International Journal of Science Education

ISSN: (Print) (Online) Journal homepage: www.tandfonline.com/journals/tsed20

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To cite this article: Katharine Hubbard, Dominic Henri, Graham Scott, Howard Snelling & Elke Roediger (23 Feb 2024): Developing undergraduate practical skills and independence with ‘at home practical kits’, International Journal of Science Education, DOI: 10.1080/09500693.2024.2311087

To link to this article: https://doi.org/10.1080/09500693.2024.2311087

INTERNATIONAL JOURNAL OF SCIENCE EDUCATION
https://doi.org/10.1080/09500693.2024.2311087

Developing undergraduate practical skills and independence with 'at home practical kits'

Katharine Hubbard [a*], Dominic Henri [a*], Graham Scott [b], Howard Snelling [a] and Elke Roediger [a]

[a]School of Natural Sciences, University of Hull, Hull, UK; [b]Teaching Excellence Academy, University of Hull, Hull, UK

ABSTRACT
The COVID-19 pandemic posed significant challenges for practical teaching within the sciences. While many instructors adopted innovative alternatives to conventional practicals, many relied on digital approaches that did not give students hands-on experience. In this study we evaluate the use of 'at home' practical kits used in first year physics and biology teaching at a UK university as an alternative to laboratory classes. In particular we focus on the enforced independence over time, space and help-seeking inherent in the at-home model as a driver of student learning and confidence. Students reported the kits encouraged independence, problem solving and self-reliance. Students associated the at-home practical kits with higher level cognitive skills as defined by Bloom's revised taxonomy. While most students enjoyed using the kits, those who did not enjoy them tended to have higher previous experience of practical work before university. Students saw potential value in the kits after the pandemic, so could be an alternative or supplement to in-person practicals. We recommend that practical organisers use our findings around the development of student self-reliance to reconsider practical design and incorporate more opportunities for students to solve problems independently to increase effectiveness of practical teaching.

ARTICLE HISTORY
Received 6 January 2023
Accepted 24 January 2024

Introduction

The COVID-19 pandemic impacted massively on education across the globe. The inability to teach on campus was particularly acutely felt in experimental science subjects, where students were unable to access laboratory spaces (Campbell et al., 2020). A variety of approaches were taken across the sector to replace practical work with meaningful equivalents, which included online lab simulations, computational practicals,

CONTACT Katharine Hubbard k.hubbard@hull.ac.uk School of Natural Sciences, University of Hull, Hull HU6 7RX, UK @KEHplantsci
*These authors contributed equally to the work presented.
Supplemental data for this article can be accessed online at https://doi.org/10.1080/09500693.2024.2311087.

simulations and data-driven projects (Delgado et al., 2021; Francis, 2020; Stafford et al., 2020; Wilkinson et al., 2021). While these have significant value, particularly in the unique circumstances of the pandemic, most alternative models used in the pandemic did not require students to physically participate in practical work. As such they cannot replicate the physicality of practicals, or develop more generic skills such as problem solving and resilience that are also associated with hands-on practical work (Noel et al., 2020; Wilkinson et al., 2021). In this paper we describe our ‘at home kit’ approach to providing 1st year biology and physics students with practical training independent of the laboratory, and evaluate student perceptions of their own learning.

The purpose of practical work in science education

Most scientific programmes of study require some practical work component, which is considered by most to be an essential component of scientific training. However, when designing degree programmes we often fail to define what the purpose of that practical work actually is. Seery asks the question ‘What is distinctive about laboratory work that cannot be met elsewhere in the curriculum?’ (Seery, 2020). Reid and Shah identify four potential goals of laboratory work; (i) learning about scientific theory, (ii) developing practical/technical skills (iii) developing broader scientific skills such as interpretation and experimental design, and (iv) developing transferable skills such as teamwork and problem solving (Reid & Shah, 2007). It has been noted that labs are an expensive and inefficient way to teach theory (Kirschner & Meester, 1988; Seery, 2020), and that the development of transferable skills is not unique to the laboratory (Seery, 2020). The distinctive value of practical work therefore resides in opportunities to learn specific technical skills and more general scientific skills. Practical work does not have to be laboratory based. Multiple studies provide evidence for field-based practical learning supporting the development of technical, scientific and transferable skills (Arrowsmith et al., 2011; Peacock & Bacon, 2018; Peasland et al., 2019; Scott et al., 2006). Equally, students may gain scientific skills through computational ‘dry labs’, including analysis of complex data sets, simulations and mathematical models (Landau, 2006). We therefore refer to scientific ‘practical work’ as a general mode of learning rather than just ‘laboratory work’ as a specific example.

Practical-based teaching is not inherently a more effective pedagogy than a passive lecture-based curriculum. Much research has focused on the importance of the level of student independence in a practical setting (Berg et al., 2003; Domin, 1999b; Kirschner et al., 2006; Pols, 2020; Vorholzer & von Aufschnaiter, 2019). For example, there has been significant criticism of the ‘cook book’ model of practical work whereby students follow a set of instructions to carry out a procedure, with limited cognitive engagement with the activity (Brewer & Smith, 2011; Domin, 1999b). A content analysis of laboratory manuals aligned to Bloom’s Taxonomy (Bloom et al., 1956) found that the majority reinforced language around the lower levels of knowledge, comprehension and application (Domin, 1999a). Highly structured practicals present science as a ‘solved problem’, so removing students from the more authentic and messy scientific process that requires problem solving and the ability to deal with uncertainty (Brownell & Kloser, 2015; Kampourakis, 2018). An alternative approach to practical teaching is more inquiry-driven, and emphasises the research process, experimental design and problem solving (Brownell & Kloser, 2015). Several frameworks define multiple levels of inquiry-driven learning, from structured inquiry where the activity is driven by an instructor through to genuine open inquiry where the student drives both the scientific questions and methods used (Bell et al., 2005; Berg et al., 2003; Brownell & Kloser, 2015; Domin, 1999b; Pols, 2020; Vorholzer & von Aufschnaiter, 2019).

A wealth of literature supports the idea that encouraging independence in a practical setting develops learner confidence, interest, and 'higher' cognitive outcomes (Berg et al., 2003; Brewer & Smith, 2011; Healey, 2005; Scott et al., 2019; Wang & Degol, 2017; Weaver et al., 2008). However, students find independence challenging, and educators must balance student ownership and guidance in the design of such activities. Insufficient guidance can overwhelm students self-efficacy (belief in the ability to achieve particular tasks), reduce their confidence and persistence with challenging tasks (Aditomo & Klieme, 2020; Bandura, 2012; Harmer & Stokes, 2016; Kirschner et al., 2006). Finding an appropriate level of expected independence is an especially difficult task because all students come with different levels of prior experience of (and hence different self-efficacies) and interest in working in a practical setting (Figure 1). Expectancy-Value theory suggests that prior experience and student interest could be key mediators of a student's ability to engage with challenging educational tasks (Vu et al., 2022). Higher intrinsic interest can lead to deeper engagement with a task, while previous negative experiences with similar tasks can reduce engagement (Vu et al., 2022). In short, if student independence in a practical setting is to promote positive educational outcomes, educators must carefully choose which aspects of the practical expect students to act independently and allow for this expectation to scale with student experience and interest (Brownell & Kloser, 2015).

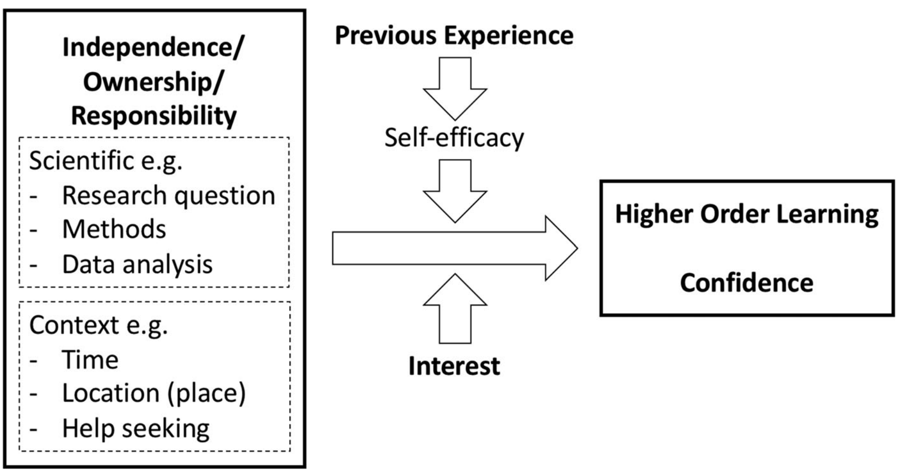

Figure 1. Conceptual model of relationship between independence, higher order learning, confidence, interest and previous experience. Interest and Experience are presented as mediators of the relationship between independence and learning; note that negative previous experiences can reduce higher order learning and confidence, while positive previous experiences can increase both.

Alternatives to practicals in the pandemic

In the pandemic situation, students were unable to physically access university facilities, and learning was mostly asynchronous. This means that the disruption to practical classes was more than just lack of access to particular pieces of equipment, but involved both spatial and temporal disruption to conventional practical teaching. Being unable to meet in typical practical environments meant that students were isolated from peers, instructors, postgraduate demonstrators and technicians, so were unable to gain the benefits of being around scientific role models and the unique environments usually associated with scientific inquiry. The challenges to scientific learning were therefore potentially far greater than just the ability of students to learn particular experimental techniques. However, given that many instructors adopted innovative alternatives to traditional practicals, the particular scenario of the pandemic allows us to interrogate the assumption that effective scientific learning is tied to the traditional locations of scientific practical training.

When finding alternatives to traditional practicals, science educators took two different models. Many instructors adopted digital approaches when designing alternatives, using laboratory simulations, video tutorials, datasets or virtual reality laboratories (Delgado et al., 2021; Wilkinson et al., 2021). While digital approaches were wide-spread, other educators adopted an 'at home' model. In this approach, practical kits were physically posted to students, who then completed the activities in the domestic environment (Destino & Cunningham, 2020; Hubbard et al., 2022; Kelley, 2021; Pols, 2020; Schultz et al., 2020). The home experiment is not a novel pedagogy; distance learning courses in STEM have successfully used 'at home' kits for many years (Kaye, 1973; Kennepohl, 2007; Long et al., 2012; Lyall & Patti, 2010). Distance learning practical kits typically contain relatively simple experiments that can safely be carried out at home. This places significant constraints on the experiment(s) that students can perform; for example chemicals and liquids may not be possible to post. Despite the design constraints of at home kits, the physicality of practical work is retained, with students doing experimental work themselves. This approach to practical teaching therefore allows us to explore whether students can learn how to do hands-on science in alternative spaces, and what students felt they learned from at home practicals.

Enforced independence as a key dimension of the at home kit pedagogy

A key feature of the at-home kit pedagogy is enforced independence over the research context, as students had to complete the activities in their own time and setting, and were not able to immediately seek help from academics or demonstrators. Research on student independence in a practical setting has typically focussed on as ownership of the science; i.e. student ownership of the research goals and/or methodologies undertaken (Brownell & Kloser, 2015; Domin, 1999b; Pols, 2020; Vorholzer & von Aufschnaiter, 2019). However, this project allows us to consider a new dimension of contextual independence as students must choose the time and place the practical takes place, as well as help seeking strategies given the separation from lecturers and demonstrators. This level of enforced independence is more common within field-based practical education, and is thought to foster learner autonomy and higher level learning (Peasland et al., 2019; Scott et al., 2019). Prior research has identified that students adopt a different 'role' within the at-home practical setting compared to when they are on-campus (Kennepohl, 2007), becoming the most experienced scientist at home rather than being an inexperienced student in the lab. The impact of this on student learning requires further study. Similarly to traditional considerations of research-based independence, students are likely to respond differently to the challenge of working independently according to their prior experience and interest in practical learning (see Figure 1). This study attempts to consider whether students report the enforced independence of 'at-home' practicals as an experience that builds confidence and 'higher' cognitive traits in a similar way to open-ended laboratory practical learning that focuses on 'research independence', or as one that decreases their confidence because of a perceived lack of guidance (Kirschner et al., 2006).

Research questions

Our study investigates first year university undergraduate perceptions of 'at-home' practical kits across two science subjects (Physics and Biology). We are particularly interested in whether students perceive their responsibility for choosing the time and place of the practical work as a source of independence and ownership (Kirschner et al., 2006; Vorholzer & von Aufschnaiter, 2019). We used online surveys, completed after students had completed their practical work to investigate the following questions:

1. How did students experience conducting scientific practical work in a domestic setting?
2. Did students report the kits promote 'lower' or 'higher' levels of learning, as defined by Bloom's revised taxonomy, through their engagement with the kits?
3. How did the enforced independence of the at home kit model shape student learning and confidence?

Methods

Survey distribution and participants' information

In our evaluation of the at home kits as a pedagogical strategy, we adopt a mixed method approach using an online questionnaire based methodology. This provides a relatively easy approach to collecting data from a cohort, and allows for quantitative and qualitative approaches via the use of closed and open questions (Cohen et al., 2017). The survey was written to encapsulate (i) student opinions of their learning aligned to Bloom's revised taxonomy, (ii) level of previous practical experience, (iii) student confidence in their practical abilities, (iv) overall opinions of practical science, and (v) the student experience of carrying out the at-home experiments. We use a mix of ordinal scale items and free text to give both quantitative and qualitative information about the student experience of the at home kits.

At home kits were developed and used independently by the two subject areas, but are evaluated here using a common methodology. After discussing and refining the survey within the research team, the survey was distributed via Microsoft Forms to biology and physics students in a civic university at the end of their first year of study while most pandemic restrictions were still in place in UK universities (May–June 2021). The questionnaire was delivered online as our institution was still delivering the majority of education remotely at this point in the pandemic, but we recognised that this may have reduced the response rate (Cohen et al., 2017). Consent and demographic questions (subject, year of study) were compulsory to ensure appropriate targeting of the survey population, but all other questions were optional to maximise completion rates and to comply with best practice guidelines from the local ethics committee.

The survey was completed by 53 students; 12 from Physics and 41 from Biology. This represents a 36% response rate from Physics, and 32% from Biology. As such, the responses cannot be considered representative of the whole class, but gives insight into the student experience of using the practical kits. One Biology student had not received their practical kit, so was removed from the dataset, giving a total of 52 students. Not all questions were compulsory, resulting in different sample sizes for each question. To allow direct comparisons between the constructed scales, we present quantitative data for the 45 students who answered all of the Likert style questions. We verified that excluding students with partial answers made no difference to mean or median score and had no effect on statistical significance (Supporting Information 3). For completeness, qualitative data is presented for all students answering the respective questions, so n values vary.

Statistical methods

All data analysis was performed in Rstudio (RStudio Inc, 2016), and graphs generated with the package 'ggplot2' (Chang et al., 2018). Analysis of Likert statements was performed using the package 'Likert' (Bryer & Speerschneider, 2016). Cronbach alpha was determined using the package 'psych' (Revelle, 2020) and Spearman-Brown coefficients with the 'splithalfr' package (Pronk, 2021).

For all statistical analysis we assumed that data was not normally distributed, so used non-parametric statistical tests throughout. Statistical significance was defined at $\alpha = 0.05$, unless multiple statistical comparisons were made on the same data, in which case Bonferroni corrections were made with $\alpha = 0.05/\text{number of comparisons}$.

Bloom's revised taxonomy: development and validation

In exploring the potential of at home kits to promote scientific learning, we particularly wanted to focus on the cognitive engagement of students with the activities. As such, we use Bloom's revised taxonomy (Anderson & Krathwohl, 2001) as a framework for cognitive aspects of learning. In this study we apply Bloom's revised taxonomy to our at-home kits, defining and assessing each level of learning through a questionnaire based design (Table 1). For our study, we adopt the 'higher' and 'lower' classification of Crowe et al. (2008), whereby 'remember' and 'understand' are lower order cognitive skills, 'apply' is a transition between lower and higher, and 'analyse', 'evaluate' and 'create' are all higher levels skills. For evaluation of student learning based on Bloom's revised taxonomy, we developed a series of twelve statements, in line with the principles of the Blooming Biology Tool (BBT) of Crowe et al. (2008). The level of learning was

Table 1. Question prompts aligned to Bloom's revised Taxonomy.

Level of Bloom's taxonomy	Higher or Lower Order Cognitive Skills?	Question wording: 'The at-home kits helped me to … .'	Spearman- Brown Reliability Coefficient
Remember	Lower	Remember concepts relevant to my course Memorise experimental techniques	0.725
Understand	Lower	Understand concepts relevant to my course Appreciate how experimental techniques work	0.717
Apply	Lower & Higher	Use information from my course to understand a new situation Apply knowledge from my course to a new situation	0.874
Analyse	Higher	Analyse data using techniques from my course Perform numerical or graphical analysis of data	0.827
Evaluate	Higher	Evaluate the success of the experimental technique used Identify the strengths and weaknesses of an experimental technique	0.683
Create	Higher	Create a new method to answer a scientific question Design a new experimental strategy to investigate a scientific question	0.873
Cronbach alpha coefficient (all items)			**0.92**

primarily indicated by the verb used in the prompt; verbs were drawn either directly from the name of the taxonomy level or from those classified against Bloom's taxonomy by Stanny (2016). We balanced overall questionnaire length with survey validity by developing two statements for each taxonomy level (Table 1). Questions were developed to use a five-point Likert scale from 'strongly disagree' to 'strongly agree' to allow for quantification of responses and determination of internal consistency.

Responses were numerically coded such that 'Strongly disagree' was given a score of 1, and 'Strongly agree' a score of 5. Cronbach alpha was 0.92 for these questions, which is slightly above the maximum recommended alpha of 0.90 and suggests some items may be redundant (Tavakol & Dennick, 2011). However, we did not think it was appropriate to remove any questions as the questionnaire was structured to give only two items per level of Bloom's Taxonomy, so dropping items would have reduced coverage. As further validation, Spearman-Brown reliability coefficients were also determined for each level of the taxonomy (Table 1), as this is the most robust method for calculating internal consistency for a two item scale (Eisinga et al., 2013). Spearman-Brown coefficients were above 0.68 for all questions, indicating high levels of consistency. As the internal consistency between items was high, data are presented with the two questions combined into one scale item.

Practical interest and experience measures: development and validation

We constructed three measures from Likert questions; a laboratory practical 'interest' score, practical 'experience' score, and higher level learning score derived from the Bloom's taxonomy questions, all scaled from 0 to 100 to allow for easy comparison of measures constructed from different numbers of questions. The interest questions were drawn from previous research into perceptions of practical science, providing a validated measure of student opinion of practicals. The experience questions were based on a previous study of pre-university exposure to practical science (Hubbard et al., 2017). The survey asked participants to reflect specifically on their practical experience during their A levels or equivalent pre-university experience. All questions are provided as Supporting Information 1. After conversion to numerical codes, Cronbach alpha for the lab interest questions was 0.83, indicating high internal consistency. For each of the students who answered all seven interest questions we calculated an Interest score using the formula below (Goulder et al., 2013)

$$Normalised\ score\ = (100/(X-1)) * [(\ \Sigma scores\ -\ N)/N]$$

where N = number of statements and X = maximum Likert score, giving a normalised score between 0 and 100 for each student ($N = 7$ and $X = 5$ for interest questions). For example, if a student answers neutral (3 on a 5 point Likert scale) for all 7 questions (Σscores = 3 × 7 = 21) the interest score is calculated as:

$$Lab\ interest\ score\ = (100/(5\ -1)) * [(\ 21\ -\ 7)/7]\ =\ 100/4 * 14/7\ =\ 25*2\ =\ 50$$

Scores below 50 represent relative lack of interest in labs, and above represent positive interest. The median interest score was 67.9 (min = 50, max = 96.4), so all students in our sample had positive interest in lab practicals.

To construct the equivalent normalised score for practical experience, we numerically scored experience levels as Never = 1, Once or twice in the whole course = 2, Once or twice a term = 3, Every week = 4. Cronbach alpha for the experience questions was 0.92. We then calculated a practical experience score as above ($N = 7$, X = 4 for Practical Experience). Experience scores ranged from 0 to 100, with a median of 57.14. Our sample therefore contained students with a wide range of previous practical experience. Using the same method, we also constructed a Higher Learning Score for the 6 Bloom's Taxonomy questions classified unambiguously as Higher Learning (Analyse, Evaluate, Create; $N = 6$, X = 5).

Qualitative data analysis

For the two free text questions (what students felt they had learned from the kits and how they discussed the kits with friends or family) we performed a thematic analysis (TA) based on the six-phase framework of Braun and Clarke (2006). Reflexive TA is a flexible method for qualitative analysis that emphasises the active role of the researcher(s) in constructing themes from data (Braun & Clarke, 2006, 2021). As part of the reflexive process, we identified a potential conflict of interest in being both designers of the kits and researchers. To mitigate this, all qualitative analysis was co-performed by one researcher who taught using a kit (KH) and one who had not been involved with either kit (DH). We originally intended to take a deductive approach based on Bloom's taxonomy for data about student learning, but soon established that many of the responses did not fit with this framework (e.g. those about independence or confidence). We therefore switched to an inductive approach for all analysis. Both researchers familiarised themselves with the raw data for all students, then one researcher conducted initial coding and proposed preliminary themes. Establishment of final themes was done as an iterative process through discussion with the second researcher until both were satisfied with the coverage and naming of themes. All responses were then re-coded against the final themes and number of responses quantified, subsequently checked by the second researcher until agreement was obtained.

Results

Student experiences of undertaking practicals 'at-home'

We first asked our students where they had completed the kits. Of the 52 students who received their kits, 29 did the experiments in their family home (or equivalent), 15 in their hall of residence, 7 in their student house and one in their own flat. All students therefore completed the activities in a domestic setting, which in the majority of cases involved shared space e.g. with family members or other students. 34 out of the 52 students said that they had discussed the at home kits with either friends or family, and 30 students provided a free text comment that could be thematically coded. Four major themes were present in the responses; explanation, space, experience and value (Table 2). The most frequently coded theme was 'Explanation' ($n = 22$), where students discussed what they were doing (e.g. via demonstration) and/or why they were doing it (e.g. the theory behind experiments). The second major theme was 'Space' ($n = 10$), which related to conversations about doing science in the domestic environment, either in terms of the physical location or the people in that space. These responses ranged from asking permission to use a shared kitchen, to two students who actively recruited their partners as technicians to help them carry out the experiment. Within the 'Experience' theme ($n = 5$) were students who used affective domain language (e.g. enjoy, stress); both positive and negative experiences were mentioned. The final theme

Table 2. Reported topics of conversations between students and friends/family about the kits.

Theme	Illustrative Quotes	*n*
Explanation (What and/ or Why)	I explained what the components were and how they worked and I also showed them parts of the experiments (Physics) I was able to explain to my partner what I was doing and the reasons and applications for the use of photospectrometry. (Biology) Alternative ideas for experiments, best way to get standardised results (Biology)	22
Space (People and place)	i told them that i would need to do the practical in the kitchen and they allowed me to (Biology) my mum asked why i was making so many cups of tea so i explained the experiment (Biology) I also asked my partner to act as a technician and bring some of the kit into the living room and hold a phone torch above the cuvette to give better light as the daylight was fading (Biology)	10
Experience	mostly how close I was to finally getting it done (Physics) How much I enjoyed it (Biology) That it was stressful and that I didn't enjoy doing it (Biology)	5
Value	It helped me also question why I'm doing the course I am and really experience how what I'm studying can be applied (Physics) How good it was that we got the opportunity to do an experiment through covid times (Biology)	4

Question text: Did you talk to friends/family who are not studying this module about your at home experiments? What did you talk about? *N* values give the number of people describing the theme; some participants described multiple themes. 32 students provided a free text comment, of which 30 contained sufficient information to be coded against at least one theme.

was ‘Value’ ($n = 4$) where a small number of students made comments either about the positive value of the experiments to their learning or to the student experience (particularly during the pandemic). In responses to other free text questions there were some students who mentioned discussing the experiments with their tutor group via asynchronous chat platforms. However there was no evidence to suggest that students were receiving substantial amounts of help from friends or family in performing the experiments at home.

Student self-reported learning

We asked students what they had learned from using the kits as a free text response field; 45 students submitted a comment, of which 41 responses could be coded to at least one of four major themes; Independence, Scientific Skill, Negative Experiences and Science from the Everyday (Table 3). ‘Independence’ was the most commonly described theme ($n = 22$), which included sub themes of ownership, problem solving and help seeking

Table 3. Thematic Analysis of student perceptions of their learning.

Theme	Subtheme	Illustrative Quotes	*n*
Independence	Ownership	it really helped me be independent and learn how to conduct an experiment in my own way (Physics)	22
		Normally when we come into the lab, everything is already set up for us, so it was nice to be able to start and finish everything myself. (Biology)	
		this at home experiment gave me the opportunity to think for myself, and read instructions carefully. When I completed the assignment and handed it in I felt completely in control of my own work (Biology)	
	Problem solving/Help seeking	it helped me to be more persistent in trying to figure things out (Physics)	
		If I was in a lab with a lecturer it is likely that I would have asked for help from start to finish because I would have wanted to make sure it was done perfectly (Biology)	
		I learnt how to conduct scientific experiments without assistance from peers or lecturers (Biology)	
	Confidence	It also helped with confidence as I was not comparing my work to anyone else around me and allowed me to come up with my own results and own conclusions without worrying what anyone else concluded. (Biology)	
Scientific Skill	Experimental technique	How to use components such as LEDs and resistors (Physics)	15
		I learnt the general steps in using a photospectrometer (Biology)	
	Data analysis	I’ve also learnt what the different types of t-tests are and how to perform them (Biology)	
		how to evaluate results e.g. calculate uncertainties (Physics)	
Negative/ Prefer traditional labs		I wouldn’t say that I learnt a lot from the at home kits because, as I said, it was extremely complicated to try and work out on your own (Biology)	8
		I learnt how terrible I am at managing practicals outside of a lab setting, which I’m not particularly good at in the first place (Physics)	
Science from the everyday		That practical don’t have to really complex and need to be done in a lab. (Biology)	7
		the fact that simple things, such as tea can be used to make a fun experiment from which data can still be collected (Biology)	

Question text: What do you think you learned by using the at home kits? *N* values give the number of people describing the theme; some participants described multiple themes and subthemes. 45 students provided a free text comment, of which 41 contained sufficient information to be coded against at least one theme.

behaviour and confidence. 'Scientific skills' were the next most frequently mentioned ($n = 15$), which included both experimental technical skill and data analysis skills. There were some students who described a negative or frustrating aspect to their learning ($n = 8$), some of whom actively stated that they thought the lab would be a more favourable environment in which to do the experiment. The last theme was 'Science from the Every-day', which related to comments realising that it was possible to do meaningful practical work without sophisticated equipment ($n = 7$).

Student self-reported Bloom's taxonomy cognitive development

We then asked students a series of twelve questions about what they learned from the kits, aligned to the levels of Blooms' revised taxonomy (Figure 2). The strongest level of

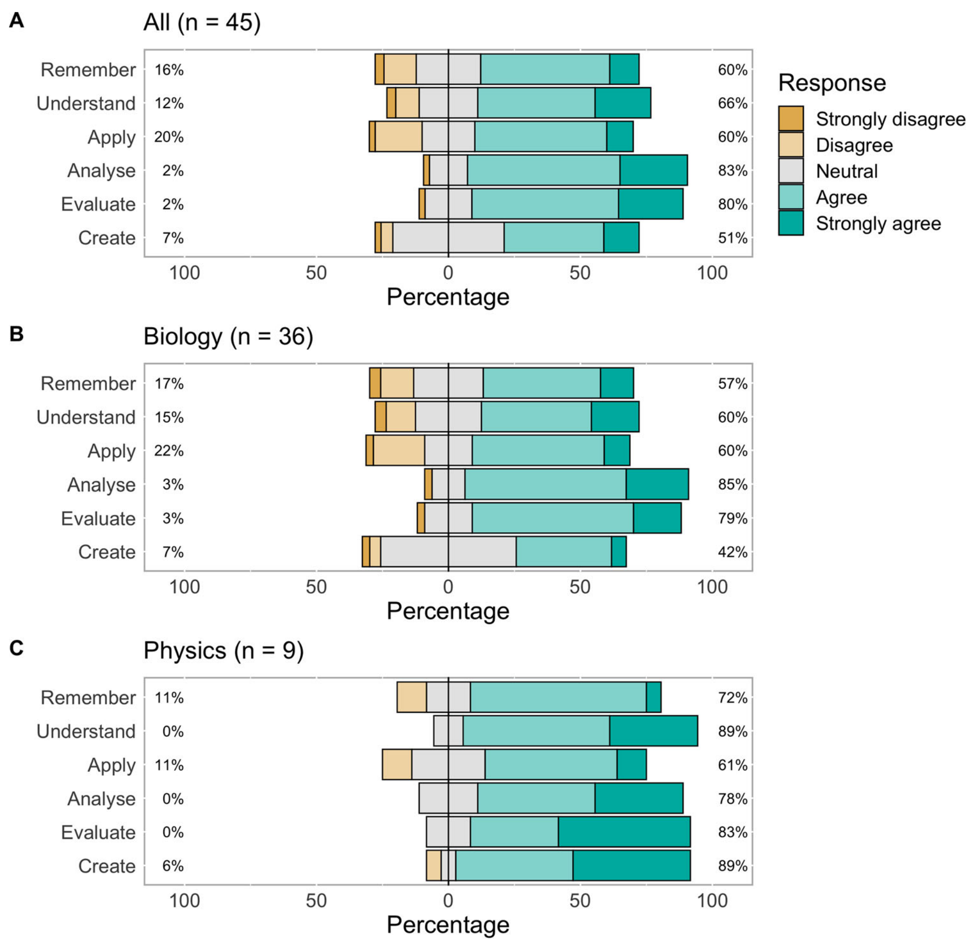

Figure 2. Student learning from the kits aligned to Bloom's revised taxonomy. Data for the two departments are presented as A: All students, B: Biology and C: Physics. For all statements, the percentage of responses disagreeing with the prompt is displayed on the left, agreeing on the right, and neutral in the centre. Results presented for the 45 students who responded to all quantitative question prompts. The two statements for each level have been combined, i.e. 'Remember' contains $45 \times 2 = 90$ responses.

agreement was for the higher order classifications of 'Analyse' (83% agreement), followed by 'Evaluate' (80%). The lowest level of agreement was for 'Create' (51%). However, the lower level of agreement for 'Create' masks differences between the two departments for this level which were not seen for the other Bloom's questions (Figure 2B,C). For the physics students there was 89% agreement with the 'Create' statements, whereas for biology there was only 42% agreement (Mann–Whitney U = 269, $p < 0.001$).

Student confidence development

We also asked students to reflect on their levels of confidence associated with practical work before and after using the kits (Figure 3). Before using the kits, the most common response was 'Somewhat confident' (20 out of 45 responses). After using the kits the most common response was 'Confident' (21 out of 45), representing a significant increase in self-reported confidence levels (Chi-square test $\chi^2 = 20.3$, df = 9, p-value = 0.016).

Impact of previous practical experience and opinions of laboratory work on student perception of 'at-home' practicals

As prior student experience and interest in practical work influence future engagement, we wanted to understand both their previous level of experience in experimental work before university, and their overall opinions of laboratory work. We asked students to indicate how frequently they had participated in experimental work at school/college through seven statements (Figure 4). This identified that our students had varying levels of experience of practical work before university. Most students reported that they had never designed their own experiments (23 out of 45), or had only done so once or twice in their pre-university course (16 of 45).

There was no significant difference in the practical experience of the Biology and Physics students (Mann–Whitney U = 176, $P = 0.69$). However, there were modest differences in what the two groups of students were experienced in. Notably, 8 out of the 9 physicists had never designed their own experiment at school, compared with 17 of the 38 biologists. From these questions we calculated an experience score for each

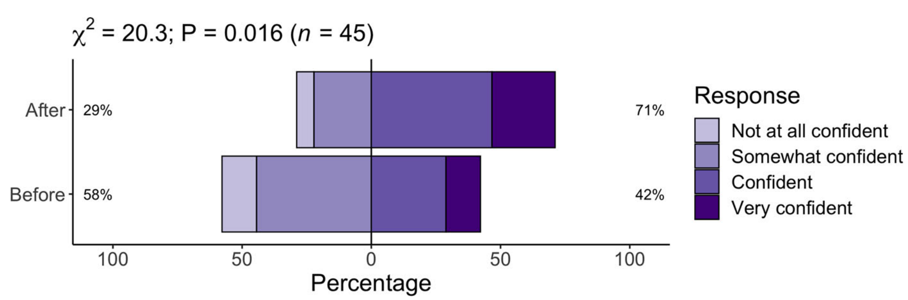

Figure 3. Student self-reported confidence in practical work before and after using the kits. Lower levels of confidence are on the left, higher levels on the right. Responses are shown for the 45 students who answered all Likert questions.

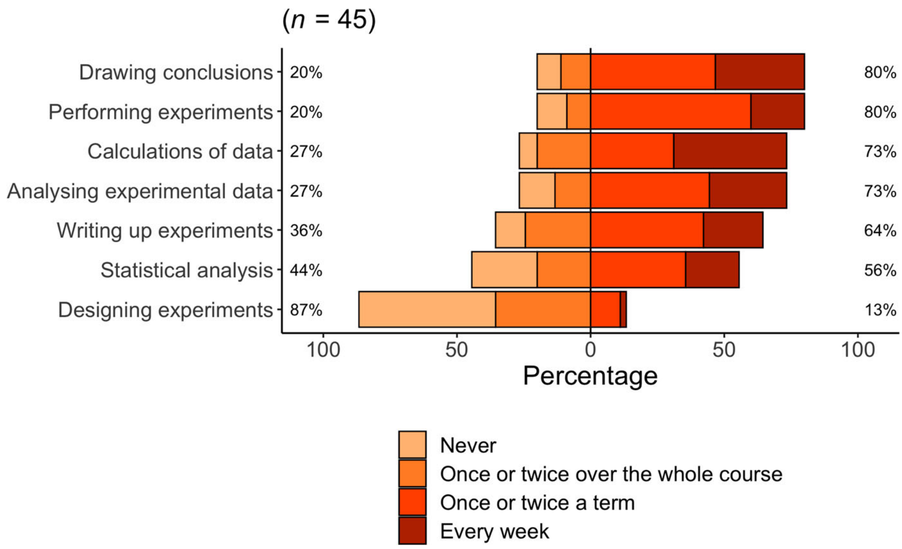

Figure 4. Practical Experience of Students Prior to University. Responses are shown for the 45 students who answered all Likert questions. Lower levels of experience are on the left, higher levels on the right.

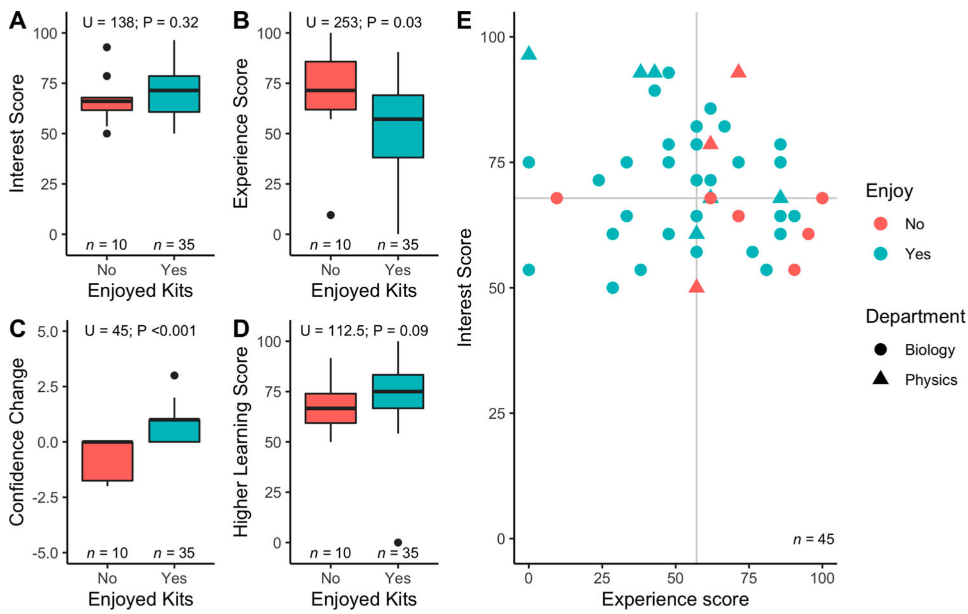

Figure 5. Student enjoyment of using the kits. Enjoyment is presented in relation to A: Interest B: previous experience of practical work. C: Change in confidence D: Higher Level Learning aligned to Blooms Taxonomy and E: Relationship between interest and experience score for those students who provided all relevant data for Lab perception score, Experience score, department and enjoyment of the kits ($n = 45$). Note that some points represent multiple students with identical scores. Grey lines indicate the median for each score.

student; there was no difference in the experience score for the two departments (Mann–Whitney U = 105, *p*-value = 0.11). There was no correlation between experience and interest scores (Spearman's correlation coefficient = −0.14, *p*-value = 0.33, *n* = 45).

We also wanted to understand whether enjoyment of the kits had shaped experiences. Of the 45 students with complete quantitative data, 35 students stated that they enjoyed using the kits, while 10 did not enjoy using them. These proportions were similar for students in both departments. There was no difference in the Interest scores between the students who had and hadn't enjoyed the kits (Mann–Whitney U = 138.5, *p*-value = 0.32, Figure 5A). However, students who reported that they did not enjoy using the kits had higher Experience scores than those who enjoyed using the kits (U = 253, p = 0.03; Figure 5B). Students who did not enjoy the kits also reported a negative impact on their confidence, while those who enjoyed them reported a positive impact (U = 45, $p < 0.001$; Figure 5C). However there was no significant impact on the level of agreement with the Higher Order learning Bloom's taxonomy statements (U = 112, $p = 0.09$; Figure 5D), indicating students still recognised their higher level learning even if they did not enjoy the experience.

We asked students if they had experienced any problems or barriers to using the kits. Of the 49 students who answered the question, 28 students reported no problems, with several commenting that the kits were easy to use. The most commonly reported problems related to getting the right lighting condition for the biology kits ($n = 7$), difficulties understanding the instructions (4 biology, 2 physics), or difficulty finding space to carry out the experiments ($n = 4$). A small number of students reported difficulties with the kit contents; a physics student reported running out of wires, and a biology student reported that acetone they had purchased had reacted with the cuvettes provided. While some students were frustrated by these issues, none of the students who completed the questionnaire reported major issues that prevented them from engaging with the kits.

Finally, we asked students if the kits should be used when we returned to on campus teaching, with all 52 students providing a response. 22 students said that they wouldn't want to see the kits used in the future; Four didn't find the kits useful at all, and 18 saw value in them during the pandemic, but wouldn't want to use them once we returned to laboratory based teaching. However, the majority of students ($n = 30$) saw some value in the kits in the long term, including as a pre-laboratory exercise ($n = 9$) or to complement laboratory teaching ($n = 10$). Two students even said that on campus practicals should be replaced with at home kits, while others said that students should be given the choice of at-home or on-campus practicals ($n = 9$).

Discussion

In this study, we sought to investigate whether students perceived the greater responsibility and reduced guidance of 'at-home' practicals as a facilitator of personal and academic development or a barrier to it. Our results support the idea that, for most students, the ownership of time and place and the physical separation of guidance can be considered as an additional and comparable dimension of student independence to the traditional focus on research independence (e.g. study aims and methodology) (Brownell & Kloser, 2015; Pols, 2020; Vorholzer & von Aufschnaiter, 2019). For the rest of the discussion we expand on this conclusion by considering our results through the lens of our three research questions.

How did students experience undertaking scientific practical work in a domestic setting?

Students most commonly described themes of independence, ownership, help-seeking and confidence in their experience of doing practical work in a domestic setting. This suggests that students recognised the enforced independence of the at home model, and that students play a different role than they would in the laboratory. In the lab, students undertaking practical work are the 'student' i.e. the least experienced person, and would expect to receive instruction from demonstrators. In contrast, at home they are the most experienced person undertaking the experiment and need to take ownership of the practical. Our data demonstrates students may even explain what they are doing and demonstrate the practical to others in the domestic setting, adopting the role of expert and contextualising their learning (Kennepohl, 2007). Students also reported responsibility for setting up the space, justifying the value of the work, and even directing familial 'laboratory assistants'. We were struck with the number of students who described the kits as having encouraged their independence, problem solving and self-reliance. These concepts are closely linked to the personal attributes of self-efficacy and confidence (Bandura, 2012). It has been argued that student autonomy can be promoted by developing student confidence in their ability to work independently and encouraging student ownership of their learning by taking responsibility for evidencing higher order thinking skills (Berg et al., 2003; Henri et al., 2017; Macaskill & Denovan, 2013; Smith & Darvas, 2017). This is particularly relevant in a practical context (Peasland et al., 2019; Scott et al., 2019) and through pedagogies such as problem-based learning (Kumar & Natarajan, 2007). At-home labs are distinctive in giving students autonomy over when and where they perform experiments, which requires self-direction (Kennepohl, 2007). This is a different component of open-ended-ness to that considered in much of the literature which focuses on scientific independence (Vorholzer & von Aufschnaiter, 2019). Our data suggests that building in opportunities for contextual independence (e.g. time, space, help seeking) can also be valuable for practical work that would traditionally take place in laboratories.

Did students report the kits promote 'lower' or 'higher' levels of learning, as defined by Bloom's revised taxonomy, through their engagement with the kits?

Prior research suggests that student ownership and autonomy are important aspects of developing 'higher order' cognitive skills (Berg et al., 2003). In our study, students agreed that the kits had supported development of the 'higher' levels of Bloom's taxonomy. For most levels of the taxonomy there was no difference between the two departments, but Physics students had higher levels of agreement with 'Create' than the biologists. This could potentially be explained by the two different kit designs. The physics kit encouraged students to find their own solutions to relatively general open ended research questions over the course of a year. In contrast, students used the biology kit to test a defined hypothesis within a two week window, and extending use of the kit beyond this was optional. The physics kit could therefore be viewed as guided inquiry, while the biology kit was a more structured inquiry model (Brownell & Kloser, 2015). The different pedagogical strategies were driven partly by learning outcomes on the respective modules, but also by what could be mailed out to students via the postal service. The physics experiments relied on relatively commonly used components such as batteries, LEDs, multimeters which were possible to post out, with relatively few constraints being imposed by the at home model. In contrast, using the postal service resulted in significant constraints placed on the biological experiments that could be performed, as chemicals and biological specimens could not be sent to students (Hubbard et al., 2022). As such, the biology kit did not lend itself so well to student-driven open-ended practical inquiry. Others who used at-home kits during the pandemic also found them to encourage student inquiry skills, and that using more 'basic' equipment required problem solving and reflection around complicating factors and experimental design (Pols, 2020). Previous pre-pandemic studies found either no difference or slight improvements in assessments scores for students undertaking at-home practicals compared with those doing supervised practicals (Kennepohl, 2007; Long et al., 2012), supporting the idea that this is an effective pedagogy that could be used more widely. We therefore conclude that at home kits can drive higher level learning, but the specific design of the kit will influence the type of scientific inquiry.

Did students perceive the ownership of time and place as an important aspect of their personal development and a builder of confidence or as a barrier to it?

We found that most students had positive views of the kits, and that use of the kits had increased their confidence in performing practical work. Confidence was closely related to enjoyment of the kits; those who enjoyed them reported increased confidence, while those who did not enjoy them reported lower confidence levels after using the kits. Students with higher levels of practical experience before coming to university were less likely to enjoy using the kits, perhaps because the exercises seemed trivial compared to their previous experience or expectations of university level practicals. Conversely, there were some students who clearly articulated in the free text responses that the lack of immediate support and guidance was a problem. This is a difficult balancing act; placing too much responsibility on the student by having too little scaffolding will have the opposite effect and reduce the development of student confidence and self-efficacy (Harmer & Stokes, 2016; Kirschner et al., 2006; Kumar & Natarajan, 2007). Based on the theory that students who recognise their personal development are more satisfied with educational experiences (Bowles et al., 2020; Burgess et al., 2018), we suggest that this task was most impactful for students with medium levels of prior laboratory experience but not those with very low or high levels of experience. Students that highlighted their growing confidence also identified that their usual threshold for seeking support is quite low, suggesting the at-home environment allowed them to develop confidence because they had to work things out for themselves. Students who described frustration with the kits also tended to have low levels of confidence about practical work both before and after using the kits. We also suggest that the opposite was true, students with greater experience in the laboratory were not sufficiently stimulated (either by the task or the 'unscientific' environment), which might explain their lower satisfaction.

Limitations of study and future research directions

This is a relatively small scale study designed to capture student experiences of kits used during the pandemic. We include two independent subject areas using different kits, but it is unclear as to whether all kits designed for at-home use would be equally effective. Our survey participants were affected by the pandemic part-way through their last year of school/college and throughout their entire first year of undergraduate study. They therefore did not have 'regular' supervised practicals to compare their experiences to, and may also have had missed out on practical skills training prior to university. Perceptions may have been significantly different had we done the equivalent with second or third year undergraduates who had already done some university level practicals. We are also unable to separate out the design of the kits from the scientific discipline; it may be that any differences between biology and physics students represent norms for the discipline rather than the learning associated with the specific kits used. We have not used this questionnaire with students experiencing supervised practicals, so have no benchmark to compare responses against. It is also difficult to separate out the experience of the particular experiments contained within the kit from the experience of doing practical work remotely. It would be interesting to consider student perceptions of the same activities performed in supervised timetabled sessions to explore these two dimensions. Our questionnaire was designed to capture cognitive responses to the kits, but the free text comments highlighted the importance of student autonomy. Further data collection should incorporate validated scales of self-efficacy and/or autonomy (Henri et al., 2017; Macaskill & Denovan, 2013) to allow for systematic comparison of these important components of learning.

Conclusions and recommendations for practice

Instructors faced multiple design challenges in providing alternatives to practicals during the pandemic that still resulted in meaningful learning. Our kits demonstrate that valid scientific learning can happen in the home environment (Kennepohl, 2007), although they are not designed to replace all aspects of hands-on science training or the use of more complex equipment that cannot be removed from the laboratory environment. The laboratory clearly has a role in providing access to specialist equipment and chemicals; only a modest range of practical activities could be delivered in the home environment. Our results indicate that at-home kits provide students with an authentic and inclusive opportunity to develop scientific skills and thinking, so may have value as a 'back-up' or even integrated into post-pandemic teaching. Both kits have already been used post-pandemic as an alternative practical for students unable to attend in person labs, allowing students to meet learning outcomes without having to reschedule labs. We also see a role for at-home kits in potentially increasing the amount of practical work students are able to do without placing further pressure on teaching labs and timetables. Future use of the kits should be designed with 'stretch goals' included to better cater to students with high levels of practical experience before university. Both of our at-home kits were designed for use by first year undergraduates; it would have been considerably more challenging to design kits to replicate more sophisticated practicals in later years of study (Kaye, 1973). The kits have also highlighted that contextual independence (e.g. independence over time, space and help seeking) can increase student ownership and confidence around practical work, possibly more so than in supervised practicals. Our study provides further support for incorporating structured opportunities for students to develop independence in practical work, particularly around problem solving and help-seeking (Brewer & Smith, 2011; Brownell & Kloser, 2015; Healey, 2005). While at-home kits are unlikely to replace in-person practical work, aspects of the independence built into the at-home pedagogy have relevance for post-pandemic teaching which could be incorporated into 'regular' practical classes to maximise their impact.

Acknowledgments

We would like to thank technical staff in both departments for supporting the development of the at home kits. The Physics kit received financial support from the Ferens Educational Trust. We also thank the Biosciences Education Research Group at our institution for input into study design and thinking that informed writing of the manuscript.

Disclosure statement

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

Funding

This work was partly supported by the Ferens Educational Trust.

Ethics statement

Ethical oversight for the questionnaire was approved by the University of Hull Faculty of Science and Engineering ethics committee (project code FEC_2021_85). Students were provided with a full study description, and were informed that their participation was optional and that they could withdraw at any time before submitting their questionnaire responses. Electronic consent was obtained from all participants, and no demographic information other than degree programme was collected.

ORCID

Katharine Hubbard http://orcid.org/0000-0002-4862-0466
Dominic Henri http://orcid.org/0000-0002-7574-5846
Graham Scott http://orcid.org/0000-0003-0896-0287
Howard Snelling http://orcid.org/0000-0003-4831-1724
Elke Roediger http://orcid.org/0000-0003-2076-6065

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