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Understanding barriers to participation within undergraduate STEM laboratories: towards development of an inclusive curriculum

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ABSTRACT
The increase in student diversity, legislative changes and shift towards the social model of disability has led to greater emphasis on inclusive curricula within Higher Education (HE). Whilst there are good examples for changes in assessment, delivery and student support, specific challenges faced by Science Technology Engineering and Mathematics students in relation to laboratory teaching are less well understood. A questionnaire approach was used to determine barriers that students face within laboratory teaching. Questionnaire invitations were distributed by email to undergraduate students at institutions within the United Kingdom with a total of 232 responses. Results indicated a lower sense of belonging for female students and those with a disability. Differences between ethnic groups could not be identified due to low numbers of Black Asian, Minority Ethnic students, which highlights broader issues of participation in STEM subjects. Prior experience of students in relation to the number of labs, rather than subject, was also important, emphasising the critical link between school and HE. Communication of information was critical for learning with students often requiring multiple methods; timing and structure of this were important. A more inclusive lab environment can be developed through the use of online support, better structuring of labs and changes to assessment.

KEYWORDS
Mental health; disability; gender; assessment; belonging; mature students

Introduction

The diversity of students on undergraduate courses has increased in recent years. For example, in the UK, the number of students with a disability has risen from 11 to 15% from 2015 to 2020, BAME (Black, Asian and Minority Ethnic[1]) students from 21 to 25% and international (non-EU and UK) students from 8.8 to 10.3% (HESA 2021). The age of undergraduate students has remained fairly stable over the last 5 years with a slight increase from 46% to 50% of students in the UK being over 21 (HESA 2021). For those students declaring a disability, mental health conditions have seen the greatest increase with a rise from 14.6% in 2014/15 to 28% in 19/20, in comparison to those with a physical disability (including visual and hearing), which fell from 6.8% to 5.2%, learning difficulties from 46.6% to 33% and two or more disabilities from 9% to 7% over the same period (HESA 2021). In the US, the Healthy Minds Study in 2016 reported that 39% of students were experiencing stress and anxiety (Burwell 2018). However, due to a number of factors including continuing stigma around mental health, these numbers are likely to be much higher as it is estimated that just under half of students with a mental health condition choose not to disclose it to their institution (Thorley 2017).

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Policy and legislation related to equality and diversity, such as the UK Equality Act (2010), require that universities make reasonable adjustments for students with disabilities to enable their full participation and achievement. However, it should be recognised that there are many countries that do not have well-developed policies in relation to equity of access, with the majority focussed on students with disabilities (Salmi and D'Addio 2021). Where legislation exists, this has led to the provision of disability support services in many institutions; however, in the UK, changes to the Disability Living Allowance and associated policies mean that Universities need to develop 'a more strategic and flexible approach to inclusive practice accepting there are needs for individual adjustments' (Department for Education 2017). This aligns with the movement from the medical model to the social model of disability, where the individual is no longer seen in deficit terms, and it is the surrounding environmental and social constructs that require change (Oliver 1990, 1996). This then requires us to move beyond the use of reasonable adjustments, which are often not anticipatory and rely on the use of assessment extensions (Hewett et al. 2017), to inclusive practice, which requires 'flexible approaches to learning, teaching and assessment' (Adams and Brown 2006). This shift from seeing particular groups of students as having a 'problem' that needs to be fixed (Dewsbury 2017) to considering the impact that a non-inclusive environment has on learning and engagement may also benefit other groups. For example, there is a clear attainment gap and lower levels of progression in BAME students, with UK data showing a 13% gap between white and BAME students (Universities UK 2019) and similar gaps have been reported in other countries (Stevenson and Whelan 2013). Providing an inclusive curriculum is one of the recommendations for addressing this issue (Universities UK 2019).

The move towards providing an inclusive educational environment within HE has been slow, and it largely remains as pockets of good practice rather than wholesale institutional change (Department for Education 2017). One of the key barriers to change is the negative attitudes of staff: for example, Moriña (2017) reported in their review of several European studies of disabilities and access in higher education that some staff (including faculty members and lecturers) did not believe that a student had a disability, did not change teaching practices or questioned the student's capacity to study at University. Bunbury (2018) also highlighted disbelief of disability, which is much more prevalent where a disability is unseen (Bessant 2011). This aggravates the problem with non-disclosure as students may be reluctant to talk about their disability for fear of discrimination or 'othering' (Slee 2001). It should be noted that academic staff can also be a very positive influence in this area, as individuals can be critical in enabling students to access the support they need (e.g. Hughes, Corcoran, and Slee 2016). Even where teaching staff and lecturers are willing to move towards a more inclusive environment or provide reasonable adjustments, there is a general lack of confidence in how to do this, and staff have identified a lack of training and support as a key barrier to implementation and change (Hewett et al. 2017; Kirsh et al. 2007; Moriña 2017). Alongside this are a lack of resources and time available to develop an inclusive curriculum (Bunbury 2018; Hewett et al. 2017; Rutherford, Hale, and Powell 2015).

There are many good examples of how individuals have moved towards more inclusive curricula through changes to assessment (Whitworth and Wright 2015), delivery (Carabajal, Marshall, and Atchison 2017; Kist and Basnet 2013) and support (Di Bartolo et al. 2016). However, before we can make appropriate changes to teaching, we need to more fully understand the barriers to learning that occur within the educational environment for different student groups.

Students with disabilities face significant barriers to learning, but these will vary according to the specific health conditions. A number of studies have reported that available time for activities and assessment can be important due to students not being able to concentrate for longer periods, tiredness and needing additional time for reading (e.g. Healey et al. 2006; Pearson and Koppi 2006; Hughes, Corcoran, and Slee 2016). Due to the need for more time, this can also impact the opportunities for students to take part in other activities such as social events, affecting their inclusion within University life (Sachs and Schreuer 2011). The type of assessment can also affect appropriate demonstration of learning and providing a choice can make a significant difference to attainment (Kendall and Tarman 2016). Physical space can also be an issue, especially lack of suitable space for adaptations (Rutherford, Hale, and Powell 2015), difficulties in navigating the University buildings/campus (Bishop and Rhind 2011) and practical work can prevent participation by students (Carabajal, Marshall, and Atchison 2017). Fieldwork in particular is a significant barrier (Stokes et al. 2019), although in a study of Geography, Earth and Environmental Sciences (Healey et al. 2006), only 19% indicated that fieldwork is a barrier, but this could be due to the nature of the disability or reflect the lack of enrolment of disabled students in these subjects. The use of digital technology for supporting learning is now widespread, but poor design of online platforms can prevent students with disabilities from accessing them, often due to structuring, colour, language and navigation (Pearson and Koppi 2006; Hewett et al. 2017; Moriña 2017)..

The higher rate of withdrawal and attainment gap for BAME students is clearly reported for HE and whilst the causes are complex, they include effects of prior education, social integration and family pressures (Kauser et al. 2021; Stevenson 2012). Social integration can be a particular challenge, especially where students are commuting and provision of facilities on campus, such as prayer rooms, can have a significant impact on the sense of belonging at University (Islam, Lowe, and Jones 2018). This lack of belonging is related to the continuous persistence of racism within Higher Education, whether this is overt or due to micro-aggressions (Owusu-Kwarteng 2020; Wong et al. 2021). In some STEM subjects, participation can be related to the association with colonialism, lack of contact with Nature prior to University and a general lack of awareness of particular course options (Dowey et al. 2021). There is a strong theme throughout the research that the sense of isolation, lack of relatedness to both students and staff and the differences in culture all impact BAME student participation and learning (Bunce et al. 2021).

Female students also face barriers to participation in STEM[2] subjects. In a comprehensive meta-analysis of self-efficacy (Sheu et al. 2018), female students experienced differential socialisation that led to poorer development of self-efficacy and less pleasant affective states during STEM activities. In the same paper, it was also noted that other peoples' experiences and messages from role models/ important others can be influential in developing positive outcomes. Unfortunately, this lack of self-efficacy for female students is considered to develop at key stages of childhood, and the experiences particularly in school can affect student self-perception throughout their career. For example, subtle forms of bias have been shown to impact female self-efficacy in high school (Hand, Rice, and Greenlee 2017) and this can persist into higher education and beyond, resulting in 'imposterism' (Tao and Gloria 2019). It is not only more subtle discrimination that can impact women in science, but also sexual harassment continues to be a problem and can lead to further reduction in a sense of belonging and increased imposterism (Aycock et al. 2019).

Sexuality and gender identity are both fluid in nature (Diamond 2008) and the impact that self-identification with a particular group has on the experiences of students on campuses is of increasing interest. Research is limited in this area, but there is clear evidence of issues with marginalisation, a lack of belonging and safety on campus for LGBTQ+ (Ngabaza, Shefer, and Clowes 2018); persistence in STEM subjects is lower (Hughes 2018). It has been suggested that sexual orientation does not negatively impact academic attainment, but marginalisation, lack of inclusion in curricular and specific issues with individual academics can lead to disillusionment and disengagement (Cech and Rothwell 2018; Meaders et al. 2020; Papadaki 2016). In a UK National Union of Students (NUS) survey, 20% of LGBTQ+ students experienced at least one form of bullying or harassment on campus (NUS 2015) and up to 42% of respondents hide their identity whilst at university due to risk of discrimination (Stonewall 2018).

Many of these are general issues across disciplines, but for STEM students, the nature of the subject has requirements that provide additional barriers to participation. The UK Quality Assurance Agency is responsible for safeguarding the standards and improving the quality of UK HE and the importance of laboratory and other practical work is reflected in the benchmarking statements for subjects such as chemistry, physics and biology. These skills are considered essential for undergraduates although evidence-based links between practical work and learning are sometimes lacking (Bretz 2019). The physical barriers posed by laboratory and field-based work can cause problems for students who are less mobile or have sensory impairments (Bargerhuff and Wheatly 2004; Carabajal, Marshall, and Atchison 2017; Kirsh et al. 2007; Seal, Wynne, and MacDonald 2002), and the requirement for inquiry-based learning can provide barriers to those with certain learning disabilities (Asghar et al. 2017). There are good examples of how well-designed laboratories, sometimes involving remote labs, can address some of these physical barriers (e.g. Bargerhuff and Wheatly 2004; Grout 2017; McDaniel et al. 1994), but there is a lack of information on how practical work creates barriers to learning for all students, particularly those with non-physical disabilities.

The importance of 'belonging' for students, whether that be at the classroom level or at a subject or institution level (Wilson et al. 2015), is now recognised as being critical to successful education. A sense of belonging in education has been shown to impact student retention, self-confidence and academic achievement (Meaders et al. 2020; Pittman and Richmond 2007; Thomas 2012; Walton et al. 2012). Social engagement has also been identified as a critical component of student's sense of belonging (Ahn and Davis 2020). Students can view University as a competitive and unsupportive environment with a lack of community (Kirsh et al. 2016), which may result in students feeling like they do not belong. This could be aggravated in a laboratory setting where there is pressure to perform, new equipment to use and a generally high pressure and busy environment. As Di Bartolo et al. (2016) highlight within STEM subjects, the sense of belonging and engagement is critical to developing a community of practice. If groups of our students do not consider that they 'belong' in the lab, we are in danger of not only disenfranchising them but also losing the valuable diverse experiences that those students can bring to the community. An inclusive laboratory should be one where all students have a sense of belonging and are able to take part fully in the activities, but only by understanding what prevents this can we have the evidence base to transform teaching and learning.

Providing an inclusive environment requires an understanding of key barriers to learning and participation for all students and therefore, this was the overall aim of the research. Within this, we specifically wanted to establish whether prior experience affects student perception of the laboratory environment and degree of confidence with working in a lab, identify the key concerns that students have in relation to laboratory teaching and to identify whether there are significant differences in perception and concern between student cohorts based on i) student background and prior experience, ii) gender, iii) ethnicity or iv) disability. From this, we wanted to establish the need for any intervention and support that may be required for students undertaking laboratory teaching, which could be used to design and implement suitable support mechanisms in the future.

Methodology

In order to address the objectives of the research, a questionnaire approach was used that included the Likert scale, closed and open questions. The questionnaire was split into four main sections (Table 1). The first section was designed to collect information on prior experience of students in terms of laboratory experience, subjects studied[3] and training. The second section explored how students were prepared for laboratory work in relation to information provided before sessions and their preferred options for receiving supporting materials. The third section was designed to determine how students felt within the laboratory in terms of belonging and confidence and their main concerns in carrying out lab work. Some of the suggested concerns provided were based upon more general issues that disabled students had identified in previous studies including fatigue, physical barriers and assessment types (Healey et al. 2006; Kirsh et al. 2016; Waterfield, West, and Parker 2006). Other concerns, including group work, using equipment and health and safety, were identified from studies based on gender (Micari, Pazod, and Hartmann 2007) or all students (Nelson 1999). We also provided open questions to allow further explanation of support that would help address these concerns. The final section collected demographic data (age, gender, sexuality, ethnicity

Table 1. Student survey protocol.

Section	Question	Data Type
Expectations	Were you aware that lab work would be part of the degree programme before you applied?	Binary (yes/no)
	Did the opportunity for labwork affect your choice of course/institution?	Binary (yes/no)
	How did it affect your decision?	Free text
	How many lab sessions were you expecting to do?	Categorical
Background	Which A/AS levels did you study (if applicable)?	Free text
	How many individual laboratory sessions have you completed before coming to University?	Categorical
	Were you able to carry out the experiments yourself?	Binary (yes/no)
	Have you had any Health and Safety Training before coming to University?	Binary (yes/no)
	If yes, did you find it helpful in preparing you for labwork?	Free text
Confidence and Belonging	Thinking about entering a lab for the first time at University, indicate how strongly you agree or disagree with the following statements?	5 point likert scale
	I feel confident about carrying out laboratory work	
	I feel that I belong in a laboratory setting	
	What causes you most concern about working in the laboratory?	Categorical
	Please explain why this concerns you	Free text
	What actions would help alleviate these concerns?	Free text
Support	Have you been provided with information on your first laboratory session?	Binary (yes/no)
	If yes, how was this information provided?	Categorical
	How would you prefer information on laboratory sessions to be provided?	Free text
	I will do all the necessary reading and preparatory work before entering the lab	5 point likert scale

and disability) using definitions from the UK Office for National Statistics (ONS 2017). Although University College and Admissions Service (UCAS) defines mature students as being over the age of 21 at the beginning of their undergraduate studies, for the purpose of this study, the mature student category was > 25 (the mature student age for postgraduate study) (UCAS 2020), which allowed collated responses to encompass students at various stages of their degree and prevented students who had completed a foundation degree or completed longer programmes[4] from being misclassified.

The questionnaire was trialled with a small group (5) of students. No amendments were necessary following this test.

The distribution of the questionnaire was in accordance with a convenience/snowball approach, whereby it was sent to STEM programme leads in 10 HE institutions across the UK and was also distributed via suitable professional organisation distribution lists. Contacts were asked to send it on to relevant programmes or course leads who would be able to distribute (either themselves or via administrators) the questionnaire to undergraduate students in STEM cohorts, including biological sciences, chemistry, physics, mathematics, engineering, geography, earth and environmental sciences. A template for an introductory email was included in the distribution outlining the purpose of the questionnaire to 'research student's thoughts and perceptions of laboratory work in order to improve and enhance the experience' and the voluntary basis for the response with the assurance that the responses are completely anonymised and confidential to encourage participation. The wording of the invitation was kept deliberately broad to ensure that we captured the experiences of not just a particular group but also all students (e.g. BAME students). The anonymised responses were automatically recorded online using SurveyMonkey for analysis with the student's consent.

Differences between demographic groups for all questions were examined using cross tabulation and Pearson chi-squared tests, completed using SPSS v 26. Thematic coding was used to identify key themes in open response questions for student concerns and recommended changes, which allowed student responses to be classified under more than one theme for their concern due to the range of themes identified.

Results and discussion

Demographics

Three hundred and forty-three responded to the survey, but only 232 questionnaires were fully completed and used for analysis. Students were represented from across STEM subjects (Table 2), the majority from biosciences (35%), but good representation from engineering and mathematics (18%), chemistry (14%), geography (14%) and environmental sciences (8%). Due to the method of questionnaire distribution, there are notable absences of representation from the medical sciences such as medicine and dentistry; however, the data set provides a good range of STEM subjects beyond this. Of the 232 respondents, 59% are identified as female, 37% as male and 2% as non-binary gender. Participation of women in STEM subjects, such as physics, engineering and computer science, is commonly reported to be lower than males (e.g. Smith 2013; STEM Women 2019). Our data show a higher % of women than men in all STEM subjects; however, this is likely to be due to the larger number of female respondents, often found in questionnaire responses (e.g. Sax et al. 2008), rather than reflecting % of females enrolled in these programmes. In accordance with national data (HESA , 2019), the majority of students were between 18 and 24 years of age (93%). Results showed that 16% of students identified as having a disability of which the majority declared unseen disabilities such as mental illness (40%), learning or social limitations (21%). This reflects the under-reporting of mental health issues as 26% of students who report a disability in 2018/19 in the UK record a mental health condition (HESA 2019). Not all students who declared a disability indicated that this affected their day-to-day activities, with only seven students reporting that their condition affected them a lot, six of whom had a mental illness. 11.6% of students identified as being BAME, which is lower than that recorded for all undergraduate degrees by HESA (2019) for the same period (~20%) and those studying STEM subjects (25%). As noted previously, medicine and dentistry were not represented in our data set which typically have higher proportions of BAME students (HESA 2019) and therefore this is a limitation of our study. Due to the low numbers of BAME students, we have not distinguished between the different Office for Statistics categories but have grouped all those in the categories of Asian or Asian British, Black, African, Caribbean or Black British and Other Ethnic Group as BAME. Mixed race students are also included in the BAME category in accordance with the OfS definition. 6% of students identified as 'other white' background who were typically European in origin; we have excluded these from the 'white category' as they are likely to have different experiences from home students. In the following analyses, we have defined non-BAME students as those identifying as White British, English, Northern Irish, Scottish or Welsh.

From our data, gender (male and female) was shown to be significant in relation to both sense of belonging ((df 4, 223) = 30.005, $p < .001$) and confidence ((df 4, 223) = 15.943, $p < .05$) in the laboratory with female students consistently reporting lower scores than male students (Figure 1). The impact of gender on participation in STEM subjects is not new, and there are numerous studies that show the lack of role models and a poor sense of belonging (Deiglmayr, Stern, and Schubert 2019; Good, Moss-Racusin, and Sanchez 2012) negatively impacts female choice of STEM subjects (Moakley and Kim 2014); however, this is the first study to specifically show this in the laboratory setting. As highlighted in the introduction, the lack of self-efficacy and long-term development of confidence, discrimination and a sense of imposterism are all key factors affecting the sense of belonging for female students (Aycock et al. 2019; Hand, Rice, and Greenlee 2017; Sheu et al. 2018; Tao and Gloria 2019). Therefore, the lack of belonging and confidence that the female students in our study report, are likely to have been created and embedded before University, suggesting that interventions are needed at all stages of education. However, the climate on campus is also important in affecting student engagement and sense of belonging. It has been suggested that this effect is lower for female students in the biological sciences in comparison to other STEM subjects, due to the higher % of female representation in the biosciences (Casad, Petzel, and Ingalls 2018). However, in our study, even when we take those

Table 2. Questionnaire Participant Summary Demographic Data, count of respondents, figures in parentheses %, n = 232.

	Female	Male	Transgender M or F	Other	Prefer not to say						
Gender	138 (59)	85 (37)	5 (2)	2 (1)	2 (1)						
	Heterosexual	*Homosexual*	*Bisexual*	*Other*	*Prefer not to say*						
Sexual Orientation	181 (78)	13 (6)	19 (8)	8 (3)	11 (5)						
Age	*17–24*	*25–34*	*35–44*	*45–54*	*>55*						
	215 (93)	13 (5.6)	3 (1)	1 (0.4)	0						
	White (including White British)	*Mixed or Multiple Ethnic Groups*	*Asian or Asian British*	*Black, African, Caribbean or Black British*	*Other Ethnic Group*	*Prefer not to say*					
Ethnicity	199 (86)	5 (2)	18 (8)	2 (1)	1 (<1)	7 (3)					
	Blindness/ Sight loss	*Deaf or hearing loss*	*Mobility*	*Manual Dexterity*	*Learning Disability*	*Mental Illness*	*Cognitive Disability*	*Other impairment*	*Not listed*	*Prefer not to say*	*None*
Disability*	0	1 (<1)	0	2 (<1)	9 (4)	31 (13)	1 (<1)	10 (4)	15 (6)	9 (4)	158 (68)
	Biological Sciences	*Earth Sciences*	*Chemistry*	*Engineering and mathematics*	*Physics*	*Geography*	*Environmental Science/ Studies*	*Other*			
Subject studied at University	81 (35)	9 (4)	32 (14)	41 (18)	2 (<1)	33 (14)	18 (8)	16 (7)			

*results are >100% for disability where students have recorded more than one condition.

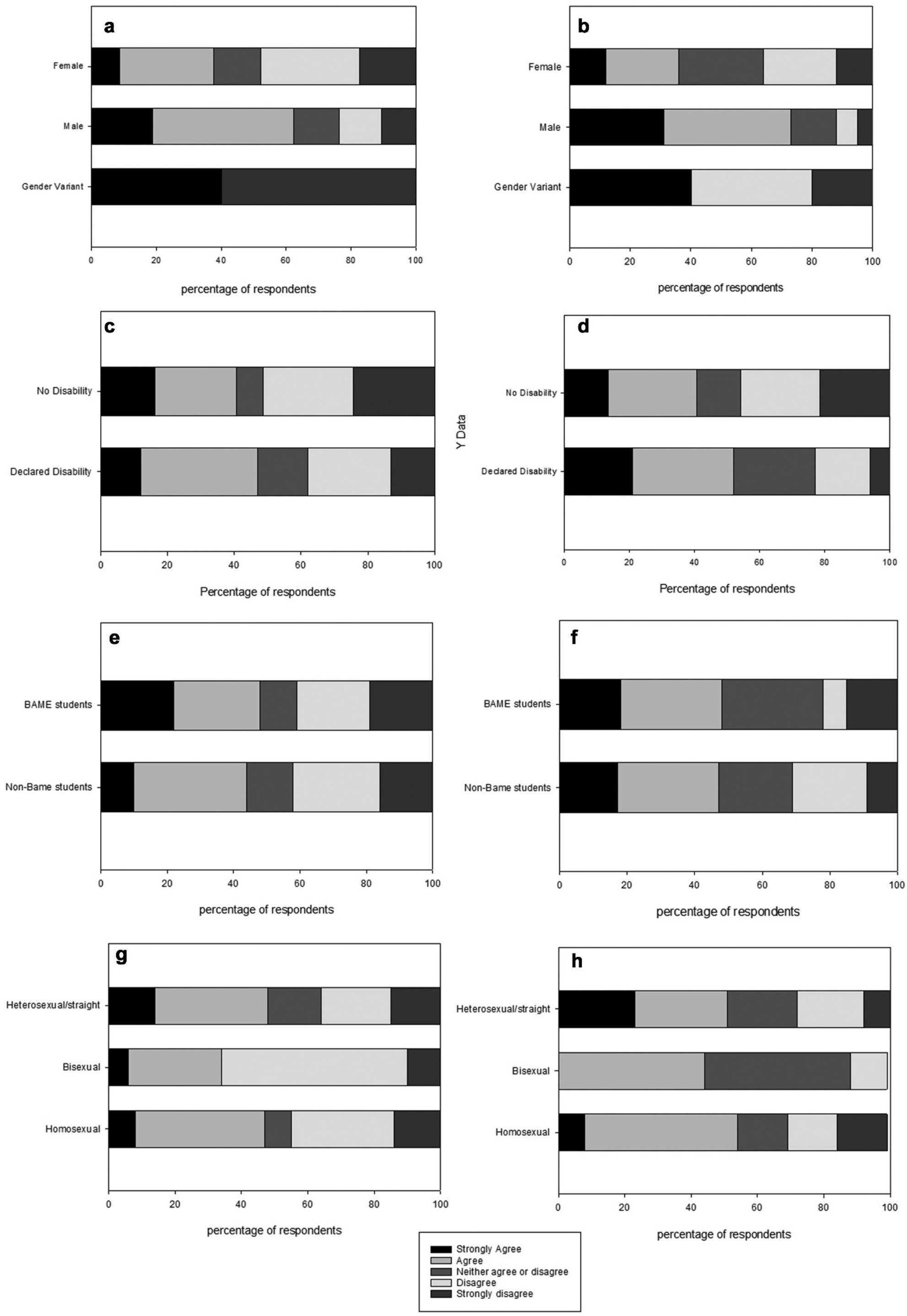

Figure 1. Importance of demographic group in determining confidence and sense of belonging in the laboratory measured on the Likert Scale. (A) gender and confidence, (B) gender and belonging, (C) disability and confidence, (D) disability and belonging, (E) Ethnicity and confidence, (F) Ethnicity and belonging, (G) sexuality and confidence and (H) sexuality and belonging.

studying bioscience subjects alone, female students show a significantly lower sense of belonging and confidence. The open questions did not specifically highlight any particular concerns related to female students (see later section on concerns), but group work is often a core skill that we expect, particularly in the setting of a laboratory where students usually complete work in teams of 2 or more. Where groups are mixed, this can lead to discriminatory behaviour with male students not listening or disregarding female contributions (Warrington and Younger 2010), potentially leading to further exclusion.

Five students identified as being non-binary gender, which due to the small sample size were excluded from statistical analysis. It is interesting to note that these students seem to have been somewhat divided in their responses, suggesting that there are other factors, possibly in combination, affecting the sense of confidence and belonging. In addition, of the 232 students in our study, 13% identified as being LGBTQ+ with 8% identifying as bisexual, 6% as homosexual. No significant difference ($p > 0.05$) was found between heterosexual and LGBTQ+ students in relation to belonging in the laboratory (Figure 1), suggesting that there may not be specific barriers to inclusion within the laboratory setting, but broader campus-wide issues as outlined in the introduction remain.

Students who reported having a disability were significantly less likely to have a sense of belonging than those without a disability ((df 12, 232) = 21.138, $p < .05$). However, there were no significant differences in confidence (Figure 1). Healey et al. (2006) reported that students with a disability experienced a variety of difficulties including confidence and participation although this can vary with individual circumstances and type of activity. There have been good examples of practice to enable disabled students to participate in lab and practical work, especially when the Universal Design for Learning is used (Bargerhuff and Wheatly 2004; Seal et al. 2002; Stokes et al. 2019; Vitoriano et al. 2016). However, these adjustments still tend to be dependent on individual instructors with a focus on physical disabilities and barriers to broader implementation are significant in terms of resources, time and teacher knowledge/understanding (Hewett et al. 2017; Rutherford, Hale, and Powell 2015). As far as the authors are aware, there is little understanding of the specific challenges that are faced by students with mental health conditions within the laboratory and impact their sense of belonging. The laboratory environment can be noisy, time limited, involve multi-tasking and require a high degree of interaction and collaboration, all of which can be particularly challenging for those with a mental health condition and/or learning disability. This is highlighted by students within our study, for example, 'being autistic I feel working with big groups offputting', and 'I have a learning disability and other health issues. In the lab students working in groups are too competitive thus they leave the slow ones behind'. Many students highlighted anxiety and time constraints as being a significant concern to them. Although no significant differences were found between different types of disability and belonging or confidence, the low numbers of responses in some cases preclude discernments of any patterns, and this warrants further research.

Participation of BAME students in STEM subjects tends to be better than in arts and humanities often attributed to the choice of a subject that is more likely to provide high value returns in terms of employment and earnings (McMaster 2017). However, there is evidence within HE of an attainment gap for BAME students (UUK 2019). Causes of this are likely to be complex and require further research; however, it is recognised that this requires removal of institutional barriers and the importance of staff attitudes can be a critical factor (Canning et al. 2019). In our study, BAME students did not report a lower sense of belonging ((d.f. 4, 208) = 4.014, $p > 0.05$) or confidence ((d.f. 4, 208) = 3.863, $p > 0.05$) than non-BAME students. However, caution should be noted here as we were unable to statistically distinguish between different ethnic groups due to low numbers particularly in the Black, African, Caribbean and Black British group. This is in itself an issue as the importance of the development of social networks for BAME students has been highlighted in research by Claridge, Stone, and Ussher (2018) where attainment gaps may at least be partially attributed to isolation and the loss of informal academic knowledge transfer. As Wong (2016) rightly asserts, a 'one size fits all' approach is not appropriate for addressing barriers to participation for BAME students. Whilst our sample size is relatively limited, the low numbers of specific ethnic groups entering STEM subjects indicate broader scale barriers that are active before entering HE.

The importance of student background

Of 195 students who specified their A level subjects, 60% had studied chemistry (often in combination with physics, maths or biology), 25% had studied either biology or physics (without chemistry) and 15% had not studied a lab-based subject. Comparisons between those who had studied chemistry, biology or physics and those without a lab-based science (Figure 2) revealed that the latter were less likely to have a strong feeling of belonging within the lab ((df 4, 197) = 11.744, $p < .05$). However, no significant difference was found for confidence. This may seem surprising, but it should be noted that opportunities for participation in laboratory work during A Level studies can vary and therefore, we cannot assume that students who have completed a science subject have had the same experiences.

The number of labs that students had previously experienced, therefore, may be more illuminating (Figure 2). One hundred and ninety-five of the 232 students completing the survey had experienced at least 1 lab session before starting University, with 135 students completing >6 lab sessions. However, not all lab sessions involved opportunity for students to actively take part and 11% of students who had lab experience reported not having been actively involved. This is concerning as the national curricula for chemistry, physics and biology all specify the requirement for practical skills (Dept for Education 2014). A report by the Gatsby Foundation in 2011 of university staff found that they overwhelmingly considered that lab skills of new undergraduates had declined in the previous 10–20 years and there was an over-reliance in schools on demonstrations or videos rather than hands-on experience (Grant 2011).

The number of labs was shown to have a significant effect on a student's sense of belonging ((df 12, 232) = 33.582, $p < .001$) and confidence ((df 12, 232) = 29.916, $p < .005$). This was not a straightforward positive relationship between the number of labs and increased belonging and confidence (Figure 2). Whilst those students who had previously done >10 labs agreed or strongly agreed that they were confident (19 and 37%, respectively), students who had experienced 6–10 labs reported lower confidence than those with 1–5 labs. A similar pattern was found for a sense of belonging. This suggests that where students have a good deal of lab experience, this can positively impact their confidence and if students only have limited experience, especially if this was negative in any way, this can show up a lack of skills and therefore impact their confidence. As Hirschfield and Chachra (2019) report, time spent on particular projects does not always lead to greater confidence or efficacy and can vary greatly between individuals. The importance of negative experiences cannot be overestimated and the impact of poor mentors and teacher attitudes is of particular note (Cooper et al. 2019; Thibaut et al. 2019).

One hundred and forty-six students reported no lab health and safety (H&S) training before University. Whilst some of these students might have not taken lab-based A levels, the high numbers are concerning given that a 'life-long attitude of safety awareness' should be integral to scientific education (Nelson 1999). In addition, some students indicated that training had not been helpful, for example, one student highlighted the step change in requirements from school to University, 'very basic compared to the procedures and techniques used in a Uni lab'. Students who had received H&S training had a significantly higher level of confidence ((df 4, 232) = 25.470, $p < .001$) and sense of belonging within the labs ((df 4, 232) = 20.032, $p < .001$), providing evidence that at least some training can be beneficial, as highlighted by the questionnaire response

> 'I was much more confident than others in the lab and was able to work diligently without fear of safety or mistakes as opposed to those without a lab based background.'

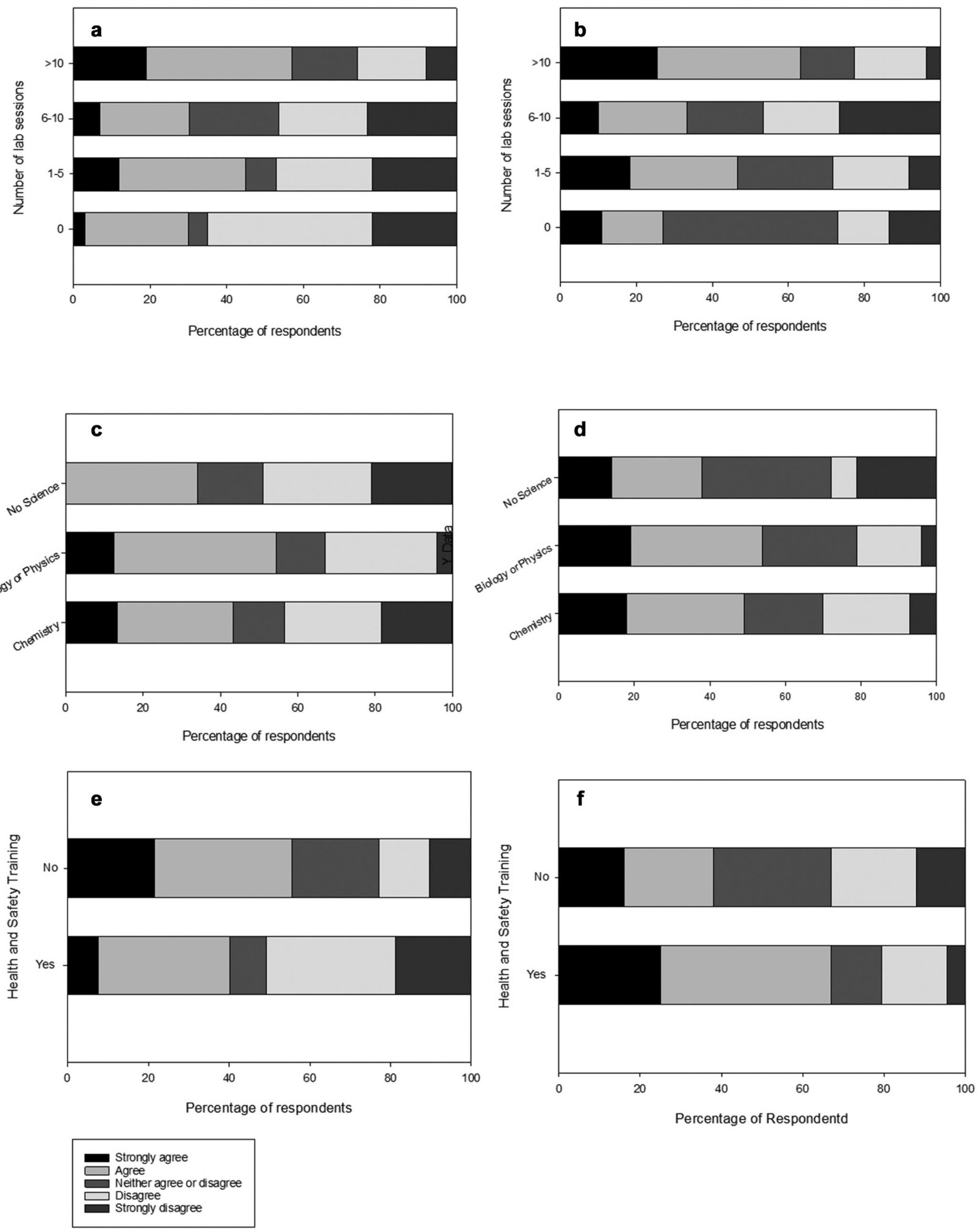

Figure 2. Importance of background in determining confidence and sense of belonging in the laboratory measured on the Likert Scale. (A) number of lab sessions prior to university and confidence, (B) number of lab sessions prior to university and belonging, (C) A level subject studied and confidence, (D) A level subject studied and belonging, (E) Health and Safety training and confidence and (F) Health and Safety training and belonging.

It is critical that students carrying out laboratory work have sufficient H&S training, not only due to the need to work safely but also because it contributes to their sense of belonging and confidence. This training can be provided in different forms and virtual training can be as effective as that provided in-lab (Coleman and Smith 2019; Wu et al. 2020) and can be provided throughout the year, rather than a one-off event.

It is evident that increased practice within a laboratory setting will enable students to develop their confidence, but laboratory time can be constrained by availability of labs and staff (including technical support), timetabling and H&S considerations. This can significantly reduce the opportunities for students to practise techniques leading to labs being high pressure and high risk (often associated with assessment) learning environments. There has been increasing interest in alternative ways to provide students with learning opportunities and the development of online learning including the use of videos, interactive labs and virtual immersive experiences has shown enhancement in student learning and an increase in confidence (Coleman and Smith 2019; Quiroga and Choate 2019; Syed et al. 2019).

Provision of learning support for students

Statistical analysis showed that there were no significant differences between demographic groups in relation to key concerns in the laboratory environment ($p > 0.05$); however, important themes emerged that are addressed in the following sections to make laboratory learning more inclusive overall. This is important as inclusive teaching can benefit not just the target group but also all students (Rutherford, Hale, and Powell 2015). By responding to student concerns and creating an inclusive environment, we have the ability to help students who do not yet feel comfortable disclosing their disabilities or identities. As Taylor (2011) notes, we may all experience impairment at some point in our lives, and students may have issues that are transitory and therefore not diagnosed or disclosed.

Assessments

The top concern reported was assessment in lab environments (40% of all students, n = 232, Figure 3). Specific concerns varied from being unsure of the data generated to being unclear on formatting that is required for the write-up. This is an understandable concern as labs are often a new style of assessment and individuals specifically identified lack of prior experience as being an issue. It is also worth considering that students feel more pressured in laboratory experiments as they are reliant on lab performance and data for the subsequent write-up. A number of students felt that if their experiment did not work, they ran out of time or encountered issues with equipment, then it significantly affected their final grade. Providing students with 'ideal' sets of data for assessment rather than relying on rather variable data collected in the lab can alleviate some of this stress (Whitworth and Wright 2015). Laboratory report writing is a professional skill for many subjects under QAA, and requires a different approach to conventional essays. This could be daunting for students who have no prior experience and, in addition to data collection and analysis, collectively requires a different set of skills to other assignments. Formative assessment is used to provide students with feedback in a low-stakes environment. Feedback can be provided by the teacher or by peers and has been shown to improve student performance (Huisman et al. 2019). Therefore, providing opportunities for formative lab assessments enables them to action feedback and to become familiar with the process and formatting of lab reports, without affecting their overall degree performance. Varying assessment methods also have the potential to minimise the detrimental impact that singular formats could have on individuals, as it provides a range of opportunities to demonstrate their understanding and ability to apply their learning (Cotner and Ballen 2017). Recent suggestions for inclusive curricula in accordance with Universal Design for Learning also emphasise the need for allowing student choice in assessment methods (Griful-Freixenet et al. 2017; Ketterlin-Geller and Johnstone 2006), although this needs to be considered in the context of learning outcomes for practical-based work.

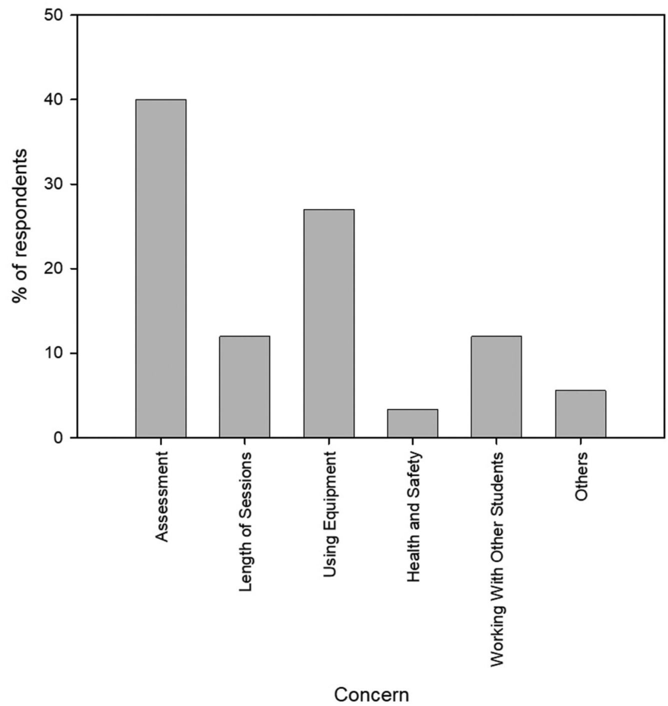

Figure 3. Percentage of respondents indicating their main concern with working in the lab environment (n = 232).

Using equipment

A key concern for students (27%, Figure 3) was using unfamiliar equipment or breaking expensive equipment. Undergraduate labs are often fast-paced learning environments that cover a range of techniques and experiments to support theoretical learning. Depending on content, this could mean that students are learning new techniques and equipment each session with limited opportunity to review previous methods due to constraints with laboratory scheduling. A way to mitigate this would be to use virtual lab space that students could not only access at any time to review practical sessions but also explore methods and equipment that will be used in future sessions, maximising their time in the physical lab. The use of online material and Virtual Reality has been effective in a range of settings and has been found to increase student confidence in handling equipment and lab safety (Syed et al. 2019; Whittle and Bickerdike 2015). A good example of this is the Open STEM Labs where students can access onscreen instruments, remote access experiments and data sets anytime to complement their learning. This includes laboratory settings that allow the user to execute the experiment in a virtual reality, for example, pipetting aliquots in the correct order, mixing solutions, flame tests, etc. (OU 2020). Online labs can also be used to provide formative assessments and feedback (Purkayastha et al. 2019).

Working with other students

Providing an inclusive environment not only requires physical and logistical considerations but also needs to be a focus on social inclusion within the practical elements of student's courses; when students feel included, they are more confident with their skills and understanding, which benefits their learning (Osterman 2000). This allows connectivity between peer groups and creates potential for further informal learning within the group (Claridge, Stone, and Ussher 2018). However, 12% of students (Figure 3) rated working with other students as their main concern. One of the key challenges often faced by mature students is differences in social mixing and inclusion (van Rhijn et al. 2016); although viewed through a laboratory focused lens, this was not the priority concern for the majority of mature students in our study.

One of the recurring themes in the responses was being partnered with someone who does not take the work seriously, for example, ‘Depending on how good your lab partner is, the session can be really enjoyable and interesting, or a stressful mess’. ‘If they do something wrong that will affect the grade we get at the end. I prefer to work individually because then if something goes wrong I only have myself to blame’. Students need to develop interpersonal skills whilst also balancing their own degree performance, which can be challenging. Although group work is an important skill to develop, as education facilitators, we have an obligation to ensure that students are not detrimentally impacted by monitoring the laboratory environment for poorly motivated individuals. However, we also need to consider what is preventing students from fully participating rather than assuming that they are a ‘free-rider’. In fact, a feeling of inadequacy has been suggested to be a cause for free riding in group work (Dommeyer 2007), the very issue that we have highlighted as being a problem for particular students. Hall and Buzwell (2012) identified a range of issues that may result in non-contribution from members of groups including differing working styles, lack of knowledge and/or skills and external pressures on time, such as work and family responsibilities. The issue of group work is therefore a broader challenge for education beyond the specific setting of the laboratory and we need to consider how we develop these skills in students. Recent research has provided evidence for the value of teaching compassion within group work and could be used as a model for future development of lab-based group activities (e.g. Gilbert et al. 2018).

Length of the session

The duration of laboratory sessions is the top concern for 12% of students (Figure 3). As identified earlier, a significant number of students have had limited experience of lab work before university and therefore may be unsure of how to pace their work. A key concern was that they would have insufficient time to complete the allocated work. However, there were also students who find laboratory work tiring due to time allocation, for example, having to concentrate and multitask for 2–3 hours on average for one session. Long sessions can be particularly challenging for students with disabilities due to concentration fatigue (Healey et al. 2006; Hughes, Corcoran, and Slee 2016) and is a particular challenge for students with chronic illnesses (Hughes, Corcoran, and Slee 2016). Students suggested that there are allocated breaks within the session, although this is sometimes not feasible due to the style of experiment. It is important to emphasise to students that if they wish to take a break than that is acceptable, however, this could lead to additional pressures on those not taking a break in the interest of finishing the work. It may also lead to ‘othering’ of students who remove themselves from the lab for periods of time. Despite being a popular concern for students there were limited suggestions on how to address this problem, although regular timed breaks for all students would be a more inclusive strategy.

Safety

Safety did not feature as a key concern for the majority of students (3%, Figure 3), although it was noted by several that they had not undertaken any formal safety training before starting university. Several reported that they found it difficult to access safety training materials after the session and therefore it would be sensible to include safety material that students can access as they require. Although not significantly different, mature students reported safety concerns to be their key concern, more so than the rest of the survey respondents. If students had completed H&S training, they tended to report a higher sense of belonging in laboratory environments (Figure 2F). This is a relatively easy and important change to make for inclusivity in laboratories as it is important for students to be safe and informed during their practical sessions.

Communication

Due to small numbers, it was not possible to statistically test for differences in preferred methods of communication for students with particular demographics, but having autonomy in when material is accessed is identified as being beneficial for students with disabilities (Hughes, Corcoran, and Slee 2016; Kirsh et al. 2016). Effective communication for laboratory-based learning can be broken into three phases: prelab, within-session and post-lab. Different communication methods may be more suitable for various stages of the learning process. Currently, the majority of information provided to students prior to labs was in the written (74% of students) or verbal (50%) form, often in combination (Figure 4). When we look at student preferences for communication, however, less indicates the written (57%) and verbal (34%) form and there is an increase in those opting for demonstrations, podcasts and online methods. In addition, the majority of students indicated a preference for a combination of communication methods, mostly written and verbal, but often including video as well. Some students indicated a preference for videos, which have been shown to be effective at helping students to grasp the key skills that they need in the practical, 'Videos work well as can visualise experiment', although it is important that the equipment in these videos is the same as what the students will be using to prevent any confusion. Although videos are one of the more time and resource-intensive methods of communication to prepare, compared to a verbal presentation or written handouts, it is a method that the students value and has been shown to be effective in helping students to understand technical concepts and increasing efficiency during the practical (Agustian and Seery 2017). This could help address the concern of students who find time pressures to be a concern during the practical sessions. A limited number of students reported currently being provided with lab demonstrations, either before or in-lab, which can be an effective tool to support students and actively communicate any technical or safety concerns. These were often reported to be given by technical staff or teaching assistants and to be effective, they need to be familiar with the practical, equipment and intended learning outcomes, in addition to being approachable and a good verbal communicator (Wheeler et al. 2017).

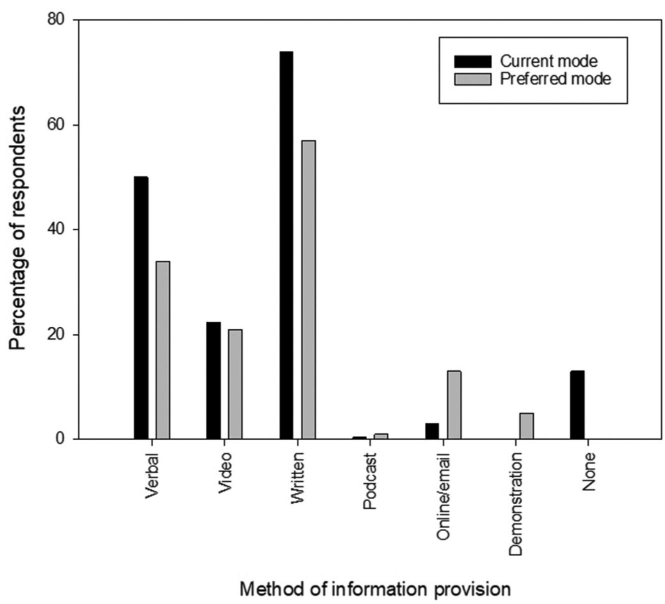

Figure 4. Percentage of respondents indicating the current and preferred method of providing laboratory practical information (n = 232). Note that % are >100 due to students indicating more than one method.

One of the best ways to give students information is online and allowing them access to the material at times that suit them, in addition to in-person communication, 'Preferably before the session occurs, I would like information in the form of a booklet/system of notes that may be computerized or on paper' and 'During, or at the beginning of a session, I find it helpful that some of the necessary information (i.e. How to handle a specific piece of equipment) is gone over verbally'. This is something often reported for practical labs as students prefer to have time to process the information in their own time ahead of the session and can benefit engagement and comprehension (Agustian and Seery 2017).

It is important not to overload students with information at the start of a session. Spending more time covering less material has previously been demonstrated to be beneficial in fieldwork environments (Gilley et al. 2015) as this allows all participants the opportunity to engage with the content and they feel less rushed and pressured. In our study, students who identified as having autism or other social disabilities highlighted the preference for allowing space whilst giving instructions. They often find it challenging to take in information when crowded with their peers; therefore, a system where you can give instructions to students in their own space without gathering as a close group would be beneficial. One student questionnaire response highlighted this issue succinctly 'Think about students who have dyslexia you can't put them into a noisy lab and expect them to perform as normal. Actions let people with learning disabilities have a choice to work on their own or with the class (in a group) that knows their needs) if they wish to tell them.'

Stokes et al. (2019) also highlighted that it is advantageous to supply material to students on a task-by-task or day-by-day basis to prevent students from becoming overwhelmed or confused by multiple handouts at once as it focuses them more on the specific activity. This type of step-by-step instruction can be particularly helpful to students with learning disabilities (Asghar et al. 2017).

Timeliness of information was also deemed to be critical by students, 'I would have preferred information to be given during the summer holidays and not when uni reopens, because I couldn't prepare thoroughly for the lab works.' Providing fully accessible information well in advance of sessions is one of the simplest ways of providing a more inclusive learning environment.

Recommendations for developing an inclusive laboratory

Our data show that some groups have a lower sense of belonging in laboratory settings than others, notably women and students with a disability. In addition, women reported a lack of confidence. Lower levels of self-concept have been linked to reduced achievement, even where students have the same abilities, and over time, this will cause a lag in relative progression (Ertl, Luttenberger, and Paechter 2017). The issue of self-efficacy cannot be overstated and as Wilson et al. (2015) found, students with low self-efficacy correspond with negative emotional engagement, essentially meaning that students are likely to withdraw from studies (Meaders et al. 2020). Building confidence is therefore of primary concern for our students. Our conclusions on the importance of developing a sense of belonging are also reflected in the literature. Interpersonal relationships, perceived competence, personal interest and science identity have been found to be important in a student's sense of belonging and were lowest in under-represented groups, leading to a continued dominance of privileged white males in STEM (Rainey et al. 2018). Gender bias within departments can strongly affect gender gaps and targeted interventions specifically related to increasing female sense of belonging and to reduced levels of anticipated discrimination have been recommended (Moss-Racusin et al. 2018). The important finding from our studies is that both women and students with a disability are less likely to feel a sense of belonging in the lab and therefore actions should be focussed towards these groups. Our data align with the majority of other research to identify issues around the sense of belonging and confidence of female students, but specifically highlights this in relation to the laboratory. There have been a range of suggestions for ways in which we might tackle this persistent issue, some of which are more strategic in nature (e.g.

Martin-Hansen 2018) and clearly there are changes that need to be made long before higher education. However, there are some actions that could be taken to provide a more inclusive laboratory environment.

Previous work has shown that workshops and bridging programmes are a valuable way of introducing students to new techniques (Di Bartolo et al. 2016) and providing students with no previous experience with a non-threatening environment for them to practise basic techniques. As we saw, the number of students who had not had any or at least very limited experience of lab work prior to university was much higher than that might have been expected and therefore, we cannot assume prior knowledge and experience. Therefore, providing learning opportunities before the start of university may be a suitable option. This can be undertaken for specific target groups although this may risk the 'othering' of students. The transition from school to university can be particularly challenging for students with disabilities (Moriña 2017) and therefore, providing opportunities to engage and get experience of the environment prior to the start of term may be beneficial. These do not necessarily have to be conducted in person and as we have seen, virtual laboratories and online learning resources can provide valuable additional learning opportunities.

It was clear that the provision of information about the laboratory work is critical for many students and there is a need for providing relevant information in a structured and timely manner, as well as in multiple formats (written, verbal, video) to allow students to choose which is most appropriate for them. All materials that are provided should be fully accessible, and in the UK, this is in accordance with the Public Sector Bodies (Websites and Mobile Applications) (No. 2) Accessibility Regulations 2018.

Students were very concerned about using equipment and lack of experience. Students with manual dexterity issues specifically highlighted this and the need for practice sessions. It is also clear that the assessment provides students with a significant amount of stress and anxiety within laboratories. Providing sessions that allow for practice with equipment and that are not assessed allows students to get more familiar with the materials before adding the stress of being assessed. Lab demonstrations of equipment can also help to alleviate anxiety, especially in relation to new equipment. This can be done in person or through online videos. We also need to consider the design of the sessions themselves. Due to the limit on lab resources, particularly in relation to timetabling, there is a tendency sometimes to provide very long and activity-heavy sessions. This negatively impacts students with disabilities and chronic illnesses and therefore, sessions and activities should be designed with regular breaks and space for consolidation of learning.

Group work is clearly an essential component of laboratory practicals and there are a number of issues associated with this, including the dominance of individuals, lack of engagement, bullying and exclusion. The number of students identifying this as a key concern draws attention to the continuing and broader issues with developing the appropriate skills for students. The model of compassion in learning (Gilbert et al. 2018) provides a very promising development in how students can be trained in working as part of a group and it would be worth further research as to whether this would benefit students working within the laboratory.

Finally, although not specifically highlighted by students in this research, the importance of the teacher in the classroom can be critical in providing an environment where all students belong. Role models for students are important and we need to ensure that we have a diverse staff profile. Many studies related to inclusivity and disabled student experiences in HE provide clear examples of where individuals make either a critical positive or negative experience for the student (Bessant 2011; Hughes, Corcoran, and Slee 2016; Kirsh et al. 2016; Moriña 2017). It has also been shown that women can respond positively when provided with a safe space for learning where there are supportive peer networks and this can also improve with same-gender teachers (Daniels et al. 2019). However, despite the changes to legislation and the increased interest in the Universal Design for Learning and Inclusive Curricula, staff continue to report issues with a lack of time, resources and training to allow them to provide an inclusive environment. Therefore, inclusive curricula development in HE needs to be fully embedded with the university strategy, properly resourced and based upon pedagogic research.

Conclusions

This study sought to identify barriers to student engagement within the laboratory in order to better understand how a more inclusive educational environment could be developed. From the data, it was clear that specific groups, notably female students and those with disabilities, felt more excluded from the laboratory. However, the lack of prior experience was also important and it was evident that the number of labs and hands-on experience was variable at the school level. This means that university-level teachers in introductory modules cannot assume prior knowledge of laboratory work and need to provide opportunities for learning and practice. No differences were evident between different demographic groups in terms of concerns about practical work supporting the suggestion that providing an inclusive environment can benefit not just target groups but also all students. Assessment was not only the major concern, but issues related to working with others, using equipment and timing were also important. Free-text comments provided valuable indications of why these affect students and this has allowed us to suggest some simple changes to laboratory practicals to make them more inclusive. Students clearly value structured information to support their practical work and this needs to be provided in a timely manner and preferably online so that students can access it at a suitable time for them. No specific differences were found when comparing BAME students with non-BAME in relation to barriers, belonging or concerns, which was most likely related to the small numbers of students in the BAME category. This emphasises the issue of participation in STEM subjects more broadly and, in particular, those who fall outside the Medical Sciences. We hope that this study provides STEM teachers with a better understanding of the barriers to engagement in laboratories and provides some potential changes to practice that will provide a more inclusive environment.

Notes

1. BAME (Black, Asian and Minority Ethnic) is a term currently used in UK Higher Education as a broad classification of students who identify as these ethnic backgrounds. Although there are limitations within this classification due to the broad and homogenous nature of the grouping, data within UK institutes for reporting of demographic data predominantly uses this definition and therefore the definition has been used throughout this paper due to the UK HE framework used to underpin the initial data collection.
2. STEM (Science,Technology, Engineering and Mathematics) is term used widely in education and for the purpose of this paper, we are referring to the subjects that fall within these categories. A useful review of STEM as a definition is provided by Hasanah (2020)
3. The question to determine subjects studied refers to A (Advanced Level, normally 2 years of study) and AS (1 year of A level completed) levels, which are a UK school or college qualification, typically taken between the ages of 16–18 in preparation for further study, training or work. Entry to UK Universities is usually based on the subjects studies at A level and the grade attained.
4. Foundation degree in the UK is equivalent to a Higher National Diploma (HND) or a Diploma of Higher Education (DipHE) and 2/3 of a Bachelor's degree and is often undertaken prior to starting an undergraduate Bachelor's degree (Prospects 2019).

Declaration Section

Author's contributions

Dr Batty was responsible for the survey design. Both the authors contributed to the collection and analysis of data and both read and approved the final manuscript.

Availability of Data and Materials

The datasets used and/or analysed during the current study are available from the corresponding author on reasonable request.

Declarations

The authors have no conflicts of interest to declare that are relevant to the content of this article.

Ethical Approval

Ethical approval for the study was provided by the University of Birmingham Ethics Committee (ERN_17-1209) and in accordance with the ethical standards as laid down in the 1964 Declaration of Helsinki and its later amendments or comparable ethical standards.

Disclosure statement

No potential conflict of interest was reported by the author(s).

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