gender (Eddy and Brownell, 2016). Furthermore, how students approach educational activities in STEM disciplines has been associated with previous experiences in education (Bian et al., 2017), and exposure to gender stereotypes in the media (Steinke, 2017), as well as other intersectional identities (National Academies of Sciences, Engineering, and Medicine, 2020), such as race (Ireland et al., 2018). For instance, future experimental research could manipulate the salience of gender stereotypes such as the "secretary" (Doucette et al., 2020) and examine whether they are still serving to influence both female and male student's expectations of role distribution, and thus their active participation in practical lab sessions.

Fourth, Study 1a included the use of single-item questions. Although previous research has showed that the use of single-item measures can be useful, valid, and reliable (Fisher et al., 2016; Allen et al., 2022), it is important to acknowledge the potential limitations of single-item measures in our study. The single item measures used were not previously tested nor validated in prior studies. Future research needs to test (a) the reliability and validity of the single item measures used in these studies, (b) previously used single item measures, and (c) multiple item measures in similar studies.

Finally, although our study included a total sample of over 500 participants, both phases demonstrated a small effect. Future studies should replicate this study, and include a larger sample to ensure the generalisability of our findings. Another limitation that could affect the replicability of our findings is the challenges of setting up cameras to record in the lab, which can prove challenging in terms of human and material resources. Future research needs to consider the implementation of high quality and the quantity of equipment available to conduct recording research.

Conclusion

Our study contributes to the limited literature focusing on gender inequalities in lab-based activities within STEM disciplines in undergraduate programmes. With this study, we propose a novel approach to investigate gender inequalities, that is, the use of observation in educational settings and the measure of the time that students spend in different activities. Our research shows that focusing on students' self-reports is important, but not enough, to evaluate gender equality, and multiple approaches and methodologies are needed to analyse the state of gender inequalities. Indeed, paradoxically, in STEM disciplines numbers are not enough, and we need to look at not only the levels of participation of women in STEM, but also the quality of their participation. Otherwise, universities will contribute to a false sense of inequality and leaving women outside critical educational experiences for their discipline and identities as scientists.

Data availability statement

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

Ethics statement

The studies involving humans were approved by College of Social Sciences and International Studies Ethics Committee. University of Exeter. The studies were conducted in accordance with the local legislation and institutional requirements. The participants provided their written informed consent to participate in this study.

Author contributions

DF: data curation, formal analysis, project administration, validation, visualisation, writing—original draft, and writing—review and editing. SW: formal analysis, visualisation, and writing—original draft. HS and PC: conceptualisation, data curation, funding acquisition, investigation, methodology, project administration, resources, software, supervision, validation, and writing—review and editing. MR: conceptualisation, data curation, funding acquisition, investigation, methodology, resources, software, supervision, validation, and writing—review and editing. All authors contributed to the article and approved the submitted version.

Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Publisher's note

Supplementary material

The Supplementary material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/feduc.2023.1194968/full#supplementary-material

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