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Using lessons from a comparative study of chemistry & bioscience pre-lab activities to design effective pre-lab interventions : a case study

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ABSTRACT
Laboratory classes form an important aspect of bioscience education. However, this environment is challenging for students due to cognitive load and lack of confidence. Familiarising students with aspects of their laboratory classes prior to the session can improve this. This study compares the pre-laboratory scaffolding that bioscience and chemistry students experience across UK HE institutions. Typically, bioscience modules used fewer types of activities than chemistry although reading the protocol was the most common activity for both disciplines. Within bioscience, pre-laboratory activities differed by level: first year undergraduates were more likely to be asked to read the protocol, watch videos or do calculation practice in their modules whereas final year undergraduates were more likely to experience experimental design or contextualised activities. Alongside this, this paper discusses an institutional case study of the development and evaluation of technical laboratory videos as pre-laboratory scaffolding for first year students. These were found to benefit both student focus and enhance confidence: implying that using the videos impacted on cognitive load and hence learning. Exploring barriers to the uptake of these resources identified a lack of awareness of them as a major factor, suggesting that greater integration of such resources would enhance engagement and impact.

KEYWORDS
Pre-laboratory scaffolding; video; laboratory education; multimedia

Introduction

Learning in laboratories

The study of bioscience has long involved both practical and laboratory classes. These demonstrations of real-world phenomena can take multiple forms; not all of which involve the student as an active participant. Laboratory classes can take the form of instructor demonstrations as well as students conducting experiments; similarly not all student experiments are confined to a laboratory space. Examples of this are ecological, forensic and animal studies that often involve investigation in the field. In this study, we will consider those laboratory classes which infer a degree of active participation ('hands on' experience) from the students in the class.

Laboratory classes can provide a range of different potential benefits to students. In a similar manner to Carnduff and Reid (2003) and Johnstone and Al-Shuaili's observation in chemistry (Johnstone and Al-Shuaili 2001), Adams et al. (2008) described bioscience academics' perception of first year laboratory classes in undergraduate education as multi-purpose. Alongside the

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development of practical skills or competencies and illustration of theoretical concepts, Adams et al also ascribed benefits including safety awareness, personal development (such as confidence building), understanding of how to design experiments and accurate data recording. Earlier reflections also described affective outcomes for doing laboratory work such as interest in and enjoyment of the subject (Kerr, Boulind, and Rolls 1963) that should not be overlooked as an important motivating factor for students. Indeed, according to Novak's theory of meaningful learning, factors such as motivation and interest, along with cognitive and psychomotor aspects, are needed for students to connect with concepts in a way that allows them to situate what they are learning in the context of their prior network of knowledge (Bretz 2001).

Laboratory classes can therefore be described as a form of inquiry which provides authentic ways for learners to explore the scientific method used to understand the natural world and solve meaningful problems through an active learning approach (Hofstein and Lunetta 2004). Whilst the work of Hostein focusses on observations within the school environment, the same holds true in a University setting: a review of literature of university laboratory provision by Adams (2009) highlighted numerous examples of how more open-ended inquiry-based lab learning improved outcomes, improved students' reasoning skills and enhanced enjoyment of the classes. These 'problem-solving' skills are particularly valued from the point of view of preparing graduates for the world of work and a recent review highlighted that authentic assessment (such as lab reports and lab skill portfolios) were beneficial in enhancing student employability skills (Sokhanvar, Salehi, and Sokhanvar 2021). Bioscience benchmark statements (QAA 2019) recognise both problem solving and the importance of practical skills for graduates and whilst these can differ according to discipline, university courses build student skills over the life of their course. In bioscience, accredited programmes such as those recognised by the Royal Society of Biology, require students to undertake a capstone project: enabling them to build on the skills and competencies that they have developed to undertake original research (Royal Society of Biology 2019).

Despite the many potential benefits of practical classes, the laboratory can be a challenging environment for students to learn in (Johnstone and Wham 1982). More recently, its characteristics have been described as creating a 'complex learning environment'; acknowledging that supporting learning in this type of environment is a challenge for academic staff (Seery, Agustian, and Zhang 2019). In laboratory classes, students will typically be entering an environment in which they encounter a significant amount of new information that they need to process. This can range from unfamiliar equipment and processes, to the scientific language style used in experimental protocols, hence creating a challenging and complex environment for learning (Agustian and Seery 2017). Each of these new and unfamiliar elements adds to the students' cognitive load: cognitive load can be broadly defined as the amount of different pieces of information that is being processed at any one time (Sweller 1988) (see Sweller (2010) for updated perspective). The different aspects of cognitive load are described as being either intrinsic (the inherent difficulty of the subject matter), extraneous (caused when having to discriminate important information from peripheral material) or germane load (motivation to organise and integrate material) (Sweller 2010). In a laboratory setting, intrinsic load could relate to how challenging the protocol the student is working with is; extraneous load could be how difficult it is to extract the important information from the protocol or data generated; and germane load being how this new information is integrated into long term memory (Agustian and Seery 2017).

Psychological models of learning provide insight into why increasing cognitive load can become a barrier to learning. The theory of working memory describes that for an individual to make long-term memories, they use their working memory to organise and connect experiences to prepare them for long term storage (Johnstone 1984; Reid 2008). The capacity of the working memory is described as the working memory limit and describes the number of items or pieces of information that can be processed at one time. Excessive cognitive load which exceeds this limit impairs students' ability to learn and results in an inability to discriminate important and peripheral information (Reid 2008).

Prelabs

Familiarisation with elements of the laboratory experience ahead of the class itself has been shown to help reduce cognitive load, enabling greater learning gains because the working memory is less likely to become overloaded (O'Brien and Cameron 2012; Gregory and Di Trapani 2012; Rollnick et al. 2001). In the case reported by Gregory and Di Trapani (2012), second year science undergraduate students accessed a combination of web-based activities and quizzes that related to their laboratory experience before the class itself (cohorts' sizes included in the study were 117 and 122 students). Comparing student success at meeting one of the learning outcomes (successful bacterial plating for single colonies at first attempt) with the previous year's cohort, showed a significant increase in the proportion of students successfully achieving this when students were provided with the pre-laboratory resources to better scaffold their learning experience.

In addition to learning gains in practical skills, providing pre-laboratory resources can also have a number of other benefits. This can be in terms of increasing student confidence going into the laboratory (Coleman and Smith 2019; Dyrberg, Treusch, and Wiegand 2017); student perception of preparedness (Rodgers et al. 2020); or a shift in cognitive focus leading to increased ability to link laboratory activities with the underlying theory (Winberg and Berg 2007).

A systematic review of pre-laboratory activities in chemistry education categorised pre-laboratory support into three types according to their rationale or aim (Agustian and Seery 2017). The rationales described were:

- introducing concepts (achieved via lectures, quizzes or discussion);
- introducing techniques (via technical video, interactive simulation, mental preparation, safety information);
- affective considerations (activities designed to enhance learner confidence or provide motivation for laboratory work).

Whilst this type of review has been undertaken in the field of chemistry, there are no similar systematic reviews available for biosciences. However, numerous case studies have been published which demonstrate that pre-laboratory scaffolding in biosciences could be categorised in a similar way to that proposed by Agustian and Seery (2017).

In line with these categories, pre-laboratory quizzes have been described by both Cann ((2016)) and Gregory and Di Trapani (2012) as beneficial for introducing students to concepts. A range of methods have been employed to introduce students to techniques, including virtual practical classes (Cheesman et al. 2014), instructional videos (Croker et al. 2010; Gregory, di Trapani 2012; Rodgers et al. 2020) and using virtual platforms such as Labster® for safety preparation (Dyrberg, Treusch, and Wiegand 2017; Coleman and Smith 2019). In the latter case, the authors noted that using Labster simulations increased student confidence, which means that this approach also impacts affective considerations: the final rationale for pre-laboratory work according to Agustian and Seery (2017). Whilst case studies highlight novel approaches used to enhance scaffolding of student laboratory learning, they do not give a sense of how prevalent these or other practices, such as traditional pre-laboratory lectures, are.

To this end, this study aims to establish how pre-laboratory activities are used to support student learning in Bioscience and gives a case study example of how we can develop this further.

Methodology

In order to address the aims outlined, two studies were undertaken. The first involved a survey of 30 chemistry and bioscience departments in UK higher education institutions to establish current pre-laboratory practice. Alongside this, a case study is reported that describes the experience of developing technical videos to enhance pre-laboratory scaffolding in our department at Nottingham Trent University (NTU). The latter describes the reflective cycles used to develop and assess the efficiency of this intervention.

Pre-laboratory practice in UK higher education institutions

Study design

To investigate the range of pre-laboratory activities undertaken by chemistry and bioscience academics in UK higher education institutions, a survey tool was constructed which covered key approaches. Potential pre-laboratory activities were identified from a range of literature as described above. The categories selected were: pre-laboratory seminar or lecture; read the protocol/script; take an online quiz; watch a video; further pre-sessional reading e.g. journal article, textbook; complete relevant calculations; complete a safety exercise; hot pen writing; write a preparatory essay; draw a schematic diagram; virtual simulation; and experimental design/development.

As part of the survey design, participants were also given a free text section in which they could add any additional methods for pre-laboratory preparation of their students that had not been included in the specified list.

As well as what types of activities were undertaken in each module, the survey also investigated whether the activity was compulsory or voluntary; and the estimated completion (or attendance) rate for these activities. The options given for completion rate were: 0–40%, 41–60%, 61–80% and 81–100%. Compulsory sessions or activities were defined as those where completion contributed to the module mark or where non-completion prevented entry to the laboratory. The aim of including these questions was to assess what proportion of pre-laboratory activities were used as gate-keeping activities for laboratory classes and how the level of student engagement varied.

The completion rate and compulsory/voluntary nature of the pre-laboratory lectures and seminars were investigated as these represented a student interaction with an academic team member; as opposed to the other categories where the activity required the student to interact with a resource or other material.

Participants – study 1 (UK-wide HE survey)

Bioscience module leaders working within UK HE institutions were invited to participate in the study on a module-by-module basis; meaning that individuals were eligible to contribute more than one response provided that each response related to a different module. Invitations to participate were either sent electronically (by personalised email or mailing list) or through paper survey distribution. Module leaders in chemistry disciplines were also actively recruited to allow for comparison of approaches used in bioscience with those used in chemistry.

A total of 30 institutions participated in the study, providing data for 88 modules (45 chemistry; 43 bioscience). The survey was designed for use across the UK and so government terminology, which is applicable across England, Wales and Northern Ireland was used. Scottish universities use different terminology; however for UK levels 4–7 as used in this survey, the equivalent levels are 8–10 and so there is no overlap. The numbers of modules at each of the levels (4–7) and their Scottish equivalent are shown in Table 1.

Where data is presented in the results section as a percentage of responses, these have been rounded to the nearest whole percentage point.

Case study 2: development of video resources to support laboratory classes

Alongside the survey of the pre-laboratory practice, a case study was undertaken to investigate the impact of creating a suite of technical videos to support first year undergraduates with key laboratory skills.

Table 1. Summary of the levels of taught modules in the pre-laboratory survey for bioscience and chemistry modules across UK HE.

Module level of study	NQF level	SCQF level	Bioscience modules	Chemistry modules
First year undergraduate	4	7/8	10	19
Second year undergraduate	5	8/9	15	14
Final year undergraduate	6	9/10	10	9
Postgraduate	7	11	3	1

Institutional context

In 2012, our institution opened a technology rich laboratory (Kirk et al., 2013). As a microbiology category 2 containment facility, this is a paperless laboratory. To accommodate this, students working in this laboratory make use of tablet and Cloud technology that is housed within the laboratory to access material and record data during their practical classes. This enables them to make use of their personal preparatory material and files provided by the module team, as well as providing a mechanism of exporting data (using cloud-based save/retrieval facilities) without the risk of contaminating the environment outside the laboratory. Tablets remain in the laboratory and are disinfected before/after use. At the time that this research was undertaken, all first year term 1 practical classes took place in this laboratory.

Prior to this study, students and staff completed evaluation surveys to give feedback on this new environment: including questions about what techniques students found difficult. This survey (i.e. laboratory evaluation survey) is referred to in the study design as it informed the choice of video subject material used in this case study.

Participants

Undergraduate biology and forensic biology students at our institution who were studying first year term 1 modules were invited to participate in this study. Creating resources was an iterative process where survey data from the first cohort was used to develop resources for testing with the next year's intake of students (second cohort), meaning that multiple year groups of first year students participated. Cohort 3 had access to the same resources and in the same format as cohort 2. The first cohort consisted of 319 students; the second cohort consisted of 228 students; the cohort for the focus group (cohort 3) consisted of 323 students.

Study design

As mentioned above, the laboratory evaluation survey of staff and students identified techniques that students found challenging (author's unpublished work). Based on the observations of the benefits of videos for pre-laboratory scaffolding by other authors (Croker et al. 2010; Rodgers et al. 2020; Gregory, di Trapani 2012), we created a suite of video resources with the aim of familiarising students with these techniques. A summary of this study design showing response rates (to the nearest percent) can be seen in Figure 1.

These videos were created in two groups over a 12-month period in Superlab using the same equipment that the students use, as it was thought that this would remove any barriers created by differences in different models of equipment (e.g. microscopes). Once completed, the videos were published as unlisted videos on YouTube (Google LLC, San Bruno, CA) with customised subtitles. Analytics from the YouTube channel were collected to allow comparison of the usage of videos by different cohorts and whether this differs from the current academic year (2020/21) where students are experiencing reduced lab access due to pandemic restrictions (see Figure 5 and later discussion).

In the first group (the pilot phase), the videos focussed on basic microbiology techniques that had been identified through personal communication from staff as areas that students would benefit from additional scaffolding. These videos (covering making a bacterial smear, heat fixing slides, Gram

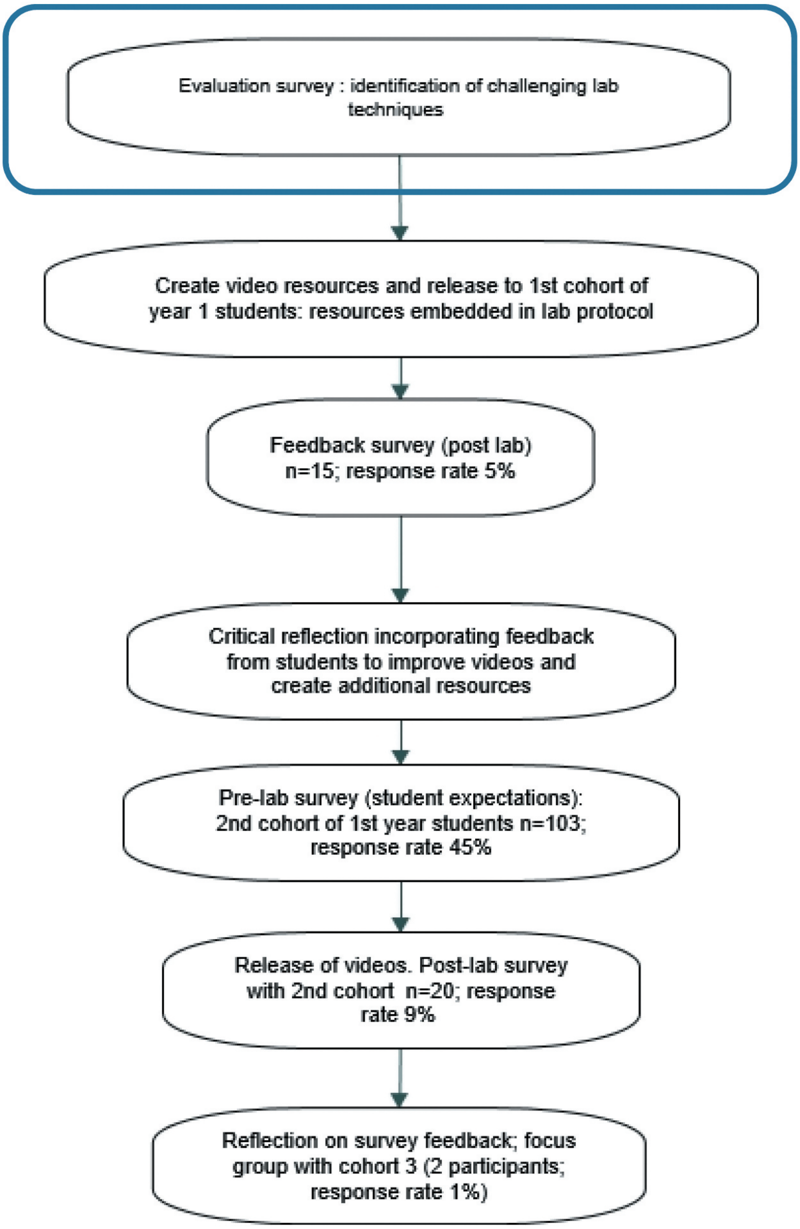


Figure 1. A schematic diagram of the development of the video case study methodology showing the survey tools used, reflective cycles and number of participants and response rates at each stage. The study highlighted in the box preceded the current study but provided information that was used in its design

staining and microscopy of bacterial samples) were embedded into the students' laboratory protocols at the relevant point and were available to the students before, during and after the laboratory class in which those techniques were being used. After making these videos, we went through a critical reflective cycle in a similar way to that described by Gibbs (1988). This involved personal reflection, informal feedback from academic and technical staff, and feedback from students by survey.

This was then used in a subsequent cycle where videos for core laboratory techniques were produced, and a similar reflection cycle completed with a second cohort of first year students. These videos focussed on making dilutions, spectrophotometry and fundamental aspects of microscopy (microscope anatomy, alignment and focussing) and were embedded in modules that used these techniques (though these were not linked to specific protocols as they were used across multiple experiments).

To supplement our understanding of the survey data and how engagement with the resources could be improved, a focus group was held: due to time constraints imposed by the researcher entering a cycle of assessment with cohort 2, this was conducted with the subsequent cohort of first year undergraduates who had the same access to resources as cohort 2.

Survey design

The survey was designed to provide data in three key areas: reporting on the quality of the video resources provided; information on how students used the videos; and whether using the videos improved student understanding of the topic or technique.

In the first cohort (pilot study), students were surveyed after they had used the microbiology video resources produced. A Likert-like scale approach was used to evaluate the resources as shown below (Figure 2) and included questions not only relating to quality but also accessibility and ease of use.

To establish what impact these video resources have on the students' laboratory experience, the survey included a series of open and closed questions. Open questions were used to facilitate discussion of how the videos were used such as '*Would you find it useful to access the videos after the lab and if so, why?*'. A series of positively and negatively worded questions using a 5 point Likert-like scale were used to investigate other aspects of video use which asked students to state how much they agreed or disagreed with a series of statements as can be seen in Figure 4.

To be able to investigate the impact of the videos on student understanding of the topic, in addition to the questions described above, a pre-laboratory and post-laboratory concept inventory style question approach was used (Hestenes, Wells, and Swackhamer 1992). These questions were

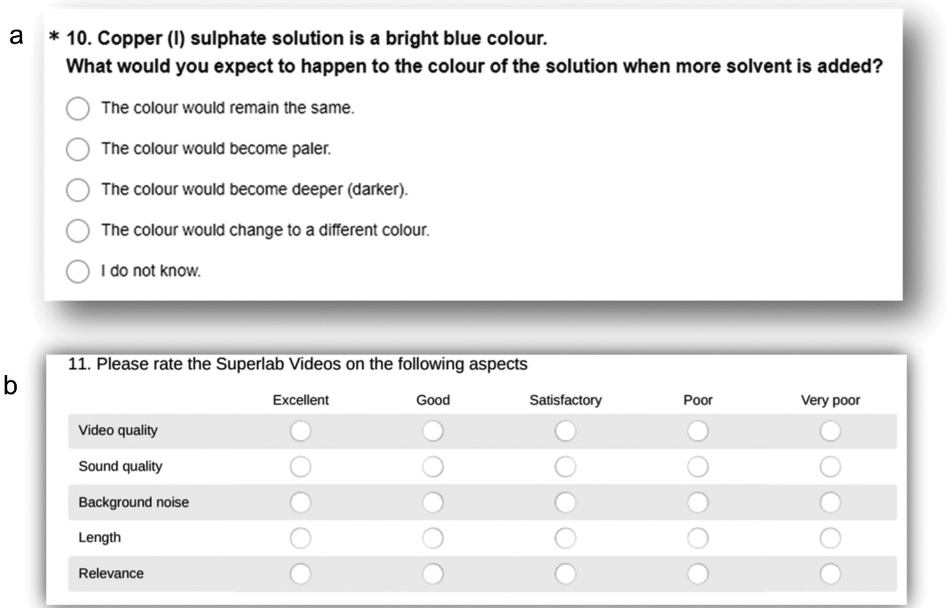


Figure 2. Examples of questions included in the video case study survey. **a** shows an example of concept inventory style questions used to test student understanding (in this case of dilution), which were included in the pre-and post-video surveys for cohort 2. **b** shows a Likert-like scaled question used to evaluate the aspects of the quality of video resources (rated from excellent to very poor) used with both cohorts.

designed to test student understanding of the key concepts of dilution and Gram staining. An example of one of these questions can be seen in Figure 2. Cohort 2 students participating in the study received both the pre- and post-laboratory video surveys to be able to test their understanding of these concepts.

It was not possible to use a pre-/ post- laboratory questionnaire with the first cohort of students as the microbiology videos were not available at the start of the academic year: this approach was used with the second cohort of students (see Figure 1) who also had access to the full suite of videos. This included an additional three microscopy videos (aligning, focussing and microscope anatomy), serial dilutions and using a spectrophotometer. These videos were included as resources that students could access from their first term modules but were not linked to specific laboratory protocols as they were applicable across a number of laboratory classes.

Focus group

To draw out more in-depth information about specific aspects of the survey data that warranted further investigation and to better understand potential for barriers to engagement with the videos, a focus group was undertaken. Participants were recruited from the third cohort through use of an online expression of interest form. The aim was to recruit 6–8 participants: only 3 participants agreed to be in the study. The timing of the focus groups was restricted by both the requirement of the students to have experienced the full laboratory programme before engaging in the focus groups, as well as the need not to impact on the students' end of year assessments. At the time of the focus group, only 2 of the recruited participants attended.

Ethics

The pre-lab survey of academics, video use surveys and focus group (Ethics approval reference number 16/17-64) studies were approved separately by the NTU School of Science and Technology Non-invasive ethics committee. The participants provided informed consent in all cases. The researcher was not involved in direct teaching or assessment of the participants at the time that the research was conducted.

Results

Pre-laboratory practice in UK higher education institutions

Analysis of survey data from across the HE sector showed that pre-laboratory lectures and seminars were used in 65% (26/40 responses) of bioscience modules and 60% (27/45) of chemistry modules that participants included in this study. In more than half of the bioscience modules (15/28, 54%) these sessions occurred on the same day; a further 3 respondents stated that sessions sometimes took place on the same day (11%); and 10 (36%) said that they were not held on the same day. In chemistry modules only 22% (7/32) of pre-laboratory sessions took place on the day of the laboratory; 9 respondents (28%) stated the sessions sometimes took place on the same day; and half of participants (16/32) said they were not held on the same day.

A total of 11 out of the 26 bioscience respondents (42%) whose modules had pre-laboratory sessions indicated that these were compulsory or that attendance was required for entry into the laboratory; in chemistry this figure was 67% (18/27 responses). It should be noted that the total number of chemistry module responses to this question was greater than the number of participants indicating that they held pre-laboratory sessions.

Participants were asked to estimate session attendance: one third of bioscience participants estimated attendance of 61–80% (9/27 responses) with two thirds indicating 81–100% attendance (18/27 responses). In chemistry, 12% (3/26) module leaders estimated attendance as 0–40%; 69% (18/26) estimated 81–100% attendance with each of the other categories accounting for 19% (5/26).

Amongst bioscience survey respondents, 65% (34/52 responses) expected their students to undertake some form of preparatory exercise or activity before the laboratory classes in their module, compared to 73% in chemistry (32/44). Of the 34 biology module responses to the question about whether pre-laboratory activities were required/compulsory, 5 (15%) responded that they were compulsory or summatively assessed, with a further 3 (9%) responding that completion of the activity was required for entry into the laboratory. The proportion of modules with a compulsory element to the pre-laboratory activities was higher in chemistry than biology modules: 14 (out of 32; 44%) stated that completion of activities were compulsory or graded and 9 (28%) responded that the activity was required to allow entry to the laboratory.

Participant answers for what percentage of these activities were estimated by module leader to be completed in bioscience and chemistry modules can be seen in Table 2.

The number of pre-laboratory activities that bioscience and chemistry students were asked to undertake are shown in Figure 3(a). These data indicate that the numbers of activities used in chemistry modules (highest frequency of 3–5 activities) is greater than that used by bioscience modules: where one activity was the most frequent response. In addition, the proportion of modules not using pre-lab activities was smaller in chemistry (27% of respondents) compared to bioscience (34%). A small number of participants stated that they did not carry out pre-lab activities with their students but then selected a number of types of pre-lab activities that their students completed, which would appear to be contradictory. For the purposes of this study, all data has been reported, as it was theorised by the researchers that the respondents' apparent contradictory responses could reflect their interpretation of what a pre-lab activity was. For example, that they do not set specific pre-lab activities but there are activities that students on the module do as part of their lectures, seminars etc which relate to the laboratory (e.g. theory underpinning the practical) and so impact their preparedness for the laboratory class.

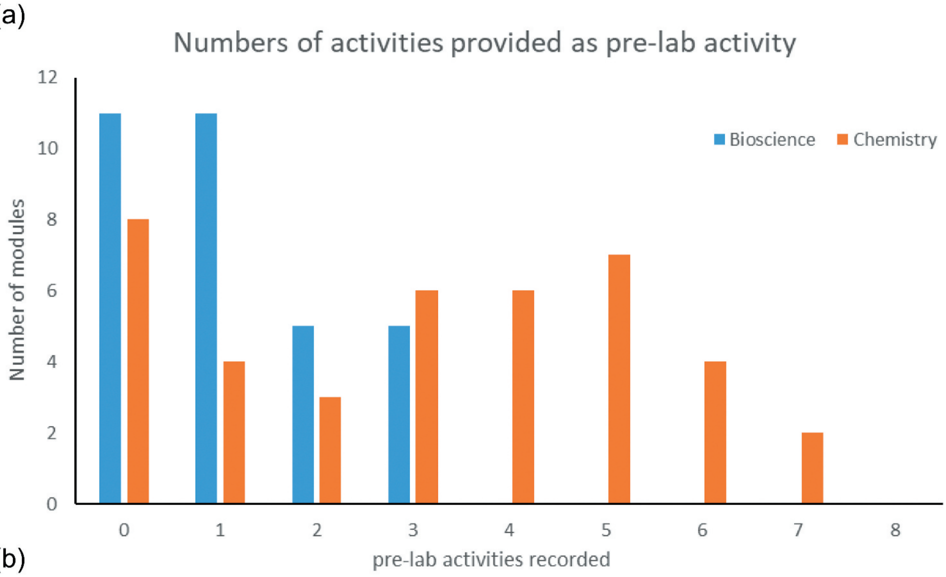
When comparing the types of activities that were undertaken, the most common activity in both disciplines was for students to read the protocol (see Figure 3b). In Chemistry, safety activities, online quizzes, videos and calculations were also commonly reported as pre-lab activities. Other than reading the protocol, bioscience students were most likely do activities listed under the 'other' category including lectures and seminars that could include contextual information such as clinical diagnosis, or practice at identifying insects prior to field work.

Comparing response data for module level showed a clear difference in the types of activity that level 6 bioscience students are asked to do compared to that of level 4 students. A similar proportion of the modules at these levels stated pre-lab activities were given to the students (5 out of the ten level 4 modules; 6 out of the 1eleven level 6 modules), however some activities were different. All modules with pre-lab activities at level 4 and some level 6 modules (4 out of 6) asked students to read the protocol before the laboratory class, some with additional pre-reading (two level 4 modules; one level 6 module). For some level 4 modules, students were also asked to perform calculations (2), take an MCQ (1) or do a safety pre-lab activity. These activities were not observed in level 6 modules, being replaced by experimental design activities (2) and others not specifically listed (3), which were described as workshops and activities that had been integrated into lectures and seminars.

Table 2. Comparison of the completion rates for pre-laboratory activities in biology and chemistry modules across UK HE as estimated by module leaders.

Percentage completion of pre-laboratory activities	Bioscience modules	Chemistry modules
0–40%	9 (35%)	6 (16%)
41–60%	4 (15%)	4 (11%)
61–80%	2 (8%)	7 (19%)
81–100%	11 (42%)	20 (54%)

(a)



(b)

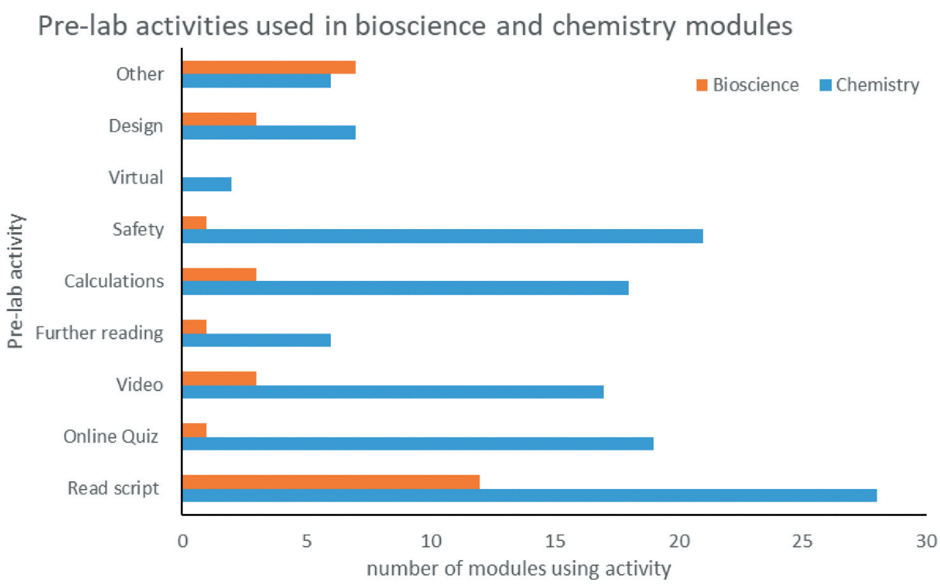


Figure 3. Data from the survey of UK HE institutions showing (a) a comparison of the number of pre-laboratory activities used in bioscience and chemistry modules. (b) a comparison of the number of bioscience and chemistry modules using different types of pre-laboratory activities.

Video resources were more commonly used as pre-lab activities at level 4 (3 out of 5 modules compared to one out of the six level 6 modules). Whilst both groups use technology-based activities such as online quizzes, virtual simulations and access to videos to support their students ahead of laboratory classes, all of these activities have a higher frequency of use in chemistry compared to bioscience modules: e.g. 25% of bioscience modules used videos compared to 42% in chemistry.

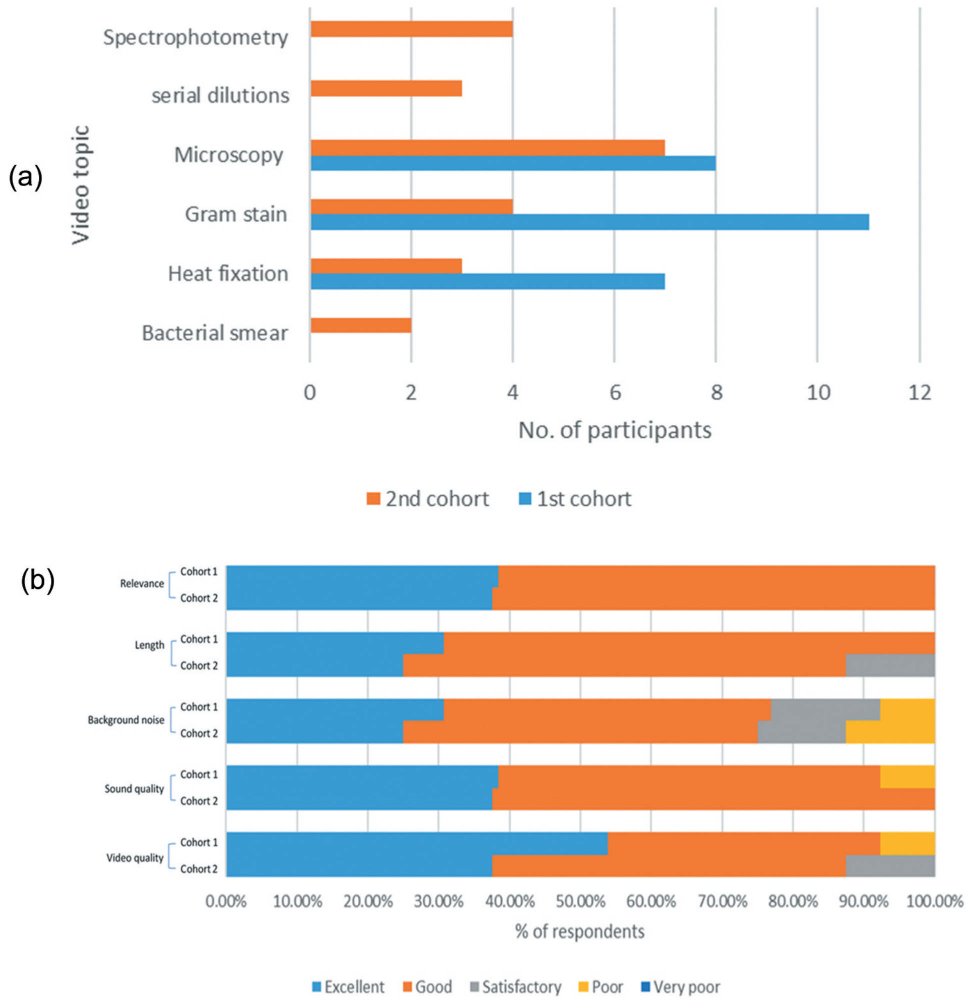


Figure 4. Case study survey data for both cohort 1 and cohort 2 showing the number of participants using different videos (a) and the participant responses for quality and relevance of the resources (b).

Case study: use of video resources to support laboratory classes

Quality of the video resources

In the first year that students were provided with video resources (cohort 1), 15 students participated in the evaluation of the microbiology technical videos. Of these, 13 had watched at least one of the videos: a summary of the frequency of videos used is shown in Figure 4(a). In both this and cohort 2 studies some participants had watched more than one video (i.e. the total number of videos watched by participants was greater than the number of participants who had watched videos)

Overall, the video qualities were positively rated as can be shown in Figure 4(b). Based on the observation that cohort 1 participants were most likely to have issues related to audio quality, the subsequent resources that were created (following the critical reflective cycle) used alternative sound recording devices to try to improve this. In the second cohort, after additional videos had been added, the resources received a similar response (Figure 4b) but with improvement to the video and sound quality score: background noise was the only aspect that was scored negatively by the second cohort.

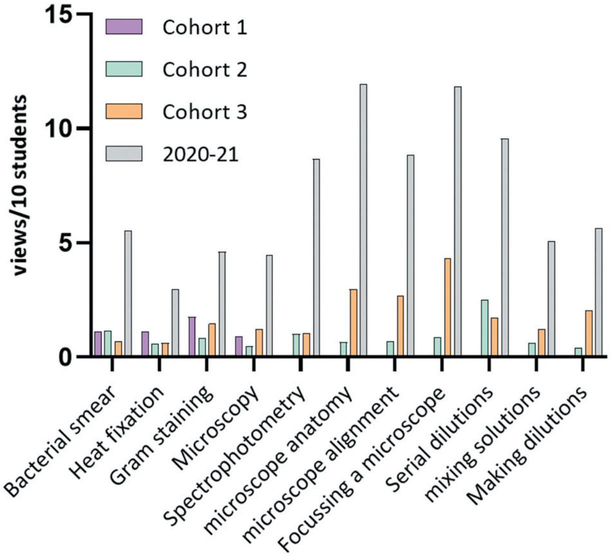


Figure 5. YouTube analytics showing the number of views that each video received over the course of the study (cohorts 1–3) compared to usage so far in the current academic year (2020–2021). views are expressed as views per 10 students within a cohort to standardise the data to account for differing cohort sizes.

In addition to survey response data, YouTube analytics were used to get a better indication of the overall usage of the videos independent of that described by the survey data. The viewing numbers for the 3 cohorts in this study can be seen in Figure 5 alongside the number of views in this current academic year (2020/21). The viewing figures for the current year per 10 students are a lot higher than in previous years, although for most videos, the numbers of views increased in the third cohort compared to the first or second.

Evaluation of how students used the videos

Figure 6 compares the responses from participants in evaluating key aspects of the use of the technical videos which includes some statements about accessing videos while in the laboratory. In most cases the data from the first and second cohort were similar with 50% or more of the participants agreeing/strongly agreeing with positive statements made such as that the videos helped them to be more confident in working independently (depending on cohort, 60–70% of participants agreed or strongly agreed with this statement) and that they would be able to repeat the procedure without assistance (<85% in both cohorts). Similarly 85–100% of students agreed or strongly agreed that the videos were useful to their learning. In both cohorts more than 65% of participants agreed or strongly agreed that ‘using the videos in the lab helped me focus on the task I was set’ although in the first cohort a number of participants actively disagreed with this statement.

Some positive statements were paired with a negative statement to ensure that participants were giving due consideration to their responses. For example, when considering cognitive load the following statements were included: ‘the videos helped me think more deeply about what I was doing in the laboratory’ was reflected in the negatively worded question ‘the videos helped me complete a procedure, but I didn’t really understand what I was doing’. In this instance, the positively worded statement resulted in 45–50% agreement from participants in both cohorts compared to 38–54% of participants disagreeing with the negatively worded statement. Similarly, there was a reversal of responses seen in whether students perceived the videos easy or difficult to access when in the laboratory: 60–85% of students agreed that it was easy to access the videos within the laboratory, whereas 50–70% disagreed that it was difficult to access them.

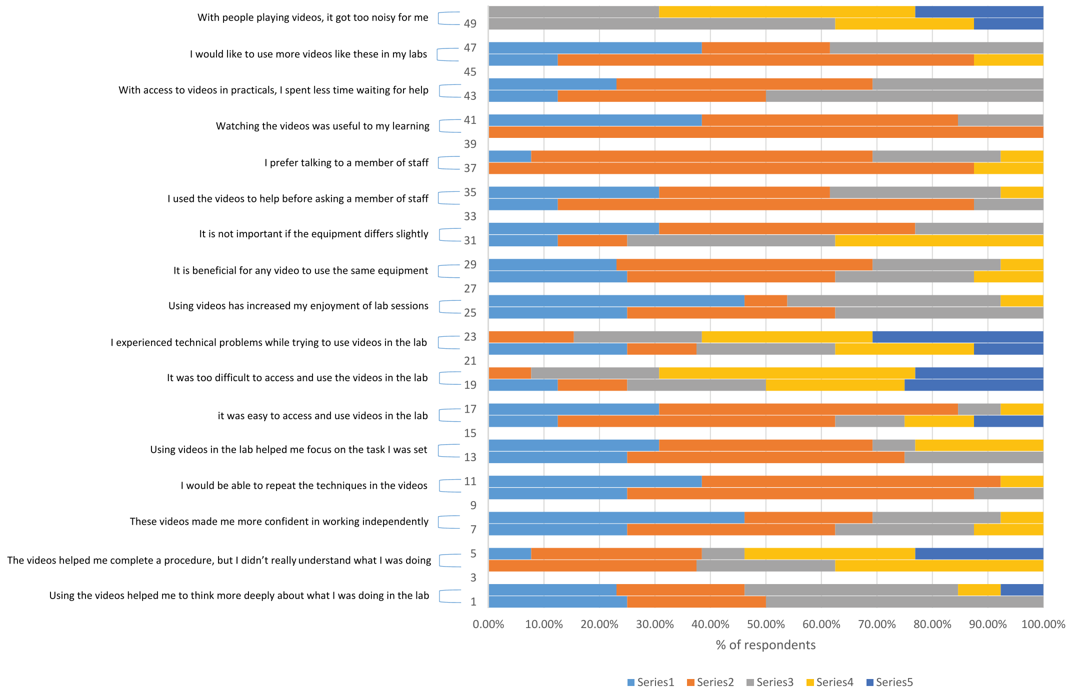


Figure 6. Representation of Likert-like scale data (participants were asked to what extent they agreed or disagreed with the statements provided) for the 1st and 2nd cohorts. Positive and negatively worded statements were included, with some addressing use of the videos within a laboratory setting, with other questions being more generally applied.

In response to the question '*Would you find it useful to access the videos before the lab and if so, why?*', participants from both cohorts frequently commented that it would be useful to increase familiarity with the laboratory material as well as boost their confidence and help them to use their time in the lab more efficiently. Familiarisation was described as helping to offset a lack of clarity or confusion when undertaking an experiment (e.g. related to protocol write up). In addition to the positive responses, one participant stated that they would not find it useful to have access to videos before the laboratory, as their preference was to use them during the session.

This quote from one of the participants in cohort 1 is indicative of the type of comments that participants made in answer to this question:

> *"Yes . . . It gives you the chance to learn how to successfully use techniques/ equipment that you may or may not be familiar with and is a real confidence booster once you get into the actual lab as you already know what is expected of you and you're able to use your time more efficiently and do the work."*

The most frequent responses to the question '*Would you find it useful to access the videos after the lab and if so, why?*' were that the videos would help with revision, self-assessment and consolidation of learning. In addition to these responses, one participant in the first cohort said that it would not be useful to access video resources after the laboratory.

An example of participant responses to this question can be seen in this quote from one of the participants from cohort 2:

> *"Yes. I could consolidate what I had learnt in the lab. It would also be useful for revision purposes when it comes to revising for the exams later on."*

Due to the low numbers of participants, it was not possible to make a meaningful analysis of the responses to the concept inventory-style questions.

Focus group

Two first year bioscience students participated in the focus group for this study. With such low numbers of participants it is not possible to comment to what degree the opinions expressed encapsulate the entire student experience. Exploration of the data showed that barriers to the uptake of the videos aligned with managing student expectations and anxiety.

Students described their laboratory preparation as reading the laboratory protocol but highlighted that encountering material multiple times helped them to remember it and that using videos helped them with information synthesis.

> For example: *"so you may build to watch a video and then when you're going through reading a protocol, you can relate back to the video"*

Access to the videos was reported to make it easier for students to learn and to help bridge the gap between the complexity of written protocols and doing the experiment as well as reduce anxiety, as shown in these participant quotes.

> *"Sometimes when you're reading, a protocol can be confusing, but then when you watch it being done it's actually quite simple. We've over complicated it by reading."*

> *"And I remember thinking how complicated it looked on the protocol and panicking about getting it wrong, but I think if I watched a video before . . .. . . it would have stressed me out less."*

Both participants stated that a key barrier to their uptake of videos was a lack of awareness that they were available and where to find them.

Discussion

Pre-lab activities in biosciences

Despite marked similarities in the purpose of laboratory work described for bioscience (Adams et al. 2008) and chemistry disciplines (Carnduff and Reid 2003; Seery, Agustian, and Zhang 2019) the data collected from module leaders in bioscience and chemistry showed differences that is suggestive that these disciplines approach pre-laboratory support in different ways.

In biosciences, pre-laboratory sessions (such as lectures or seminars) were less likely to be compulsory than in chemistry (42% were compulsory for bioscience compared to 67% in chemistry) but were more likely to be scheduled on the day of the laboratory itself (bioscience 54%; chemistry 22%). Despite these differences, the overall attendance at these sessions was not dissimilar: 67% of bioscience modules reported the highest category of attendance compared to 69% of chemistry modules. It is perhaps not surprising that chemistry pre-laboratory sessions were frequently not on the day of the laboratory itself, as the compulsory nature of these sessions included either the requirement for completion of a summative assessment or that failure to attend would bar attendance to the laboratory and so an appropriate opportunity must be given for students to complete these. Conversely, it is possible that attendance at non-compulsory bioscience pre-lab sessions was enhanced by situating them on the same day as the laboratory was taking place.

In this study, bioscience and chemistry modules reported a similar proportion of modules with pre-laboratory activities (65% in bioscience; 73% in chemistry). These observations suggest that the prevalence of pre-laboratory activities has increased since the study by Carnduff and Reid (2003). In their study of 47 chemistry departments in the UK and Ireland, 40% of institutions used prelabs to support their laboratory teaching, with 20% using videos. In their study, pre-labs were primarily aimed at understanding theory, dealing with terminology, predicting outcomes, calculation/data analysis practice, safety, equipment/processes and motivation of students.

As with the provision of pre-laboratory sessions, chemistry modules were much more likely to have an assessed element for these activities or non-completion barring entry to the laboratory compared to biosciences (56% in chemistry compared to 24% in bioscience). Despite the large proportion of the bioscience modules providing optional pre-laboratory activities, completion of these activities was higher than might have been predicted: with 42% of modules reporting an 81–100% completion rate despite only 24% of modules having compulsory pre-laboratory activities. When looking more closely at the data, it was observed that 5 of the 11 modules which reported 81–100% completion for their activities were at level 6–7 (final year undergraduate or masters level students) with only two of the 10 modules reporting that these activities were compulsory. These data suggest that either students at these academic levels are more motivated to engage with pre-laboratory activities or the type of activities themselves are more engaging to the students. Alternatively, these activities may be more integrated with the laboratory sessions and hence seen as higher value and engaging to the students (Agustian and Seery 2017). The data for the types of activities that the level 6–7 students take show a marked shift compared to those for first year undergraduates. Based on the survey data, in their first year undergraduates are most likely to encounter pre-laboratory activities aimed at familiarising them with what has been described by (Agustian and Seery 2017) as the technical aspects of the laboratory; such as reading the protocol or performing calculations. This was also true in the case study where the technical videos produced aimed to help familiarise first year undergraduates with key practical techniques they would encounter on their course. This is in keeping with the framework described by Seery, Agustian, and Zhang (2019) which described the laboratory classes for first year undergraduates as focussed on developing experimental skills and competencies as the foundation for later learning. The types of pre-laboratory activities described in the survey data would support students in achieving this.

In contrast, the laboratory curriculum design modelled by Seery, Agustian, and Zhang (2019), describes the purpose of laboratories developing as students move through their course from being focussed on developing core skills and competencies as well as familiarisation with key experiments in the first year, to being able to design their own experiments to open-ended questions by the time they reach their final year of undergraduate study (such as the opportunity provided by a capstone research project). This movement from being able to memorise and recall basic facts and concepts through being able to use information in new situations until they finally reach the stage of being able to create original work falls in line with the interpretation of Blooms' taxonomy (Bloom 1956). In the context of the module leaders' pre-lab survey, it is clear that at level 4, the types of activities that students experience are in keeping with familiarising students with key ideas (e.g. health and safety, reading the protocol) and techniques; whereas by level 6 these activities support the wider context and creative processes that enable students to achieve the higher level skills.

It should be noted that across the UK, there is different practice in how laboratory classes are structured within different institutions: some embed practical classes into subject specific modules whilst others have a single module which is focussed on laboratory learning. In the latter case, these institutions may potentially be under-represented in the data compared to institutions who submitted multiple responses because their practicals are embedded across a number of modules. In the post-pandemic learning environment, it may be of interest to investigate the extent to which institutions have adopted a 'Lab learning module' format.

Student experience of using videos

From the case study data it was clear, from the response to the open questions in the survey, that students felt the key benefit of accessing videos before laboratories was familiarisation with the material; and is in keeping with expectations of curriculum design described above. This observation was re-iterated in the focus group which highlighted that it helped to reduce anxiety about the laboratory class when students were able to familiarise themselves with the methods or equipment they would be using (preferably having multiple opportunities to do so).

This observation, when taken in combination with data from the survey in which students agreed with statements such as 'using the videos in the lab helped me to focus on the task I was set' and 'the videos helped me to think more deeply about the task at hand', give an indication that the videos have impacted cognitive load and working memory limit. Both Reid (2008) and Sweller (2010) describe how the ability to discriminate between important and peripheral information (as a function of extraneous cognitive load) to be able to focus on the task, is lost when our working memory limit is exceeded, supporting the supposition that familiarisation reduces cognitive load and thereby reduces the potential for working memory overload. In examining the data for the first and second cohort of students, a smaller proportion of participants in the first cohort responded positively about whether the technical videos helped them to think more deeply about what they were doing than in the second cohort. Between the first and second cohorts, the number of videos available to the students was supplemented with additional resources covering a variety of laboratory techniques. It is possible that this increase in the number or content of the videos available prompted more participants in the second cohort to agree with that statement: especially since in both cohorts participants frequently reported having used multiple videos. The observation that participants frequently reported using multiple videos in both cohorts indicated that additional resources being made available to the second cohort was not a barrier to student engagement.

A number of studies have described how familiarising students with aspects of the laboratory class can improve learning gains by reducing the potential for overloading the working memory limit (O'Brien and Cameron 2012; Gregory and Di Trapani 2012; Rollnick et al. 2001). Although this case study has not been able to investigate learning gains due to low participant response rates, the data is in keeping with the model described by these researchers.

In addition, to improve learning gains through a reduction in cognitive load, Gregory and Di Trapani (2012) also observed that students appeared more organised, with students themselves commenting that watching the videos had saved them time because they already knew what to do. The student perception of preparedness was also observed by Rodgers et al. (2020), and is mirrored in comments from case study participants.

Managing expectations and enhancing student engagement

One of the more recent challenges in bioscience laboratory education in HE has been increasing student numbers, which has put pressure on the time and availability of academics to support individual students in laboratory classes. With this in mind, strategies that build student confidence to work independently, enabling them to complete activities and meet their learning outcomes, are desirable. Both the surveys and focus group conducted in the second case study showed that access to technical videos could increase student confidence to work independently. Not only did students feel more confident to work independently but in both case study surveys, participants expressed that they felt it helped them to spend their time in the laboratory class more efficiently as they knew what they needed to do. Similar observations have been made when students have been given virtual laboratory exercises to undertake before the laboratory class (Coleman and Smith 2019; Dyrberg, Treusch, and Wiegand 2017). Such preparation can have a lasting impact as can be seen a year on from the original simulation where at least 90% of students responded positively when reflecting on whether they felt the skills they acquired from the virtual lab exercise were appropriate and over 80% saying that they were useful (Coleman and Smith 2019).

Whilst the participants who used the videos for the most part described this as a beneficial experience, engagement with these optional resources was low. This observation was mirrored by the estimates provided by module leaders in the pre-laboratory survey which suggested that in one third of cases, 0–40% of their students would complete optional activities. This is in stark contrast to the provision of pre-lab sessions where two thirds of module leaders reported 81–100% attendance even though only 40% of modules had compulsory attendance.

With the recently emerged global pandemic, HE institutions are being presented with a different set of challenges, but also an opportunity for innovation. Where availability of laboratory teaching time is greatly reduced, there are changes to the class sizes allowed and ways of working when in the laboratory, and there is scope for developing innovative solutions to the current need for a blended learning approach. One way in which UK academics have been innovating in the area of laboratory provision is in developing dry lab solutions to support student learning and sharing practice through creating a network of bioscience academics known as #DryLabsRealScience (Francis 2020); with a network that has similar goals established for chemistry (Campbell et al. 2020). Through the DryLabsRealScience network, colleagues are able to showcase innovation in videos, animations and simulations as well as remote experiments and sharing strategies and resources for designing meaningful capstone projects. As well as sharing practice, open access resources and information are hosted on the lectuREmotely webpage, which colleagues at De Monfort university have created to support others in developing strategies for teaching in a pandemic (Rushworth, Moore, and Rogoyski 2021). An example of this can be seen in approaches to teaching immunology which highlight the use of videos (especially branched videos which have interactive elements that tailor user experience and outcome); quizzes; live demonstrations with the possibility of learner input into the next stages or students needing to spot errors; lab simulations such as those provided by Labster® (Copenhagen, Denmark) and Learning science (Bristol, UK); as well as augmented and virtual reality experiences (Wilkinson, Nibbs, and Francis 2021).

This approach is not unique to bioscience: lab provision in chemistry which has similarly been affected by the global pandemic have also made use of virtual tools to support an online lab provision (Jones, Shepler, and Evans 2021). In the context of the global pandemic, use of virtual labs to support development of experimental design, problem-solving and data analysis skills has been shown to give a high level of satisfaction (68%) amongst postgraduate bioscience students: with many agreeing that this type of lab should be continued irrespective of the situation (Bassindale, LeSuer, and Smith 2021).

Whilst dry labs are a valuable alternative to students having time in laboratories, it is also crucial to consider how we prepare students for the limited opportunities that they do have in labs and the scaffolding that we provide to enable them to learn when they are there. Perhaps unsurprisingly, the YouTube analytics for the technical videos have shown a dramatic increase in usage this academic year compared to case study cohorts (see Figure 5) and show that the combination of a blended learning approach and better integration of resources (this year resources were embedded in specific activities and, discussed and used in taught sessions for level 4 students) can make a difference to student engagement with this type of resource. The latter of these points addressed some of the main barriers described by the focus group participants (that of signposting resources and use in sessions).

Within our university (NTU), the use of the microbiology videos has also been extended to support assessment for level 5 students in the 2020–21 academic year as a way of demonstrating techniques that students would have been using in the laboratory to get data for their reports but were unable to do so in person due to the pandemic. In this case, it is not possible to assess the relative contributions of level 4 and level 5 usage of videos as the periods when each group were likely to access these overlapped.

The recent review of pre-laboratory activities in chemistry by Agustian and Seery (2017) highlighted the need to integrate pre-laboratory activities with the laboratory experience itself to ensure that students are able to see their value as part of the laboratory class as a whole and therefore be more likely engage with them. Given the current teaching situation and the observations in the survey of UK HE bioscience modules, a review of how pre-laboratory activities are used would be timely. As highlighted above, increased integration of resources not only helps to increase engagement but may also help to remove barriers described by one of the focus group participants as a source of anxiety: lack of clarity about expectations for their use. Creating a laboratory experience which begins with pre-laboratory activities before moving into the laboratory would more clearly signpost expectations about use of these resources. The case study provided here is only one of many approaches that can be taken to scaffold this pre-laboratory support as can be seen in the discussion by Wilkinson, Nibbs, and Francis (2021). Pre-laboratory quizzes (Cann 2016; Gregory and Di Trapani 2012), virtual lab classes (Cheesman et al. 2014), instructional videos (Croker et al.

2010; Gregory and Di Trapani 2012; Rodgers et al. 2020) and using virtual platforms (Dyrberg, Treusch, and Wiegand 2017; Coleman and Smith 2019) are also well established as having benefits to students.

Perhaps another key aspect of how to increase engagement with optional resources lies in the areas of student interest and motivation in laboratory classes. Novak's theory of meaningful learning as discussed by Bretz (2001) describes the need for this affective aspect in order for meaningful learning to occur – an observation supported by Seery and Agustian (Agustian and Seery 2017). Research into the affective domain has shown that it has an important role to play in chemistry student laboratory experience (Galloway, Malakpa, and Bretz 2015); and that using the personalisation principle (which draws on the idea of creating more of a conversation between instructor and students) can help to create a more positive attitude towards e-resources (Mayer 2017).

In the current climate, where remote study is in place for most undergraduates, creating that connection to foster engagement and building student confidence seems especially important. The role that the academic team have in this should not be underestimated since evidence suggests that the expectations of their teachers have a great influence on students' perception of and behaviour in the laboratory (Hofstein 2004).

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