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Article

The Role of Technology in Undergraduate Bioscience Laboratory Learning: Bridging the Gap between Theory and Practice

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Abstract: Integration of technology is widespread in laboratory teaching, whose purpose includes building theoretical understanding and practical skills. How second-year bioscience undergraduate students at a UK university use technology to construct their understanding of laboratory-based topics was investigated using a concurrent think-aloud protocol in the laboratory, followed by semi-structured interviews. Analysis of think-aloud data used socially shared metacognitive coding since students may co-construct their understanding in these collaborative spaces. This analysis demonstrated that participants used technology within the laboratory either as a tool to conduct their experiment or, as a source of information to help them understand, apply or perform their experimental task. Semi-structured interviews demonstrated that students integrated technology into all aspects of their laboratory learning. Eight out of the ten participants described using technology to help them make connections between theory and practice as part of post-laboratory activities such as analysing or conducting further research on the topic. A survey of UK bioscience undergraduate modules found that 22% of modules did not use post-laboratory activities, suggesting that more scaffolding of post-laboratory activities could provide bioscience students with greater integration of practical and theoretical understanding and consequently meaningful laboratory learning.

Keywords: protocol-driven laboratory; practical skills; post-laboratory activities; reflection; think aloud; metacognition

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1. Introduction

1.1. Laboratory Learning

Whilst practice varies within subject areas, the provision of a practical lab education is a common factor in biosciences education. The purpose for undertaking laboratory classes is multiple and can include teaching the scientific method, skill development and providing real world context for theoretical concepts [1]. The latter is especially important when considering that integrating new knowledge into an individuals' existing knowledge base provides them with a more meaningful learning experience which is more likely to result in lifelong rather than rote learning [2]. Practical classes are ideally suited for providing students with a meaningful learning experience as they have the potential to combine the three aspects required for meaningful learning: cognitive (understanding), psychomotor (skills) and affective (attitude and emotion) domains [3].

Despite this, learning in laboratories is known to be challenging due to the high cognitive load that students can experience [4]. This can be due either to the intrinsic difficulty of the material, or lack of familiarity with the equipment (especially in the early stages of transition to higher education), processes or terminology used, but can be reduced through scaffolding and familiarising students with aspects of these prior to the laboratory. These pre-laboratory activities can target any of the domains of meaningful learning by aiming to enhance students' content understanding (cognitive domain), increasing their understanding of equipment or experimental processes (psychomotor domain) or increasing student motivation or interest (affective domain).

1.2. Metacognition and Socially Shared Metacognition

Whilst students are experiencing high cognitive load, their metacognitive skills which enable them to plan tasks, monitor activities and performance and reflect on their experiences of the task and how it fits to their existing memories/knowledge, are reduced resulting in fewer learning gains [5]. However, this may not be true for problem-solving or inquiry-based laboratory classes where appropriate scaffolding can support students to specifically make use of metacognitive practices as part of the class such as in the case of secondary school chemistry lab classes in an Israeli school where students developed or used their metacognitive skills whilst undertaking an inquiry-based lab [6]. Similarly, the development and implementation of a short research-based module within an undergraduate bioscience programme demonstrated an enhancement in student metacognition compared to using standard laboratory classes based on the more sophisticated problem-solving abilities shown by these students [7].

There are two aspects to metacognition, and both are required for self-regulated learning (SRL) [8]. The first of these is metacognitive forms of knowledge which allow a learner to understand what they know about a task as well as when and where to apply this knowledge to a task. The second aspect is metacognitive thinking which gives an individual awareness of their metacognitive knowledge so that it can be applied to a specific task. Learners who have strong metacognitive skills/awareness typically perform better than those who do not. This can be seen in the work by Cook [9] who demonstrated that chemistry students who attended a lecture on metacognition and learning strategies achieved higher grades than those who did not attend.

Whilst a number of metacognition models of learning exist there is broad consensus that there are three phases to this, which occur in a cyclical process [10]. These are the preparatory phase, performance phase and appraisal phase. Whilst metacognition is often referred to in terms of "self-regulated learning", more recent theories have identified the possibility of metacognition being shared, meaning that participants in a group task construct their understanding and performance of the task through socially shared metacognition (SSRL) [11]. Alternatively, individuals may develop their own SRL through social interaction with others (Co-regulation of learning; CoRL). These types of metacognitions have been observed when students of across different age ranges are solving maths problems. For example, ten-year-old children who were set maths problems to solve engaged in SSRL and were more likely to do so when dealing with more complex problems [12]. A similar study of 9- to 10-year-old students' video-recorded discussions that occurred when students were trying to solve maths problems and noted that metacognition occurred collaboratively through a combination of individual and group processes [13]. Similar observations were made in a study which investigated the metacognitive processes underlying group work in pharmacy graduates [14]. In this study, the student groups who self-identified as having a high level of collaborative metacognition were more like to produce targeted strategies in discussing their project work than those who did not. This current study focuses on the role of technology in the metacognitive processes of students working collaboratively in a laboratory space.

1.3. Research Context

The laboratory setting is becoming an increasingly technology-rich environment for bioscience undergraduate students as the range of equipment and resources used increases to meet the skills expected by graduate employers. Bioscience undergraduates at Nottingham Trent University (NTU) have many of the laboratory classes across their course (commencing from the start of their first year of study) in a state-of-the-art multidisciplinary laboratory facility which can accommodate 194 students at maximum capacity [15], with students usually working in pairs, and on occasion, larger groups. As described by Kirk et al. [15], the technologies range from the use of tablets (with the students using Lenovo Thinkpad 10 at the time of the study; Lenovo Group Limited, Hong Kong) for accessing and recording written material; standard laboratory equipment and facilities such as laminar air flow cabinets for cell culture, binocular light microscopes, spectrophotometers and centrifuges, up to research equipment such as qPCR machines and fluorescence spectrophotometers and microscopes. [NB The Lenovo Thinkpad 10 tablet computers are referred to as "tablets" throughout this study].

Currently, there is a dearth of information about the role that these technologies play in metacognition, metacognitive development and student lab learning. A recently published reflection on the challenges and opportunities in metacognitive research highlighted our current lack of knowledge in relation to technology and learning [16]. The focus of their commentary was based on whether learning technologies such as simulations and virtual reality impact the rate of metacognitive development or whether the accessibility of technology in everyday life results in changes in metacognitive structure and development. This gap in our existing knowledge is supported when looking at the literature as these typically:

- discuss student metacognitive strategies in general [17];
- include the use of technology as an incidental feature of the experiment, such as the effect of different types of formative feedback on student assessment (using polling software) and metacognitive skills [18];
- or demonstrate the impact of learning technology in a specific area of student learning outside of laboratory education. Such as the observations by Yusuf and Widyaningsih, who explored how virtual simulations impacted metacognitive skills in physics students [19].

1.4. Aim

The aim of this research was to enhance our understanding of the role that technology has in bioscience undergraduate lab learning. To be able to evaluate this in the laboratory itself, a concurrent think-aloud methodology was used, which was followed up with semi-structured interviews to investigate students' attitudes to technology and their perspective on the role of technology in their preparation for the laboratory and any post-laboratory activities that they undertook. Furthermore, this study reviews data gathered during a UK-wide survey showing the prevalence of post-laboratory activities to compare staff practice to student experience.

2. Materials and Methods

2.1. Think Aloud Method Design Rationale

When designing this study, it was important to recognise that there were some differences in the way in which think-aloud data was recorded compared to the methodology, it has been used by some researchers. For example, in the retrospective approach used by Galloway and Bretz [20], video recordings of participants in the laboratory were made and the think-aloud methodology was applied retrospectively. Video recording participants in the laboratory was not feasible in this study due to a risk of breaching GDPR (e.g., if students were to open their email to send data files to themselves) since the laboratory is paperless (as it is a category 2 containment facility) and students access all their files and resources via tablet technology. Removing the visual component of the data had potential implications for the analysis, e.g., gesture coding would not have been possible; however, since the focus of the analysis was on metacognitive processes, the audio data generated were appropriate for the analysis strategy proposed. This is consistent with the approach taken by a number of researchers (see [21–23]). In the case of Fan's study [22] comparison of audio and video as methods for generating data recordings highlighted that the speech features were the most significant factor in data analysis. Whereas in Laukvik's case [21], nurses were working with electronic health records, the issue of GDPR and patient confidentiality would have guided the choice of recording method.

2.2. Participants and Ethics

The study was divided into a pilot phase and a main study. The pilot phase was used to refine the methodology and analysis. In the pilot phase, a single participant undertook a session in the lab using the think-aloud method, followed by a semi-structured interview. For the main study, ten participants were recruited and undertook two different laboratory sessions using the think-aloud method followed by the semi-structured interview. This study was approved by Nottingham Trent University non-invasive ethics committee (17–18/42).

Ethics and participants for the review of post-laboratory activities in UK HE institutions were as previously published [24].

2.3. Think Aloud Methodology and Analysis

2.3.1. Concurrent Think Aloud Method

The pilot participant was prepared for the think-aloud method during a meeting with the lead researcher in which the participant gave their informed consent to be part of the study. This preparation involved an explanation of what they were being asked to do and being provided with an opportunity to practice. This practice opportunity was included as previous researchers have suggested that practicing the method prior to using it in the laboratory can help reduce the cognitive load of doing so [25]. This was considered particularly important since the laboratory environment already has the potential to have a high cognitive load. As a result of the pilot study, this aspect of the participant preparation was developed further by the lead researcher providing an example so that even if participants chose not to practice, they would have a clearer understanding of what was expected of them.

Bioscience undergraduate laboratory classes at NTU are typically 3 h long, a section of the laboratory class was selected for the participant to use the think-aloud protocol in. This section of the laboratory class was selected by the researcher as an activity that should not take more than 30 min for a student to complete. In the case of the pilot participant, the laboratory class chosen for the think-aloud session built on the previous class, both of which focused on different methods for the identification of an unknown bacteria. The section of the class used involved choosing and performing an API (Analytical Profile Index) strip test appropriate for their proposed bacterial species to confirm identification (Biomerieux, Marcy-l'Étoile, France).

Student participants were supplied with a recording device and lapel microphone that could be attached safely to the laboratory coat and switched on to record their thoughts at the appropriate time. Due to the containment level of the laboratory, this equipment needed to meet laboratory safety requirements for effective decontamination between uses and thus did not have porous surfaces: the Sony ICD-PX370 Dictaphone and Sony ECMCS3 Microphone were selected for use as they met these criteria (Sony Group, Tokyo, Japan). Participants were also offered a laminated sheet of paper with the reminder "keep talking" which could be propped up in their work area [26].

The outcome of the pilot study did not suggest that any changes to data collection were required, and so the main study used the same approach and participant preparation. Ten participants who were in their second year (NQF level 5) studying for the undergraduate B.Sc. biomedical science degree were recruited for the main study. This number of participants was selected as this was in line with other published think-aloud studies which were found to have utilized between 8 and 13 participants [12,20,21,27].

Participant recruitment ensured representation from students of different genders, ages and included participants who identified as having a recognized disability (according to the UK Disability Act 2010) that they described as impacting their laboratory experience. In the main study, the participants undertook two think-aloud sessions, each in a different laboratory class. The first of these was sample preparation and loading onto an SDS-PAGE gel. The second session was part of a microbiology laboratory class where students were attempting to investigate what bacterial species could be extracted from used washing-up sponges.

2.3.2. Analysis of Think Aloud Data

For both the pilot and main study, verbatim transcripts of participant data were made, which incorporated analytic memos designed to contextualise written data where there was a need: for example, where the participants sang rather than spoke the words they were thinking, where intonation suggested participants were reading or where there were clear sounds of equipment being used (such as the sound made when an autopipette's volume is being changed).

Coding of the data was based on the use of the socially shared metacognitive coding scheme described by Lobczowski [14]. This study used the first three levels of coding in their entirety but with the definitions of each modified to be specific for the laboratory environment as shown in Table 1 alongside pilot participant examples or quotes.

Table 1. A summary of how a socially shared metacognitive coding scheme has been applied to concurrent think-aloud data from laboratory sessions (adapted from the method developed by [14]).

Code	Definition	Example/Quotes from the Current Study
Level 1: modes of social regulation of learning		
Self-regulation of learning (SRL)	The participant monitors and regulates their own learning	*"I've literally just done them wrong. Right, let's sort this out"*
Socially shared regulation of learning (SSRL)	The group co-construct understanding/activities	*"For identification, that's all we need to do, isn't it? Unless there's anything else?"*
Co-regulation of learning (CoRL)	One or more of the group prompts/guides the learning of others in the group: typically this is a question which then moves learning into SRL or SSRL	*"What're you confused about?"*
Co-regulation of learning (other; CoRL-other)	As for CoRL but the prompt comes from outside the group, e.g., an academic or demonstrator	A demonstrator approaches the group to check if they need help, the participant queries an aspect of the protocol, e.g., how to put the lid on the API strip
Level 2: cognitive regulation processes		
Planning	Processes related to making plans for changing understanding or performance of tasks	*"Do you want to do the Bacillus one and I'll do the Pseudomonas one?"*
Monitoring/controlling	Tracking progress or regulating activities for successful completion of experiment	*"I've done the API test haven't I and destroyed all my colonies and now I've got to identify them from the thing."*
Reflection	Evaluation or review of progress/success in completing or understanding experiment	*"I wish I had read it. . .would have made my life so much easier."*
Level 3: target of regulation process		
Content understanding	Processes that target the understanding of the theory underlying the experimental process	*"It's the one where you add the enrichment thing as well. You've got one plus the enrichment one. . . So, we use the enrichment one to do the API plate."*
Task understanding	Processes that target the understanding of the experiment that is being performed	*"So, is this all you need for the API test? I don't understand it"*
Task performance	Processes that target the performance of the task	*"Do we do them on plates?"*

In contrast to Lobczowski's work, the final stage in the coding process was process coding (used to describe an action) rather than inductive coding (to describe overarching strategies). The process coding method was preferred to the inductive coding method as the laboratory is an environment in which students are physically involved in the processes of performing an experiment and so it was considered that process coding would better capture the actions of the participants. As most of the process coding generated codes that did not relate to technology, in the main study, only process codes that related to technology were applied to the data.

2.4. Interview

A semi-structured interview schedule was designed to complement the think-aloud methodology with a view to addressing specific questions in relation to how students use technology in their learning. In addition, what students defined as technology, their attitude to it and their perception of how labs impacted the development of their identity as a scientist were also investigated. Interviews were recorded using a Dictaphone (Sony ICD-PX370 Dictaphone; Sony Group, Tokyo, Japan) from which verbatim transcripts were created. Analysis of the pilot transcript showed that two questions were sufficiently similar to generate the same answer and so one of these was removed from the schedule used in the main study to avoid duplication.

Interview Analysis

Interview transcripts were analysed using two first-cycle methods: structural coding (derived from the research questions above) and descriptive coding as described by Saldaña [28]. Structural codes were derived from the following specific research questions:

- What is technology?
- How do students feel about technology?
- How do students use technology?
- How do students prepare for labs?
- How are students using technology in labs?
- What do students do after labs?
- How do labs fit into the development of identity as a scientist?

In the pilot study, the two first-cycle coding methods were followed by mapping of the descriptive codes generated in the interviews against the structural codes. Due to the number of descriptive codes generated by the main study, descriptive codes underwent a second cycle of coding (pattern coding) to group them into broader categories which could then be mapped against the structural codes. Using this approach, the 297 individual codes were reduced to 42 categories.

2.5. HE Survey of Post-Laboratory Activities in Bioscience

The survey of UK higher education institutions described by Rayment et al. [24] included questions that asked bioscience module leaders to comment on the post-laboratory activities used in their modules: in a similar way to how pre-laboratory activities were investigated as part of the paper. Module leaders were asked whether they undertook post-lab activities and whether they were compulsory or voluntary, as well as what types of activities they undertook. This survey also collected comparative data from chemistry modules. Summary statistics were generated for this data to allow comparison across disciplines as shown in Section 3.3.

3. Results

3.1. Think Aloud

In relation to the use of technology in the laboratory, four main process codes were identified which related to the use of technology which were mapped against the metacognitive coding scheme as can be seen in Table 2. These were: preparing equipment, using equipment, using tablets and querying protocol.

Table 2. Cross-tabulation of semi-structured interview metacognitive codes (based on [14]) and technology-based process codes.

	Mode of Learning				Cognitive Regulation Processes			Target of Regulation		
	SRL	**SSRL**	**CoRL**	**CoRL-Other**	**Planning**	**Monitoring Or Controlling**	**Reflection**	**Content Understanding**	**Task Understanding**	**Task Performance**
Preparing equipment	4	8	1	0	1	11	1	0	1	10
Querying protocol	13	31	3	0	7	32	1	0	32	16
Using tablet	40	54	6	0	9	80	5	14	47	35
Using equipment	53	162	27	8	4	207	29	7	42	179

In all cases the data showed that technology was most likely to feature in the monitoring or controlling phase of the cognitive regulation processes and in a SSRL mode of learning. The target of regulation varied amongst the process codes. For all except the "using tablet" process code, there was a clear difference between the frequencies observed for the targets of regulation: as can be seen in Table 2, the "preparing equipment" and "using equipment" process codes were most commonly associated with "task performance", whereas querying the protocol was most commonly associated with "task understanding". There was a spread of data across the targets of regulation for the "using tablets" process code. A closer examination of the data showed that there was a difference in the target of regulation that students were using in the two different recorded sessions as shown in Table 3. To allow for a direct comparison of data, Table 3 shows the number of coded observations per participant transcript (to account for the loss of two transcripts due to technical failure). These data show that in the microbial assay on washing-up sponges, the students' focus was on task understanding whereas, in the SDS-PAGE experiment, participants were more likely to focus on task performance; although there was a smaller difference than observed for the SDS-PAGE experiment. A higher frequency of coding for content understanding was also observed in the SDS-PAGE experiment than in the sponge experiment.

Table 3. Summary of the number of coded observations for each think-aloud session recording per participant (data represented to 1 d.p.).

	Mode of Learning				Cognitive Regulation Processes			Target of Regulation		
	SRL	**SSRL**	**CoRL**	**CoRL-Other**	**Planning**	**Monitoring Or Controlling**	**Reflection**	**Content Understanding**	**Task Understanding**	**Task Performance**
SDS-PAGE	3.0	3.2	0.5	0.0	0.4	5.6	0.4	1.3	2.1	2.7
Sponge	1.3	2.8	0.1	0.0	0.63	3.0	0.1	0.1	3.3	1.0

The schematic diagram shown in Figure 1 demonstrates the cognitive and metacognitive processes that underlie this data when the original sections of the coded transcript are examined. Broadly speaking this follows the same pattern for both targets of regulation with individual participants choosing SRL, SSRL or a mixed approach to resolving their uncertainty.

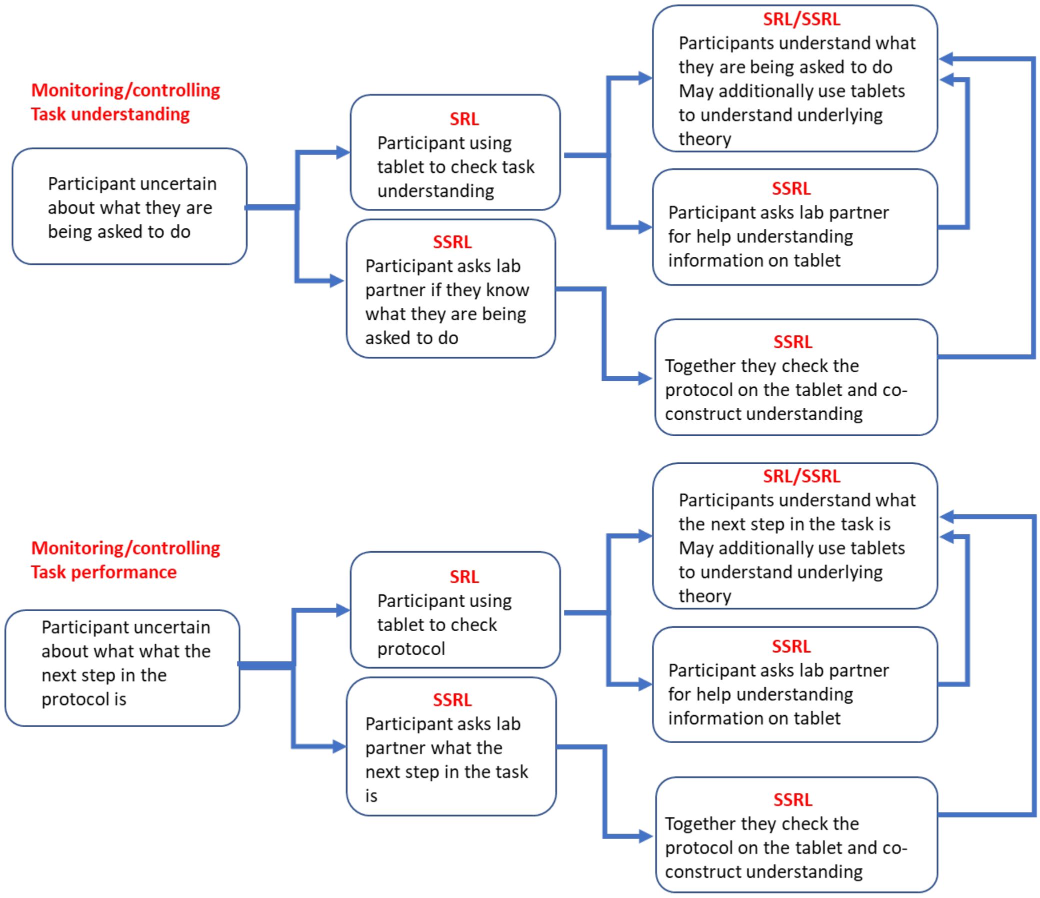

Figure 1. Schematic diagram showing the processes of participants in using technology to construct their understanding of a task or task performance. The upper diagram shows the process when students seek to clarify the task purpose, the lower when they seek to improve their conduct of that task.

3.2. *Interviews*

The coding data from the semi-structured interviews will be broken down according to the structural codes.

3.2.1. What Is Technology?

The pilot participant and eight out of the ten main study participants described that technology had an electrical component, although in one case, this was inferred as their definition described technology as a device that could access the internet. The remaining participants described it as a tool to make tasks easier or to help us in some way. However, deriving this definition was challenging for participants and in two instances, the participants revised their definition of technology during the interview as they thought more deeply about what they used technology for. An example of this can be seen in the participant quote below.

> *"Now you're asking these questions, you start thinking about it, technology is basically something you use to help you carry out the job. Or not a job, maybe that's the wrong word but I know what I mean."*

3.2.2. How Do Students Feel about Technology?

In their personal life, all participants described feeling confident about using their personal technologies which they used for a wide variety of activities some of which overlapped with their learning. Mobile phones were central to all participants' daily use of technology with many participants stating that they made use of these for three or more hours per day. Whilst many also have access to laptops and use these for both personal and learning activities, this was not universally true of all participants: one participant highlighted that most of their learning-related activities outside of the university were carried out on their mobile phone due to the need to share access to other devices (such as laptop or desktop computers) with other family members. In their personal life, students were not only comfortable with their own devices but were also confident with trying new technology as can be seen in the following quote:

> *"I'm of this generation when you get a new phone out of the box and know what to do with it straight away. We don't need to read the instructions. No matter what phone it is, we just know how to use it."*

The same was not true of technology within the laboratory environment. Students frequently described feeling anxious about using unfamiliar equipment in the laboratory and even those who did not express a preference for either a demonstration or written guidance for using new equipment. The cause of the anxiety varied among participants but the most common cause was concern over breaking the equipment given its assumed cost. An example of this can be seen in this quote from the pilot participant:

> *"It's like "why don't you go and use the scanning electron microscope?" That's exactly what I'm not going to use. I'll just use the light microscope and not destroy millions of pounds worth of equipment. That would panic me."*

3.2.3. How do Students Use Technology?

Participants described their personal technologies as multi-functional with applications to both their personal and learning. In particular, mobile phones and laptops were described as devices to which they applied. These were used for activities in their personal lives such as communication, social media, gaming, streaming and listening to music; as well as using them in their learning for activities such as notetaking, accessing the virtual learning environment (VLE), preparing assessments and in the laboratory.

Nine out of ten participants had access to a laptop outside of university; whereas one participant stated that they did not have routine access to a laptop outside the university (as a single laptop was shared by all members of their home) so the primary device used in their learning outside of university was a mobile phone.

3.2.4. How do Students Prepare for Labs?

Students used technology to personalise their pre-laboratory learning, with seven out of the ten interview participants carrying out some form of activity prior to the session. Students reported that pre-laboratory activities that ranged from pre-reading the protocol (an activity that they felt their lecturers expected–them to undertake) as well as other activities such as watching videos on the techniques to be used, revisiting lecture/seminar material or looking up unfamiliar equipment or terminology. These were self-motivated activities which the participants described as benefitting their laboratory experience. For some participants, this was because they preferred to work efficiently in the laboratory; whereas for others it was to reduce the likelihood of making mistakes in their lab work (as can be seen in the quote below).

> *"If there's a technique I'm not really sure on, I'll watch a YouTube video or something like that. Or we're using a new piece of equipment and I've never seen it before I'll give it a google just so I don't look like a muppet when I walk in there and go "I have no idea what this is."*

Being able to perform well in the laboratory was an important factor for students as they perceived that many of these would be involved in module assessment such as writing lab reports that would contribute to their final degree classification.

3.2.5. How Are Students Using Technology in Labs?

Participants described their laboratory environment as containing a range of different types of technology some of which were consistent across their modules such as tablets, centrifuges and spectrophotometers. However, they described that new and unfamiliar equipment could be a cause of anxiety. As highlighted above, students who elaborated on this described their anxiety as stemming from the concern about breaking an expensive piece of equipment. When asked how this could be improved, participants varied in their preference but stated that either a demonstration or written guidance would reduce this.

Students perceived that the laboratory and its' technology as providing them with an opportunity to put theory into practice, gather information and develop career-relevant skills as seen in this quote and the quote shown below (labelled changes in understanding during the lab).

> *"I think the technologies that we've got help to put into perspective what our trade is, actually."*

When asked if or when students perceived changes in their theoretical understanding, only two of the ten participants described this as only happening during the class; four described that their understanding changed as a result of post-laboratory activities and sometimes during the lab; with the four remaining participants only indicating changes in understanding occurred after the laboratory.

> *Change in understanding during lab: "If you. . .work in a lab, you're going to be using the same-similar-technologies there so having that experience is good for you. Because then you'll know how to work it and your results will be accurate".*

3.2.6. What do Students Do after Labs?

The changes in understanding described by participants after the laboratory resulted primarily from supporting activities such as reflection or conducting further research to support an assessment (such as a laboratory report or revising for an exam). With one exception participants described technology as integral to the process as it provided them with the tools to do further research on the topic, analyse and interpret their findings. The quotation below, from the pilot participant, demonstrates the impact of post-laboratory activities on their understanding of the theoretical content.

> *Change in understanding after the lab: ". . . sometimes we do course content and then a lab and then your report and stuff like that and then. . . and then it kind of clicks. Whereas I know for a fact that if I just did course content, no lab, no report. . . I would be struggling because finding out for yourself or writing your own words is different to how lecture tells you it".*

A summary of the role of technology in the pre-laboratory, laboratory and post-laboratory activities as described by participants during the semi-structured interviews can be seen in Figure 2.

3.2.7. How Do Labs Fit into the Development of Identity as a Scientist?

Participant responses as to whether they identified themselves as a scientist were varied. Most students did not see themselves as a scientist instead perceiving that they would not feel like they were a scientist until they were employed in a scientific job role applying professional standards to their work.

However, they acknowledged that practical experimental work gave them a sense of pride and enabled them to "do real science" or "make science real" as well as preparing them for employment through the acquisition of job-related skills. In addition, one of the participants commented that being able to support and advise colleagues in the lab increased their confidence in their own skills.

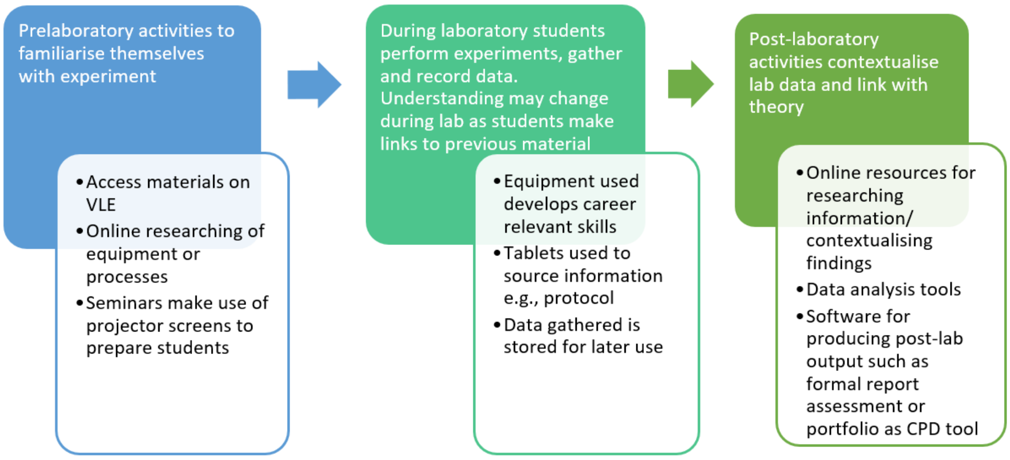

Figure 2. A schematic diagram demonstrating the role of technology in laboratory learning and the types of technologies involved. Data for pre-laboratory activities are shown on the left in blue; during the lab are shown in centre in pale green; with post-laboratory activities shown on the right in dark green.

The concept of science and scientists being an active role can be seen in the quote below.

"I don't think I would class myself as a scientist if I didn't do any lab work. Because that's what being a scientist is all about isn't it? Like it's getting stuck in, in a lab."

3.3. Survey of UK HE Module Post-Laboratory Activities in Physical Sciences

When asked whether students were expected to undertake post-laboratory activities, 78% of UK HE bioscience modules (n = 40) and 88% of chemistry modules (n = 42) whose module leaders responded to the survey indicated that students were either required to undertake post-laboratory activities or had optional post-laboratory activities. This means that one-fifth of bioscience modules (22%) do not make use of post-laboratory activities. A comparison of the types of activities used in bioscience and chemistry modules can be seen in Figure 3. In both disciplines, the activities with the highest frequency are undertaking calculations and writing reports. Given the frequency of the activities and the number of modules reporting the activities, it is clear that modules may use more than one type of post-laboratory activity. The next most frequent response was activities that did not fall into the categories listed. These varied by discipline. For example, in bioscience modules other activities included feedback tutorials, seminars with discussion, task completion with subsequent peer assessment, creating posters, reflections and creating portfolios (e.g., relating to collected specimens). In contrast, in chemistry modules students were asked to write journal-style reports; submit raw data, interim reports or worksheets; undertake vivas or questions designed to measure understanding.

When asked to confirm whether their modules expected students to handle data as part of their post-laboratory activities, all chemistry respondents (n = 35) and most bioscience respondents (26/28) confirmed that they did.

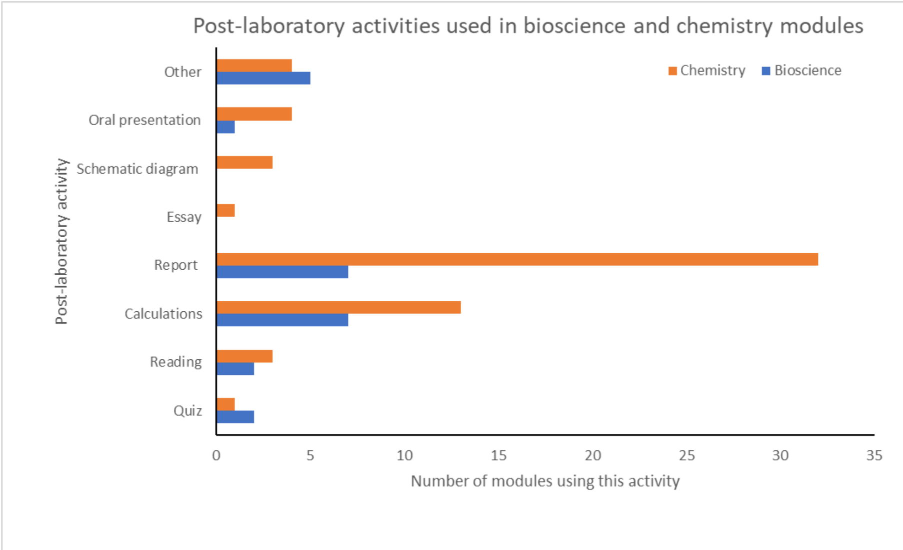

Figure 3. Frequency of post-laboratory activities described for UK HE modules in bioscience and chemistry.

4. Discussion

4.1. Student Perception of Practical Classes

The data generated in this study suggests that bioscience students at NTU perceive the practical classes undertaken on their course as primarily a place to provide them with career-relevant skills. Given that students' perception of themselves as a scientist was commonly linked with the concept of taking a physically active role in "doing science", it is clear that the laboratory (or other places where students can undertake practical work) is considered of value to them both in terms of developing their identity as a scientist and for future career aspirations.

Whilst academics may see a role in developing content understanding and linking theory to practice, the data from the think-aloud protocol and interviews is suggestive that within the laboratory the focus is primarily on task completion and generation of data rather than changes in conceptual understanding. This is consistent with studies in chemistry that described their learning in practical classes to be skills-based rather than knowledge-based [20,29].

Whilst some students did highlight that changes could occur during the laboratory, this was less frequently stated than that changes, in theory, came about due to post-laboratory activities. These activities varied but most often included an element of reflection (as in the case of the creation of portfolios in their practical class), or as a result of researching information and analysing data for use in assessments such as laboratory reports. The data from the think-aloud part of the study provided little evidence for changes in understanding during the laboratory class however the focus of this part of the study was exclusively related to how students use technology in the laboratory. From this we can deduce that either technology is not involved in participants' change in understanding or that the sections of the practical classes chosen for the study did not often result in these connections being made. The literature around laboratory education demonstrates that using a problem-solving approach to laboratory education has an impact on student content/theory understanding [30–33] and so academics that are using protocol-driven practical classes (such as those used in this study) may enhance their students' content understanding during the class more effectively through scaffolding content-related questions into the protocol as suggested by the study of Philip and Taber [34].

As highlighted above, with most participants suggesting that their understanding of their course theory changed as a result of post-laboratory activities, it would seem appropriate to reflect on the provision of post-laboratory activities across UK higher education. The data from the HE surveys highlighted that in biosciences, one-fifth of modules did not carry out any post-laboratory activities suggesting that in a significant number of cases, there is no direct scaffolding to support students in making the connection between theory and practice and that this is more common in bioscience modules than for chemistry modules. Although the survey did not ask module leaders to categorise whether their modules used problem-solving or protocol-driven approaches in their practicals, this would still seem to be an opportunity to reflect on bioscience course provision and give greater consideration to how practical education is supported: something which was supported in a comment from one of the participants. This is shown in the quote below, which was produced when the participant was reflecting on the purpose of laboratory work and expressing frustration when data generated in the laboratory was not utilised in any way.

"I'd still like to be able to use my results more than they are."

To be able to address this effectively, further targeted research would be needed to establish whether there is a difference in post-laboratory scaffolding provided to students in UK HE-based on whether they are protocol-driven or problem-solving laboratory approaches.

4.2. Impact of Technology on Student Learning

One of the aspects that were unexpected from the study is that whilst participants in the study were able to articulate how technology influenced their personal and academic life, they had significant difficulty in creating a definition for it and even within this group of students there was not entirely a consensus on what technology is. Opinion was divided primarily into either that technology was a tool created for a specific purpose to make a task easier (or possible) or that technology was a tool that specifically required electrical input to function. Whilst this meant that there was some consensus overall in terms of examples that students gave technology (such as mobile phones and laptops), it also meant that there were differences in how students perceived their laboratory experience. For example, carrying out a microbiology experiment, which used tools such as a Bunsen burner, agar plates and pipettes to make dilutions could for some be described as an experiment that used technology and for others it would not. Despite this, participants acknowledged that laboratory spaces made use of a range of technologies to support their learning.

Outside of the laboratory environment, students described feeling comfortable with their personal technologies, even those such as mobile phones and laptops which were multi-functional devices used in both the student's personal life and studies. Even trying new technologies outside of the laboratory was something that students were confident to do. Given that participants frequently described a feeling of constant connection to their technology, it would not be unreasonable to describe them as digital natives [35]. Having said this, one of the 10 participants had limited access to digital equipment off-campus due to the sharing computer access with other members of the house and requiring them to access and work using their mobile phone as their primary technology. Within a learning context, as a reliance on digital media becomes more pervasive, it is important to recognise the potential for digital inequality, particularly in terms of access. Although focussing on veterinary education, as opposed to biosciences, a recent cross-national metanalysis highlighted that 54.5–90.6% of students made use of portable technologies such as smartphones, laptops and tablets which were more versatile than non-portable alternatives [36]. Whilst the variation in use may, at least in part, be explained by regional differences in the use of technology. With such a wide range in the availability of technology, it is important to evaluate the institutional context when considering the implementation of digital resources to avoid disadvantaging particular student groups.

Digital inequality may result in students' experiences and digital competencies prior to university being varied and so, making resources available across different platforms (including mobile devices) not only makes learning more accessible to those with access to fewer technologies but also allows students to personalise their learning [37]. The recent COVID-19 pandemic has demonstrated the extent of digital inequality in the UK where during the first UK lockdown (March–May 2020) children in low-income families spent 30%

less time on home learning than higher-income families [38]. This is particularly pertinent since in 2018–2019, only 62% of the UK's undergraduate students were reported to live away from home, with the highest numbers (approximately 40%) of students studying from home being from ethnic minority or disadvantaged backgrounds [39].

However, student comfort with technology differed when considering laboratory technology. Those technologies that were unfamiliar to the students were a source of anxiety for some students either through concern for their lack of experience with how to handle the tool resulting in damaging expensive equipment or because their inexperience could impact the quality of the data collected (therefore, having an impact on use of the data in assessment). Unlike personal devices, where participants described being just able to immediately make use of a device (quite possibly, at least in part, because they are more confident to use a trial and error approach given its fundamental similarity to other devices of this type), laboratory technology interfaces can be more varied and may result in lower confidence levels in taking a trial and error approach especially given the perceived cost of damaging the equipment.

This is consistent with findings in chemistry laboratory classes. One study developed a lab anxiety questionnaire (LAQ) which was used with 92 undergraduate students at a Turkish university and reported that prior to the laboratory class, 40% of students were anxious about breaking expensive equipment; 30% felt anxious about not having enough information about laboratory equipment; 29% were anxious about making a mistake in their experiment, but 69% of participants were anxious that making a mistake could result in themselves or someone else being hurt [40]. Similarly, a more recent study using a mixed questionnaire and interview methodology in a UK university highlighted undergraduate student anxiety about making mistakes and breaking equipment in chemistry classes [41]. In this study, using pre-laboratory simulations was found to reduce student anxiety and increase confidence in the laboratory. Whilst these activities were scaffolded for students, participants in the current study highlighted that it was common for them to do independent research around the equipment or techniques they would be used to increase their sense of preparedness for the laboratory. This is in keeping with a recent review of pre-laboratory activities in UK HE institutions which highlighted that using simulations was a much less common way to prepare for a laboratory than other activities such as videos or reading the protocol and even then, only 65% of UK bioscience modules make use of pre-laboratory activities [24]. The data from this study confirms that technology plays a key role in how students prepare for laboratory classes with students using a variety of preparatory methods that, with the exception of conferring with peers, involved the use of technology.

Considering the data from this study as a whole, it can be observed that the use of technology in laboratory education can split into three separate categories: (i) skill development; (ii) information gathering, synthesis and storage; (iii) use of data analytic tools (such as Microsoft Excel).

The data provided in this study describes the perspectives of students who predominantly experience protocol-driven, rather than problem-based, laboratory classes in their undergraduate bioscience course. A logical next step would be to explore whether the self-regulated and socially shared metacognitive processes, especially those related to content understanding, differ when problem-based laboratory classes are undertaken and whether this has an impact on the role of technology in this approach to laboratory learning. In turn, this may provide valuable insights into whether scaffolding of post-laboratory activities is as important a feature for the integration of the experiment into students' theoretical understanding as it is for when protocol-driven laboratories are used. With that in mind, establishing the extent to which UK HE bioscience courses use problem-solving rather than protocol-driven laboratories may enable more focused guidance for academics to be developed.

5. Conclusions

The study presented in this paper suggests that technology forms an integral part of a student's lab education, including how they prepare for the laboratory and post-laboratory activities. Student use of technology in their laboratory learning broadly falls into one of three different categories: skill development; information gathering, synthesis and storage; or use of data analytic tools. The outcome of the think-aloud protocol and interviews highlights that in protocol-driven laboratory classes, the scaffolding of post-laboratory activities is important to bridge the gap between task and content understanding. In UK HE, there may be the supposition that providing students with an opportunity to study a phenomenon or theory as part of a practical class is sufficient on its own to achieve integration of task and content understanding; however, this study suggests that this is often not the case and that post-laboratory activities are critical to achieving this integration.

Given that one-fifth of UK HE bioscience modules do not make use of post-laboratory activities, it would be beneficial for module leaders to reflect on how these types of activities could be scaffolded into their modules to support students in moving between the psychomotor and cognitive domains of learning. The types of activities that students in this study described as supporting the development of these theory-practice connections include opportunities for reflection such as portfolios or creating logs of their professional development; and opportunities to analyse and contextualise their findings such as lab reports.

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