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Post-16 students' experience of practical science during the COVID-19 pandemic and implications for the development of students' self-efficacy in practical work

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Abstract This paper presents the findings from a detailed study investigating UK undergraduate students' experience of practical science in their post-16 studies during the COVID-19 pandemic. It also examines their perceived confidence and preparedness in relation to areas of practical science skills at the start of their undergraduate courses. The study employed an exploratory sequential mixed methods design. Findings from student focus groups held at the end of their post-16 studies were used to support the development of a comprehensive skills audit and quantitative survey for incoming undergraduate students. Survey data were collected in September and October 2021 from 275 students commencing Biosciences, Chemistry, Physics and Natural Science degrees at two universities in England.

The research is important because although almost all students had the opportunity to undertake practical work as part of their post-16 studies during the COVID-19 pandemic, there was considerable variation in students' experiences. The data indicate that COVID-19-related closures of post-16 education establishments, ongoing social distancing requirements and the consequent removal of the assessment criteria for students to have 'routinely and consistently' undertaken each of the practical assessment requirements had implications for the development of students' self-efficacy in relation to practical science. The research presents important considerations which are relevant for educators supporting students' transition from post-16 to Higher Education and have the potential to impact on incoming students over many years to come.

Keywords: Practical skills, Science Education, Post-16, Higher Education, COVID-19, Self-efficacy.

Introduction

Practical work in science is widely considered to be a vital part of science learning and an essential feature of school and university science (QAA, 2019; QAA, 2022; SCORE, 2013). The varied nature of practical work, however, means that there is often little agreement over the aims and definition of practical work in schools or in Higher Education (HE). Examples include: teaching the principles of scientific enquiry; improving understanding of theory through practical experience; teaching specific practical skills, such as measurement and observation; motivating and engaging students; to promote a logical and reasoning method of thought; and developing transferrable skills such as communication, teamwork and perseverance (Bretz, 2019; Seery, 2020; Gatsby, 2017). This study uses a modified version of the Cramman et al. (2021) definition of practical science skills:

1. Manipulative (hands-on) skills: e.g. setting up and using equipment, taking measurements, making observations.
2. Procedural skills: e.g. working safely in the laboratory, following a method, choosing suitable equipment.
3. Scientific enquiry skills: e.g. planning an experiment, identifying variables, analysing data, drawing conclusions.
4. Soft skills: e.g. using software such as Microsoft Excel to plot graphs and present data, writing lab reports, researching, referencing.
5. Transferable skills: e.g. organisation, communication, time-management.

This study undertook a detailed investigation into undergraduate students' experiences of practical science in their post-16 studies during the COVID-19 pandemic. Student participants were from six science departments within two UK universities. The study investigated the environment in which the students undertook their pre-University post-16 practical work in Biology, Chemistry and Physics as well as gathering information on their perceived confidence and preparedness in specific aspects of undergraduate

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practical work. The findings are significant for educators and policy makers in the post-16 and HE sector, highlighting both the immediate and potential long-term impact that the changed teaching and assessment landscape during COVID-19 has had on the development of students' self-efficacy in practical science.

Background

The COVID-19 pandemic brought in-person teaching to an abrupt halt in more than 100 countries, including the UK, by the end of March 2020 (Hale et al., 2021). Even after the majority of schools reopened in the UK in September 2020, measures to limit virus transmission such as social distancing, rearrangement of classrooms and reduced sharing of equipment were reported to have a significant negative impact on teaching and learning of primary and secondary science (Wellcome, 2021). A significant decrease in the provision of science practical activities was reported in a study of more than 400 teachers in the UK (Association for Science Education, 2020). The study found that there had been efforts to set some form of practical work for students during the school closures but, there was also an increase in the use of digital technologies replacing rather than enhancing hands-on practical work. Additionally, the wider purpose of practical work in helping learners to develop broader, often transferable, skills such as teamwork and communication was reportedly lost.

The majority of students participating in the current study undertook their post-16 A-Level qualifications in the UK over the two academic years 2019-20 and 2020-21. Both of these academic years were impacted by COVID-19 restrictions. To mitigate for the ongoing impact of COVID-19, for students receiving their A-Level qualifications at the end of the 2020-21 academic year, Ofqual (the UK Government qualifications regulator for schools) changed the A-Level assessment of practical skills, removing the requirement for students to have 'consistently and routinely' undertaken each of the practical requirements. This requirement is part of the Practical Endorsement, a separate assessment in the A-Level sciences which evaluates via teacher observations students' practical skills 'that are not assessable in written exams' (AQA, 2015). In 2020-21, students were only expected to undertake a minimum number of practical activities and to have aimed to cover as many of the apparatus and techniques as possible (Ofqual, 2021). Prior to the pandemic, there were 12 required practical activities which all students were expected to complete for each science A-Level (AQA, 2015). As AQA state, however, 'this list is not designed to limit the practical activities carried out by students. A rich practical experience for students will include more than the 12 required practical activities' (AQA, 2015). Although the Practical Endorsement is a requirement for A-Level science, it does not contribute to a students' final A-Level grade and is separately graded as either 'Pass' or 'Not Classified' (Ofqual, 2017). However, most universities (with discretion) will ask for a Pass grade when they make STEM course offers.

Historically, new undergraduates have been reported to lack confidence in the laboratory and to have a lack of laboratory skills (Smith, 2012), with variations in confidence levels across different practical skills (Mistry et al., 2020). This study uses self-efficacy as a framework to probe students' perceived confidence across all five areas of practical science skills, as detailed above, to investigate whether any differences are seen between the skill areas and whether there are indications that students' experiences during COVID-19 could have influenced these.

Self-efficacy is concerned with people's beliefs in their own capabilities to organise and carry out the course of action required to manage prospective situations (Pajares, 1996; Bandura, 1977). It is developed by four main sources of influence: mastery experiences relating to a person's previous successes and failures; vicarious experiences that involve observing other people's successes; social persuasion related to receiving feedback from others; and emotional states related to the well-being of the individual (Bandura, 1977). Four factors have been identified as contributing to experimental self-efficacy in chemistry laboratories: conceptual understanding; laboratory hazards;

procedural complexity; and the lack of sufficient resources (Kolil et al., 2020). There is a lack of research regarding influences on experimental self-efficacy in other STEM disciplines (Kolil et al., 2020). However, one study found that when physics laboratory courses focussed on developing lab skills, rather than reinforcing content from lectures, students 'demonstrated greater success with respect to fostering expert-like beliefs about the nature and importance of experimental physics as well as their affect and confidence when doing physics experiments' (Wilcox and Lewandowski, 2017). Additionally, it has been shown that students with a higher self-efficacy are more likely to perform more difficult tasks than those with low self-efficacy, however the link between self-efficacy and specific laboratory tasks is not clearly understood (Kolil et al., 2020). A link between perceived preparedness and self-efficacy has been observed in studies of student teachers (Giallo & Little, 2003; Housego, 1990). These studies found that a perception of being prepared is important for the development of the confidence of an individual to execute a behaviour. Therefore, if the student believes that they are less prepared to carry out an activity it will impact on their self-efficacy.

Research design

This study explored three questions. For students starting their science degrees in September 2021:

1. What were students' experiences of practical work in their post-16 studies during the COVID-19 pandemic?
2. How confident did students feel in relation to key science practical skills at the start of their degree?
3. How prepared did students feel in relation to different areas of practical skills at the start of their degree?

These findings are critical for supporting students impacted by COVID-19 in their transition to HE and for understanding the longer-term experiences of this cohort as they progress through HE. The findings could also provide insight into more general issues experienced by students during this transition.

Methodology

This study takes a constructivist approach, working from the position that COVID-19 created a new landscape in education that was not well understood. It was therefore necessary to gather insights from students, which could be interpreted to understand their experiences. In order to do this, a robust exploratory sequential mixed methods design was chosen (Creswell and Plano Clark, 2017). This enabled initial exploration of A-Level students' experiences through focus groups with a small number of students (phase 1), followed by development of an online survey and skills audit (phase 2) for the incoming first year undergraduates using the themes that emerged from phase 1 (Table 1). Use of a quantitative survey for the second phase of data collection enabled the exploration of the experiences of a large number of students within the time constraints of the students' transition period to university (a window of approximately 4-6 weeks between A-Level results day and the start of laboratory sessions at the beginning of term). Although a purely quantitative survey had the limitation of not collecting narratives from the students, it was selected in order that the survey was detailed but not overly onerous to complete for the students (maximising the response rate) and in order that the data could be analysed rapidly to be available for the teaching staff to act on in the first few weeks of term, as well as being analysed to answer the research questions of the study. As the final stage of the process, the qualitative focus group findings were triangulated with the results from quantitative survey data (Greene, 2007).

Ethical approval was granted by the ethics committees of the participating universities on 11 August 2021 and 21 September 2021. Before taking part in the study, participants were provided with an information sheet, privacy notice and completed a series of participation agreement statements.

Table 1: Summary of data collection within the exploratory sequential mixed methods research design.

Phase	Method	Aim	No. of participants	Date of data collection
Phase 1	Focus groups (Qualitative)	Exploratory study to identify key themes relating to A-Level students' experiences of practical science during the COVID-19 pandemic to inform development of survey questions.	18	July 2021
Phase 2	Online survey (Quantitative)	Detailed exploration of students' experience of practical science during their post-16 studies and the impact on confidence and preparedness for study in HE (skills audit)	275	September – October 2021

Phase 1

Five online focus groups were held in July 2021 with 18 Year 13 students at the end of their A-Level studies. The students were recruited from eight schools/colleges that undertook the AQA specification for A-Level Biology, Chemistry or Physics qualifications. The sample included a range of school types from varying geographical locations and socio-economic status (measured via the percentage of students eligible for Free School Meals). Of the 18 participants, seven had only studied one A-Level science subject: three Biology, one Chemistry and three Physics. Eleven students had studied more than one science subject at A-Level. All students had studied for their A-Levels in England during the academic years 2019-20 and 2020-21.

A question schedule of 11 items was used and included questions on: student experiences of practical science during the COVID-19 school closures; student confidence in practical science skills; and the upcoming transition to HE. Each focus group was audio recorded and transcribed verbatim. The transcript data was analysed collaboratively by two researchers using a reflexive thematic analysis approach (Braun & Clarke, 2022). This process began with the researchers familiarising themselves with the data by reading and re-reading the focus group transcriptions. 42 initial codes were then generated by the two researchers systematically coding the entire data set. These codes were then collated with their attached relevant data and separated into 20 potential sub themes. This involved a recursive merging and re-naming of themes to accurately reflect the data held within them and the removal of initial codes not relevant to the research aims e.g. the discussion of experiences in non-science subjects. The attached data extracts were then checked against the themes and a thematic 'map' created to avoid any duplication (Braun, Clarke, Hayfield, & Terry, 2019). Further analysis of the data involved a final reduction in themes through combination and re-naming as well as the outlining of theme boundaries. A total of ten sub-themes were then collated and four overarching themes were generated (see Figure 1).

Phase 2

A detailed (25-minute) survey was developed based on the findings of Phase 1. Themes included: post-16 practical science experience; confidence in general and of practical skills; perceived preparedness for undergraduate study in practical skill areas; and demographic information. The questions were reviewed for face- and content-validity by a panel of nine HE laboratory course developers and A-Level assessment experts. The survey was piloted with five current Year 13 A-Level students to assess participants' interpretation of the questions. Following refinement based on feedback from the pilot, the online survey was launched on 24 September 2021, remaining open until 20 October 2021. Students were invited to participate if they were in their first year of a degree that contained a significant component of Biology, Chemistry or Physics. The survey was voluntary and was advertised through laboratory module mailing lists and within laboratory module induction activities. Survey data were analysed using descriptive and inferential statistics in SPSS Statistics for Windows, Jamovi and Microsoft Excel.

Of the 275 first year undergraduate survey respondents, 91 were studying Biosciences, 80 Chemistry, 24 Physics, 36 Life Sciences, and 44 Natural Sciences. 58% of participants identified as female, 37% as male, and 5% as non-binary, trans-gender, other or preferred not to say.

The majority of respondents from all subjects (n=247/275) studied in England for their post-16 studies before commencing their undergraduate degree.

Approximately 15% of students reported that they considered themselves to have a disability. This is in line with the overall figures available for students disclosing as disabled in HE in the UK (Advance HE, 2022).

Results and Discussion

The following section presents and discusses the findings by research question, with broader implications discussed at the end of the section.

Students' experiences of practical work

The analysis of the focus group data generated four themes: variation in student experience; a gap in manipulative skills; improved scientific enquiry and soft skills; positive perceptions of HE transition (Figure 1).

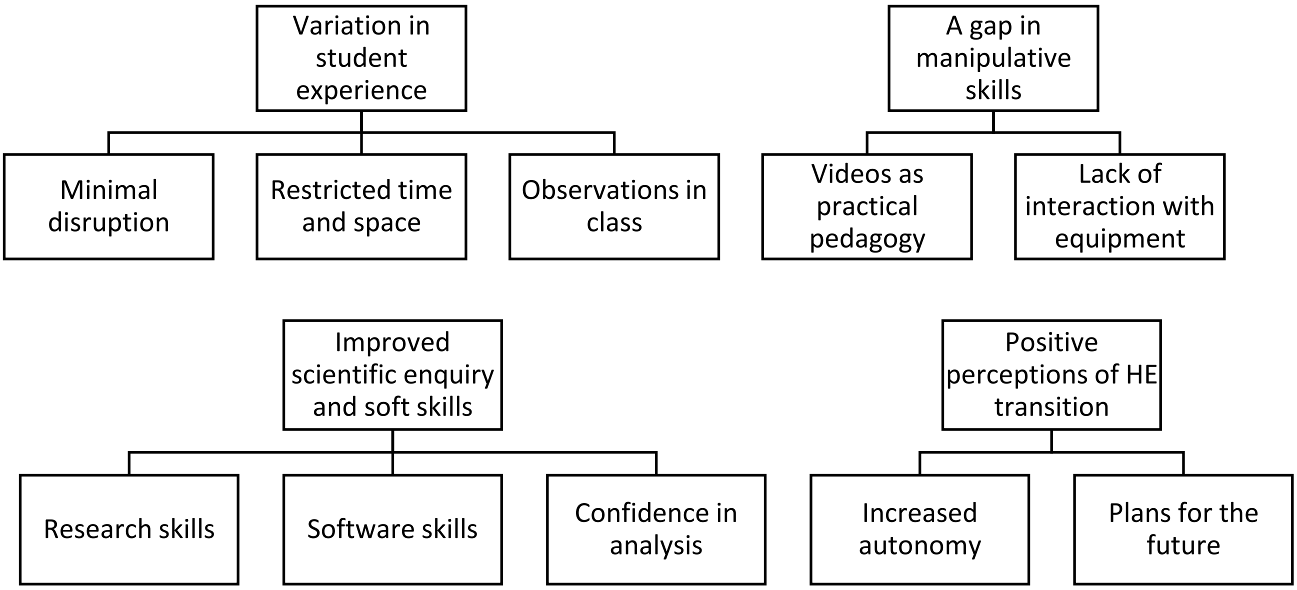

Figure 1: Themes generated from reflexive thematic analysis of the focus group data.

Although some participants felt that students had been 'all in the same boat' during their A-Level practical science studies during the pandemic, further discussion highlighted considerable variation in student experiences. When students returned to socially distanced classrooms, some students experienced minimal disruption, while other students felt their experiences had been restricted by both the time and space available for practical science. Survey data supported this finding, revealing that although almost all students had the opportunity to undertake practical work, there was significant variation in their experiences, especially between subjects. The data showed students were predominantly undertaking practical work every two weeks or once a month for an average of either 35-45 or 50-60 minutes, lower than the pre-COVID findings from the

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Cramman et al. (2019) study where teachers reported students were undertaking on average 80-90 minutes per week.

Students in all three subjects reported that their A-Level practical activities were tailored more towards following a ‘recipe-style’ pre-prepared set of instructions than ‘devising their own practical procedure’. This trend may be due to at least one of the A-Level assessment criteria placing a specific focus on correctly following written instructions (Ofqual, 2016). The majority of students across all three subjects reported that they had designed their own experiments at least once a term (62% Biology, 61% Chemistry, 64% Physics).

There was a difference between subjects in whether students were given an opportunity to carry out an extended independent practical investigation spanning more than one lesson (36% Biology, 48% Chemistry, 28% Physics). The difference could in part be due to the content of the practical handbooks that support teaching the A-Level curricula; the Chemistry handbook includes multiple practical activities that are intentionally split over a number of separate lessons (AQA, 2018b) but the Biology handbook only suggests one practical which could take place over multiple lessons. All suggested Physics practical activities fit within a single lesson (AQA, 2018a; AQA, 2018 c).

In summary, the evidence from the survey suggests that, despite the significant impact of COVID-19, students did have opportunity to undertake practical work as part of their A-Level studies, although experiences varied between subjects and schools. The focus group data, however, highlighted a mismatch between the students’ perceptions of the quantity of their practical work experienced and the actual amount undertaken (with students perceiving they had completed less practical work than our findings have indicated).

Student confidence

As would be expected from the evidence in the literature (Bandura, 1977; Mistry, 2020), across all three subjects at university, the data indicated that students were more confident in the skills that they reported having undertaken most frequently during their A-Level (or equivalent) studies (table 2 and supplementary tables). Overall, there was no statistically significant difference between subjects for the students' reported levels of confidence across a specified set of non-subject specific practical skills.

Data in table 2 show the means for the rank order for how often students had carried out particular skill types during their A-level (or equivalent) studies and their confidence to undertake different skill types. The data were generated by calculating a mean score for each skill type for each student based on how often they had carried out individual skills or how confident they felt in undertaking individual skills (see supplementary tables for a list of the individual skills within each skill type). For each student, the calculated means were then rank ordered from 1 (skill type carried out the least often by the students) to 4 (skill type carried out the most often) and 1 (skill type the student felt least confident in undertaking) to 5 (skill type the student felt most confident in undertaking). A mean of the rank score was then calculated for each skill type and is displayed in table 2. Students were not asked about how often they had undertaken transferrable skills in the survey, and hence there is no mean score for this in table 1 and the rank order is only from 1-4 rather than 1-5.

Student preparedness

In the survey, students ranked the categories of skills by how prepared they felt to carry them out at university. 'Transferable skills: organisation, communication, time-management', 'Procedural skills: working safely in the laboratory, following a method, choosing suitable equipment' and 'Manipulative Skills: Manipulative (hands-on) skills: setting up and using equipment, taking measurements, making observations' ranked highest (table 2). But these categories did not correspond to the specific skills that the students reported having undertaken most often during their post-16 studies or those which they reported feeling most confident in undertaking (table 2). The students ranked 'Soft skills: using software such as Excel to plot graphs and present data, writing lab reports, researching, referencing' as being the skill they felt least prepared for, however, both the survey data and comments from the focus group participants indicated that they had had more opportunities to undertake soft skills.

Focus group students were positive about the transition from post-16 to HE. For many, the experiences of learning from home and the greater autonomy during school closures meant they felt well-prepared for what they predicted university study would entail. 67% of survey respondents considered that the independent learning required to work from home during COVID-19 restrictions would help them adapt to independent working in HE, however, only 17% of students thought that it would help them to work independently in the laboratory at university. Survey responses across all three subjects showed that students were concerned about the increase in difficulty level between post-16 and HE studies in practical science, with over 40% of students in each subject reporting that they were concerned about it 'a lot'.

In summary, in contrast to the findings about the skills the students felt most confident in (which corresponded to those they had carried out most often in their post-16 studies) the participants unexpectedly reported feeling least prepared for undertaking skills that they reported having carried out frequently.

Table 2: Means of the rank orders of skill types for how often students had carried out skills, their confidence to undertake skills and how prepared they felt to undertake the skills at university.

Skill types	N	Missing	Mean	Standard deviation	Median	Min.	Max.
Rank order of how often the student had undertaken the skills 1: Least often to 4: Most often							
Manipulative skills	257	12	1.69	0.778	2	1	4
Procedural skills	259	10	1.66	0.636	2	1	4
Scientific enquiry skills	269	0	2.7	1.07	3	1	4
Soft skills	242	27	2.93	0.908	3	1	4
Rank order of how confident the student felt to undertaken the skills 1: Least confident to 5: Most confident							
Manipulative skills	269	0	2.27	1.45	2	1	5
Procedural skills	269	0	2.78	1.09	2.5	1	5
Scientific enquiry skills	269	0	3.15	1.19	3	1	5
Soft skills	269	0	3.13	1.2	3	1	5
Transferrable skills	269	0	3.63	1.55	4	1	5
Rank order of how prepared the student felt to undertake the skills at university 1: Least prepared to 5: Most prepared							
Manipulative skills	268	1	3.22	1.15	3	1	5
Procedural skills	268	1	3.77	1.04	4	1	5
Scientific enquiry skills	268	1	2.35	1.13	2	1	5
Soft skills	268	1	1.88	1.2	1	1	5
Transferrable skills	268	1	3.78	1.41	4	1	5

Note. The students were asked to directly rank how prepared they felt in each skill type. The rank orders were calculated for how often and how confident. Students were not asked how often they had carried out transferrable skills during their post-16 studies.

Discussion

The findings highlight the varied experience of the incoming undergraduate students across multiple science subjects after COVID-19. The insights around students' experiences of different practical skills during their post-16 studies and their perceived confidence and preparedness for undergraduate study raise some interesting questions. As would be expected from the literature, students felt most confident in undertaking the skills they had undertaken most often (Bandura, 1977; Mistry, 2020). However, it is also expected that students would feel most prepared for carrying out activities that they have carried out most often (Giallo & Little, 2003), this was unexpectedly not observed in this study though. Students' post-16 experiences appear to have developed their self-efficacy (including confidence) to some extent. However, as a perception of being prepared to undertake an activity has been found to be important in the development of self-efficacy, our findings may indicate that that students' self-efficacy may have the potential to have been developed further.

Literature shows that students' self-efficacy develops through four main areas: mastery experiences; vicarious experiences; social persuasion; and emotional states (Bandura, 1977). School closures and continued social distancing requirements due to COVID-19 appear to have led to students' self-efficacy being impacted across all of these areas. Mastery experiences may have been impacted through the loss of repeated practice of particular skills, and the experience of multiple successes and failures, due to the removal of the requirement for 'consistently and routinely' undertaking the practical skills (Ofqual, 2021). Vicarious experience may have been impacted through social distancing limiting students' ability to witness others carrying out practical work. Social persuasion may have been limited due to reduced ability to receive feedback and discuss their skills development in detail with teachers and other students. As the main source of feedback for students on their practical work, this highlights the importance of teachers (and in HE, demonstrators) understanding the impact of student self-efficacy to support personalised student learning (Awais & Stollar, 2021). There is also much evidence around the impact of COVID-19 on the emotional wellbeing of students (Evans et al., 2021; Owens et al. 2022).

Therefore, although the students had successfully gained university places, this study indicates that the conditions they experienced within COVID-19 have the potential to have influenced their development of self-efficacy in relation to practical work. This is a significant finding for educators to consider as students transition from post-16 to HE that will impact on incoming students over many years to come.

Conclusion and recommendations

The findings of this study provide an insight into the varied experience of practical work for students during their post-16 education during the COVID-19 pandemic. Although some students thought that everyone had been 'in the same boat', our findings show that this was not the case. While almost all students reported that they had had the opportunity to undertake practical work at school, there were differences in the frequency and timing of opportunities to undertake practical work. The majority of students had the opportunity to devise their own practical procedures, however, many also reported they never had the opportunity to do this. There was also a mixed picture as to whether students had the opportunity to carry out an extended independent practical investigation spanning more than one lesson.

This study indicates that school closures, on-going social distancing requirements and the changes in assessment criteria, may have had the potential to negatively influence students' development of self-efficacy in relation to practical work.

Finally, one positive aspect of the changed post-16 working environment created by COVID-19 appears to have been that students consider that it has helped them prepare for independent working more generally at university. However, the students did not consider that it had helped them prepare to work independently in the laboratory at university and there was significant concern from some students about the perceived increase in difficulty between post-16 and university studies in practical science. This again highlights the importance of ensuring support is present in the right areas for students as they transition from post-16 education to HE and the legacy impact that may remain from COVID-19 for many years.

This study provides comprehensive and evidence-based reflection of the challenges posed by COVID-19 in the context of hands-on learning. However, it also provides an opportunity to educators and HE to revisit the teaching strategies used to mitigate the negative effects on scientific enquiry and laboratory skills. Careful consideration needs to be made to support the development of undergraduate students' self-efficacy through appropriately scaffolded learning opportunities within practical work. In this context, the skills survey developed as part of this study can serve as a comprehensive skills audit for the STEM subjects at the start of undergraduate year 1. This skills audit will be a powerful tool to help identify the gaps at this early stage and allow educators to tailor the methodologies and pedagogies to provide training according to the students' individual needs. For large sized cohorts in HE, evidence suggests that demonstrators are best placed to provide this much needed support at personalised level (Awais & Stollar, 2021). To improve students' confidence and self-efficacy in the areas where students reported feeling least confident, e.g., 'experimental design and planning' and 'critical thinking', permanent integration of hybrid learning models could be considered. This could include virtual labs, simulations, data visualization platforms, flipped classroom and collaborative tools as pre- and post- lab activities. Crucially, this study highlighted that the students have varied experience, and educators could take the opportunity to use this varied experience to foster peer interactions and collaborative learning.

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Ethics

Research was approved through the Durham University and University of Liverpool ethical review processes.

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Supplementary appendix

Supplementary Table 1. Experience of practical skills in Biology during their A-Level (or equivalent) studies for respondents studying Biosciences/Lifesciences at university. (n=136).

Question	Practical skill classification	I have never done this myself or seen it done	I have seen this done (but not done it myself)	I have done this myself, but only once	I have done this myself more than once
Perform basic mathematical calculations (e.g. find the rate or the mean)	Soft-skill	1	0	2	133
Safely use a Bunsen burner to sterilise equipment	Manipulative and Procedural	5	10	13	108
Set up and use an optical microscope	Manipulative and Procedural	7	14	22	93
Safely use dissection instruments (e.g. scalpel, forceps, needle, knife, scissors)	Manipulative and Procedural	3	9	35	89
Use statistical tests including chi-squared, t-test and correlation coefficient	Soft-skill	10	6	38	82
Use sampling techniques in fieldwork (e.g. quadrats and transects to determine distribution and abundance of organisms)	Procedural and Scientific Enquiry	8	12	45	71
Effectively use microbiological aseptic technique	Manipulative and Procedural	21	21	43	50
Use a graticule to measure the length of a specimen in microscope work	Manipulative and Procedural	21	19	53	43
Produce an annotated scientific drawing from a microscope	Soft-skill	21	19	53	43
Set up and use a compound microscope	Manipulative and Procedural	58	24	13	41

Use automatic pipettes	Manipulative	31	20	59	25
Pour agar plates	Manipulative and Procedural	66	38	20	10
Use electrophoresis to separate biological compounds	Manipulative and Procedural	63	49	20	4

Supplementary Table 2. Experience of practical skills in Chemistry during their A-Level (or equivalent) studies for respondents studying Chemistry at university. (n=128-130).

Question	Practical skill classification	I have never done this myself or seen it done	I have seen this done (but not done it myself)	I have done this myself, but only once	I have done this myself more than once
Measure the mass of a compound using a mass balance	Manipulative and Procedural	2	3	1	125
Safely and carefully handle chemicals, including corrosive, irritant, flammable substances	Manipulative and Procedural	2	3	3	122
Perform mathematical calculations e.g. calculate pH or rate constant	Soft-skills and Scientific Enquiry	1	0	8	122
Set up glassware using a boss head clamp and clamp stand	Manipulative	2	2	12	115
Calculate the uncertainty of an apparatus (half of the smallest division) and express this as a percentage error	Soft skills	10	6	26	89
Use paper chromatography	Manipulative and Procedural	8	4	39	79
Set up apparatus for a distillation	Manipulative and Procedural	2	21	38	70
Measure the pH using either pH charts, pH meter, or pH probe	Manipulative	5	12	45	69
Perform a distillation	Manipulative	3	22	36	69
Know how to flute filter paper	Manipulative and Procedural	19	20	41	50
Perform heating under reflux	Manipulative and Procedural	7	27	49	48

Set up apparatus for heating under reflux	Manipulative and Procedural	6	27	52	46
Use thin-layer chromatography	Manipulative and Procedural	29	24	50	25

Supplementary Table 3. Experience of practical skills in Physics during their A-Level (or equivalent) studies for respondents studying Physics at university. (n=41).

Question	Practical skill classification	I have never done this myself or seen it done	I have seen this done (but not done it myself)	I have done this myself, but only once	I have done this myself more than once
Use an analogue device to measure length, temperature, angles and volume	Manipulative and Procedural	0	0	1	40
Use a stopwatch for timing	Manipulative and Procedural	1	0	0	40
Use a digital instrument, such as an electrical multimeter, to measure current, voltage and resistance	Manipulative and Procedural	0	0	2	39
Use a digital instrument to measure mass	Manipulative and Procedural	1	0	2	38
Use a light gate for timing	Manipulative and Procedural	3	8	8	22
Time over multiple oscillations to reduce uncertainty (increase precision)	Manipulative, Procedural and Scientific Enquiry	6	2	13	20
Use vernier scales	Manipulative and Procedural	10	3	11	17
Measure the period and amplitude of a signal	Procedural	6	7	11	17
Use an oscilloscope to view waves	Manipulative	5	8	13	15
Use a signal generator to generate waves	Manipulative and Procedural	7	9	15	10

Supplementary Table 4. Student self-rated confidence on a scale from 1 (not at all confident) to 10 (very confident) for how they felt at performing a set of not subject specific practical skills. (n=272-275).

Skills	N	Mean	Median	Std. Deviation
Using appropriate safety equipment to minimise risks with minimal prompting (e.g. wear safety goggles, lab coat, gloves)	274	8.80	9	1.41
Carefully following a written procedure/method	274	8.40	9	1.28
Rounding to an appropriate number of significant figures	275	8.36	9	1.48
Carrying out a suitable number of repeats to ensure results are reliable	274	8.19	8	1.49
Using appropriate units in tables, e.g. J for energy, ml for volume	275	8.12	8	1.67
Organisational skills (tidy workspace and laboratory notebook, bringing correct equipment)	273	7.86	8	1.83
Identifying variables (independent, dependent, control variables)	275	7.82	8	1.72
Team working skills (working and contributing well with peers)	272	7.75	8	1.75
Time-management skills (arriving on time, meeting deadlines for practical and written work)	272	7.74	8	1.79
Assessing potential hazards and risks in an experiment (e.g. harmful chemicals, electrical components, open flame, bioactive substances, trip hazards)	275	7.73	8	1.70
Using materials (e.g. chemicals or reagents) safely with minimal assistance	274	7.69	8	1.62
Analysing data from graphs (e.g. identifying a correlation or a linear relationship)	275	7.67	8	1.51
Keeping a good record of experimental findings and notes in a lab book or folder	275	7.58	8	1.93
Independent learning skills (completing tasks and meeting learning objectives within and outside lesson time without guidance)	272	7.57	8	1.75
Controlling variables (keep variables such as time, temperature, concentration and light intensity constant)	275	7.53	8	1.62
Analysing data from tables (e.g. identifying a trend in data)	274	7.50	8	1.52
Interpersonal skills (interacting with people to obtain information/assistance)	273	7.40	8	2.09
Self-motivation skills (desire to work hard to meet your goals, showing commitment, going beyond work set by teachers to enhance learning)	273	7.39	8	2.02
Selecting appropriate apparatus for a given task in an experiment	275	7.09	7	1.53
Using apparatus correctly with minimal assistance	275	7.03	7	1.67
Obtaining precise data during an experiment (readings which are close to each other)	273	6.83	7	1.74
Obtaining accurate data during an experiment (results which are realistic and expected)	275	6.73	7	1.69
Understanding the difference between a random error (results scattered over a range), systematic error (results differ from the	275	6.71	7	1.95

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accepted value by a consistent amount) and a human error (erroneous result caused be a mistake)				
Carrying out fact-finding research on the Internet from reputable sources	275	6.69	7	2.02
Evaluating data (e.g. discussing the quality of data and suggesting improvements to a method in order to collect better quality data)	275	6.64	7	1.62
Identifying sources of systematic error (e.g. if an instrument is poorly calibrated)	275	6.43	7	1.88
Recording data in a table using Excel	275	6.28	7	2.44
Presentation skills (creating and giving an oral presentation)	273	6.08	6	2.37
Using appropriate referencing (cite sources of information from online and other resources to allow the sources to be found again)	275	5.93	6	2.37
Selecting appropriate materials (e.g. chemicals or reagents) for a given task in an experiment	274	5.93	6	1.95
Plotting a clear graph or chart that is appropriate for the data using Excel	275	5.89	6	2.57
Carrying out data analysis using Excel, e.g. calculating an average	275	5.53	6	2.57