The Impact of Technology on Student Learning and Staff Practice in Undergraduate Bioscience Laboratories

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Dedication

As a PhD undertaken on a part-time basis the program of research needed to create this thesis has been a “long haul”. As such, this thesis is dedicated to my family who have supported me throughout this quest to regenerate into the second doctor. To my husband and to my son, Michael and Ryan Loughlin, thank you for the unending patience and support you have given me: it has seen me through the most challenging times, and I could not have done this without you.

No dedication would be complete without special mention to Jennifer Evans, my co-researcher. We made a great team, and I am proud of what we have achieved. Particular thanks for all the breakfast research meetings with motivational tea.

To my research supervisors Dr Karen Moss, Dr Mike Coffey, Dr Sandra Kirk and Dr Shiva Sivasubramaniam, I would like to express my deep gratitude for setting me on a path of life-long research. Thank you for always being there with insightful questioning that never failed to ensure that my work was rigorous, relevant, and well-rationalised.

Thanks also to Dr Ruth Richards for helping me to retain focus, I have valued your insight greatly. I would also like to express my gratitude to all my academic and technical colleagues who have supported me and provided me with opportunities needed to be able to develop this research; in particular to Karin Garrie whose interest in my research has helped me keep motivated.

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Abbreviated terms

Abbreviations	**Full name**
BERA	British education research association
DHS	Digital history survey
JISC	Joint information systems committee
NTU	Nottingham Trent University
SLEI	Scientific laboratory environment inventory
TOSRA	Test of science related attitudes
TROFLEI	Technology-rich outcomes-focused learning environment inventory
VLE	Virtual learning environment
ZPD	Zone of proximal development

Glossary

Term used	Explanation
Benjamini-Hochberg correction	A modification added to statistical tests to reduce the risk of a type I error (i.e., the test returning a false positive)
Box's test of equality of co-variance	Box's test is designed to test whether samples in a multivariate analysis have equal variance. This is important as parametric tests assume equal variance
Cronbach-α test	This test is used as a test of scale reliability as it measures internal consistency
Cognitive Load	The learning theory that describes how different tasks put demands on cognitive processing
Concurrent think aloud method	A research method designed to investigate cognitive processes, where individuals are asked to verbalise all of their thoughts whilst undertaking a given task
Integration	The SLEI scale that refers to the integration of theory and practical work.
Levene's test	Levene's test is designed to test whether samples in a univariate analysis have equal variance. This is important as parametric tests assume equal variance
One-way ANOVA	The one-way ANOVA (analysis of variance) is a statistical test to test whether there are differences in a single variable between independent groups.
Openendedness	The SLEI scale that refers to whether students have an opportunity to explore and investigate problems for themselves without a prescriptive protocol to follow
Rule clarity	The SLEI scale that refers to whether the laboratory has more clearly defined rules than other learning spaces
Semi-structured interview	A qualitative research method which uses a pre-defined set of open questions but provides the opportunity for researchers to explore emerging topics and themes further
Shapiro-Wilk test	A statistical test that tests whether data is normally distributed.
Spearman-Rho correlation test	A statistical test that investigates whether there is an association (corelation) between two variables. This test is used for non-parametric data.
Student cohesion	The SLEI scale that refers to the opportunities that students have to interact with their peers
Type I error	This refers to when a statistical test returns a statistically significant finding when it should not (i.e., a false positive)
Type II error	This refers to when a statistical test fails to return a statistically significant finding when it should (i.e., a false negative)
Working memory limit	The theory that suggests there are a defined number of pieces of information that individuals can process at any one time

Abstract

The bioscience laboratory is a complex learning environment with a high cognitive load resulting from unfamiliar processes and equipment, which can make learning challenging. With the increasing use of technology in education, this study uses a mixed methods approach to examine the impact of technology on learning in this environment through the case study of a large multi-purpose “Superlab” at Nottingham Trent University, as well as examining the use of pre- and post-laboratory activities to support laboratory learning across UK HE institutions in biosciences.

Use of a concurrent think aloud approach in laboratory classes demonstrated that undergraduate bioscience students used technology to undertake experiments and access information. These students perceived the laboratory as an environment for developing their skills, with changes in theoretical understanding occurring as a result of post-laboratory activities such as report writing or reflective practice. Only two thirds of UK HE bioscience modules surveyed stated that they used post-laboratory activities, suggesting a missed opportunity in some cases for scaffolding consolidation of student learning.

Data from the semi-structured interviews and the digital history survey confirmed that student participants were comfortable with range of technologies that were integrated into both their everyday life and learning. Comparison of these skills against preliminary data from bioscience graduate employers further suggested that by the time they graduated, a high proportion of bioscience students had the key technology-based skills that they required.

Despite this, anxiety or caution around using laboratory equipment was frequently expressed based on its cost or the unfamiliarity of the equipment, or the implications of errors on assessed practical classes. The survey data from UK HE institutions highlighted

that one-third of bioscience modules do not use pre-laboratory activities, thereby missing an opportunity to reduce student anxiety and cognitive load by familiarising students with equipment, potentially facilitating greater lab learning.

These findings are particularly pertinent given the impact of the COVID-19 in diversifying laboratory education, and the additional pre- and post-laboratory support needed for students whose access to laboratories has been limited by the pandemic.

Chapter 1: Setting the context.

1.1 Why do we have labs in bioscience education?

Whilst it is widely accepted that the bioscience teaching landscape should include an element of practical "hands on" experience, there is not necessarily consensus on their purpose or benefits, which can be context specific. In science education, active learning styles (such as laboratory classes) have been shown to increase exam attainment by up to 6% and significantly reducing exam failure rates (Freeman et al. 2014). Not only this, but it can reduce the attainment gap for minority and low-income students (Theobald et al. 2020). These student-centred teaching approaches can also enhance key skills such as critical thinking in bioscience students (Styers et al. 2018), and student motivation and engagement (Armbruster et al. 2009). This type of active learning provides an authentic form of inquiry which can be seen both in schools (Hofstein and Lunetta, 2004) and in a university setting.

This literature is reflected in a discussion between bioscience academics about the benefits of first year undergraduate bioscience practical classes which described a wide range of benefits which could be categorised as falling within conceptual, technical, and affective concerns (Adams et al. 2008). These categories have similarly been proposed by Agustian and Seery (2017) for chemistry students.

Conceptual understanding: One of the key benefits of labs in terms of conceptual understanding was the opportunity that laboratory classes gave to clarify or illustrate a theoretical concept that the students have been taught about, allowing them to contextualise this learning and frame it in terms of real-world examples. Practical experience was also considered important for students to be able to understand the "scientific method". Whether or not students choose a career in science, academics ascribed value to students being able to experience for themselves how scientists go about investigating phenomena. Adams' (2009) review of bioscience laboratories in higher education provided a range of evidence to support the idea that laboratory learning that used a more open-ended enquiry-based approach improved learning outcomes, reasoning skills as well as enhancing students' enjoyment of the classes. As will be discussed in more depth in chapter 4, skills such as problem solving are sought after by graduate employers and so providing students with opportunities to develop these skills and evidence them using authentic assessments such as lab reports and skills portfolios enhanced their employability skills too (Sokhanvar et al. 2021).

Technical skills: The technical benefits of lab classes described by Adams et al. (2008) were to build student practical skills and competencies as well as familiarising them with lab safety and improving their ability to record data.

Affective domain: The affective (emotional) considerations that were described in the report as being important related to the student's personal development: increasing their engagement, building confidence, and encouraging reflective practice. These characteristics were in keeping with those described for secondary school science teaching across biology, chemistry, and physics (Kerr et al. 1963).

The conceptual, technical and affective benefits of laboratory defined in the discussions described by Adams (2008) reflect observations in chemistry (Carnduff and Reid, 2003) and more recently the framework for chemistry lab learning proposed by Seery et al. (2019). Their framework describes a stepwise approach where the focus of lab learning develops over a 5-year period (as Seery's work is based on the Scottish education system where undergraduate studies extend beyond 3 years); at which point the student would be capable of developing their own research entirely independently. The first year of this framework, reflects objectives similar to those described by Adams et al. (2008): to develop the student’s experimental skills and competencies as a foundation for later learning.

One of the benefits discussed by Adams et al. (2008) that can become overshadowed by other aspects they described, is the affective concerns. In the study by Kerr et al. (1963), which investigated the teachers’ and students’ perceptions of secondary school practical classes, there was a significant difference in how different groups valued the aim of practicals, which Kerr described as having “made the phenomena studied more real and interesting”. For sixth form students, teachers ranked this aim as lowest out of the 10 aims described, whereas students ranked it highest. This showed that teachers had presumed that these students were already sufficiently motivated and interested in the subject since they have chosen to study it post-16, whereas doing practical work was actually a motivating factor for students. Kerr et al (1963) concluded that stimulating and maintaining student interest in a subject through provision of practical classes was much more likely to motivate students thereby enhancing their learning. The discussion described by Adams et al. (2008) also highlighted that academics recognised the need to generate enthusiasm for labs: which mirrored the survey data included in this study (see chapter 3) that suggested students considered practical classes to have high interest value. Notably, students also placed value on the social interactions with peers and teachers as part of their learning experience.

Student interest and motivation are an essential element in Novak’s theory of meaningful learning (Novak 1980). This theory describes the formation of long-term memories (allowing information to be retained for anywhere from minutes to lifelong learning) as a continuum from rote learning (verbatim incorporation of information) to meaningful learning (an integrated network of information). Novak (1980) built on Ausubel’s assimilation theory for cognitive learning (Ausubel 1963) which was the first theory to use the term “meaningful learning” to describe the process by which new information is assimilated into memory by anchoring it to an existing piece of knowledge. The obvious caveat to this is that students must have a pre-existing knowledge to make these connections and so it is particularly important for educators to ensure that students have suitable scaffolding to facilitate meaningful learning.

Novak’s theory of meaningful learning has itself continued to evolve. Consideration of the laboratory as a learning environment has given rise to the recognition that in addition to cognitive (concepts and reasoning) and affective domains (attitude and motivation), psychomotor functions such as precision and dexterity are required for meaningful learning in this context (Bretz 2001). This fits well with the Adams’ (2008) discussion of the aims of practical work which encompassed cognitive, affective and technical (psychomotor) elements.

1.2 What makes the lab a challenging environment for learning?

Whilst the work of Ausubel and Novak have proposed models for how meaningful learning can take place, these models can be extended with further theories of learning that describe the processes involved in our ability to form these long-term memories.

Theories such as cognitive load and working memory seek to explain how the information that we experience is organised and processed for long-term storage whilst simultaneously highlighting the limits of this system (Johnstone 1984; Reid 2008).

Cognitive load theory holds that there is a limit to the number of pieces of information that someone can process at a time (described as the working memory limit). How many different pieces of information that is will vary between individuals. In adults, it is thought that we can hold 5-7 pieces of information in our working memory (Reid 2009) whereas in young adults this may be between 3 and 5 (Cowan 2010). Whilst there are theories that attempt to describe why there is a limitation on our working memory, a consensus view has not been reached. Theories include that:

- it could be biologically expensive to have a higher limit from a neural-processing perspective.
- having a larger capacity causes interference between the packages of information leading to “misremembering”.
- mathematically more than 5 items may result in loss of distinctiveness in each item.
- having a small limit enables active items in the working memory to be more easily related to one another.

Whilst our working memory is presented with no more than an individuals’ limit of information, it can make long-term memories optimally. The working memory does this by interpreting the new information, comparing it to existing knowledge, rearranging the input (problem solving where appropriate) to prepare it for integration into the hierarchy of knowledge the individual has stored in their long-term memories (a schematic representation of how this might apply in laboratory situation is shown in Figure 1). In reality, the working memory is a more complex system than shown, with three main aspects to it. These are: the central executive which deals with problem solving and sending information to the other two sections of the working memory; the visuospatial sketchpad (for visual and spatial information); and the phonological loop for written and spoken material (Reid 2009).

In the section of Figure 1 labelled as long-term memory storage, a distinction has been drawn between fragmented knowledge (such as rote learning) where memory stores the knowledge as isolated pieces of information; as compared to what both Novak (1980) and

Ausubel (1963) describes as meaningful learning (the storage of pieces of information connected and clustered together in a complex matrix with other knowledge).

This is important because it is easier for information to be recalled if it is part of an integrated network of information than isolated knowledge fragments (Reid 2008).

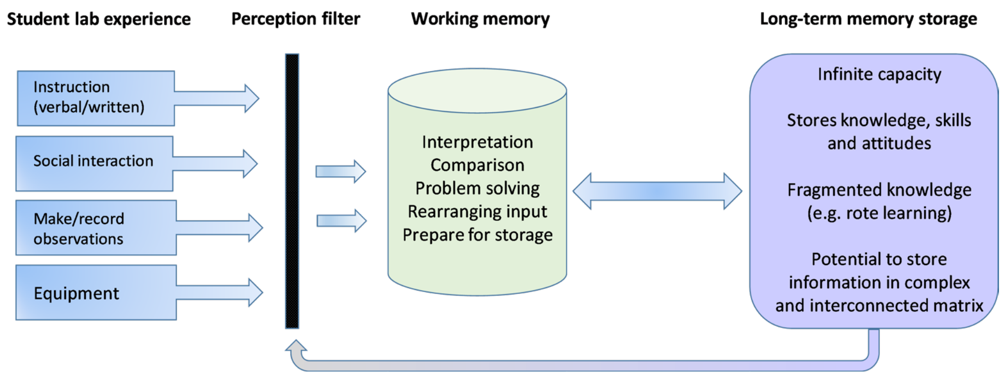


Figure 1: Schematic diagram illustrating the relationship between working memory and long-term memory formation using lab experience as the sensory input. Schematic diagram adapted from (Reid 2008)

As shown in Figure 1, the long-term memory storage also creates a feedback loop to the perception filter. This is a "sorting" mechanism which allows an individual to determine which information is important and which is not. Key to this is the fact that the information provided to the perception filter is generated based on what information the individual already has in their long-term memory storage and is therefore information the individual is already familiar with (Reid 2008). In part, this explains why laboratories can be such a challenging environment for students to learn in, particularly in their first year in higher education. The array of equipment, new processes, language/terminology used, written and verbal information is all largely unfamiliar and so needs to be processed by the working memory rather than much of this information being filtered out by the perception filter.

These observations are supported by the recent work of Agustian and Seery (2017) in the field of chemistry, who have proposed that the lab should be described as a “complex learning environment”; one that poses particular challenges for academics looking to support lab learning. They describe learning in complex learning environments as having three different aspects: integration of knowledge, skills, and attitudes; co-ordination of different skills; and the transferral of what has been learned to a real-life setting. These criteria for a complex learning environment align with the aims of bioscience labs as described by Adams et al. (2008).

The complexity of the environment means that aspects of laboratory work will add to cognitive load in different ways depending on the type of cognitive load that students are experiencing. Cognitive load is described as having three facets: intrinsic, extraneous, and germane load, as shown in Table 1 (Sweller 2010).

Table 1: summary of different types of cognitive load (as described by Sweller, 2010) and their application in the laboratory

Intrinsic Load	**Extraneous Cognitive Load**	**Germane Load**
Relates to the inherent difficulty of the material	Relates to the ability to discriminate between important and peripheral information	Relates to the motivation to organise and integrate material with pre-existing knowledge
Laboratory based examples (Agustian and Seery 2017)		
How inherently difficult the experimental protocol is	How challenging it is to identify and extract the important information from the protocol	When students process what they’ve learnt for storage into their long-term memory.

Discussion of cognitive load and working memory limit, inevitably lead on to what impact it has on learning (forming integrated long-term memories) when the working memory limit is exceeded. Research suggests that in this case, the ability to learn reduces or may cease all together as students lose the ability to discriminate between important and peripheral information (Reid 2008). This phenomenon is known as “cognitive overload” and can be measured by performance techniques (how the student performs in a scenario), subjective techniques or physiological techniques such as measuring heart rate (Cranford et al. 2014).

The complex environment presented by the laboratory, carries with it significant potential for students to experience cognitive overload and as a result for their laboratory learning to be compromised. However, steps can be taken to mitigate this. As discussed, the perception filter is an important factor in reducing cognitive load but relies upon prior exposure to material in order to be effective. Familiarising students with aspects of the practical class beforehand can reduce cognitive load because then the perception filter has information available that it can use to filter out peripheral information, allowing the student to focus on the important aspects of the task. Whilst this is the focus of chapter 5, pre-laboratory scaffolding in bioscience labs have been shown by groups such as Gregory and Di Trapani (2012) to reduce cognitive load, enabling the students to achieve greater learning gains. In this case study, students used a combination of quizzes and web-based activities to prepare for the practical class with their success at meeting a lab learning outcome assessed against the same observation from the previous year (before the pre-laboratory support was in place). With pre-laboratory support, the number of students who could successfully achieve the learning outcome (which was to plate bacteria for single colonies on their first attempt) increased significantly.

The unique environment provided by the laboratory in undergraduate science education, has been shown not only to have implications for cognitive overload but also student anxiety. Whilst current literature pertains to the chemistry laboratory, it would not be unreasonable to consider that aspects of this could also apply in the biology laboratory setting. One study of chemistry students at a Turkish university described using a lab anxiety questionnaire to explore what aspects of the laboratory made students feel anxious (Sesen, Mutlu 2014). They described that 40% of participants were anxious about breaking equipment, with 30% feeling anxious because they felt that they were not well-informed enough about using pieces of laboratory equipment. However, for these students the highest scoring source of anxiety was centred on making a mistake that would result in someone (themselves included) getting hurt (69%). More recently, a study in the UK highlighted that (in a similar way to cognitive load) pre-laboratory simulations reduced anxiety and increased student confidence about going into laboratory classes (George-Williams et al. 2022).

1.3 How do students learn in labs?

A review of lab provision in bioscience degrees, reported that students will typically experience approximately 500 hours of practical laboratory experience with all programmes offering a final year wet lab experience (Coward & Gray 2014). Given that this report was almost ten years ago, it is important to recognise that since then, there has been an increase in the provision of dry laboratory provision (e.g. bioinformatics) alongside wet laboratory activities. Advances in dry laboratory activity in undergraduate bioscience provision which has been highlighted by the recent COVID-19 pandemic (see section 1.9) although within NTU the balance of laboratory activities would still be to wet laboratory provision rather than dry laboratories. With the focus of this thesis being on wet laboratory provision and given the amount of time that students spend in a laboratory setting, it is important to consider not only the intention and aims of using this method of teaching but also the students' experience when they are in the laboratory.

Within the field of chemistry, Hofstein and colleagues have made significant contributions in this field over a period of more than 30 years. Their key findings in school laboratory classes suggest that they can promote three different modes of learning (Hofstein 2004): problem-solving, observation skills and development of skills for performing routine laboratory tasks (practical skills). Both problem solving and observation skills were similarly highlighted by Kerr et al. (1963) who explicitly linked the experience of students in secondary school lab classes with problem-solving; describing that instructors led their students to be able to ask meaningful questions and make observations to resolve the problem. Taking this one step further, they also indicated that this approach enabled students to apply this "scientific method" to problem-solving outside of the science.

Furthermore, Hofstein and Lunetta (2004) described that this inquiry-based approach to practical classes was more effective in enhancing student understanding than when the class was pre-occupied with more technical aspects because they promote cognitive and metacognitive skills whilst still enabling integration of practical skills. Development of cognitive and metacognitive skills would seem to be critical in moving the student from a state in which they are able to perform tasks and recall information (in a similar way to rote learning) to becoming independent thinkers (Bloom 1956). By bringing the student in as an active participant, central to the experiment, this would seem to integrate the affective domain with the cognitive and psychomotor (act of doing the experiment) aspects of the task; which aligns with Novak's theory of meaningful learning (Novak 1980).

Having said this, in the university setting, students may experience a range of types of practical classes. Some of these may be exploratory or problem-solving whereas others are protocol-driven and involve following a protocol or methodology. The capstone project that students undertake in their final year is an example of an extended problem-solving scenario, but the degree to which students experience problem solving laboratory classes in the earlier stages of their university career varies by institution and course. At NTU, the balance of laboratory classes at NQF levels 4 and 5 would be towards protocol-driven laboratory classes.

Irrespective of the type of session, Bloom's taxonomy is common tool applied to the creation of learning and teaching sessions. In Bloom's original taxonomy (1956) there was consideration of the cognitive, affective, and psychomotor domains in learning (in line with Novak's model of meaningful learning) although the affective domain and psychomotor domains were not classified until a later point (Anderson 2001). Bloom's taxonomy was later revised, taking into account changes in our understanding of the psychological aspects of learning with domains renamed using verbs rather than nouns to focus more on the dynamism of learning. The revised cognitive framework that is shown in figure 2(A) can be clearly mapped to the framework for undergraduate lab work proposed by (Seery et al. 2019; figure 2B), although it should be noted that the stages in Bloom's taxonomy do not always map directly with each stage of Seery's framework.

According to Seery et al. (2019) the first year of undergraduate laboratory classes would focus on familiarisation with core lab protocols and developing practical skills and competences to create a solid foundation for future lab work (Figure 2B). These types of skills are consistent with the first two steps in Bloom's taxonomy of remembering and understanding as shown in Figure 2A: the latter focussed on the students theoretical understanding of what is happening in core protocols they use. This understanding would be utilised in the second year of practical classes where it would enable students to predict outcomes for their experiments: a means of applying their knowledge (which is the third step on Blooms' taxonomy of cognitive learning). The third year of lab classes in Seery's framework takes students to the next level of not only being able to apply what they know but also to connect different ideas and areas of knowledge to design experiments using familiar protocols to test their hypothesis, which fits with Bloom's "analyse" domain.

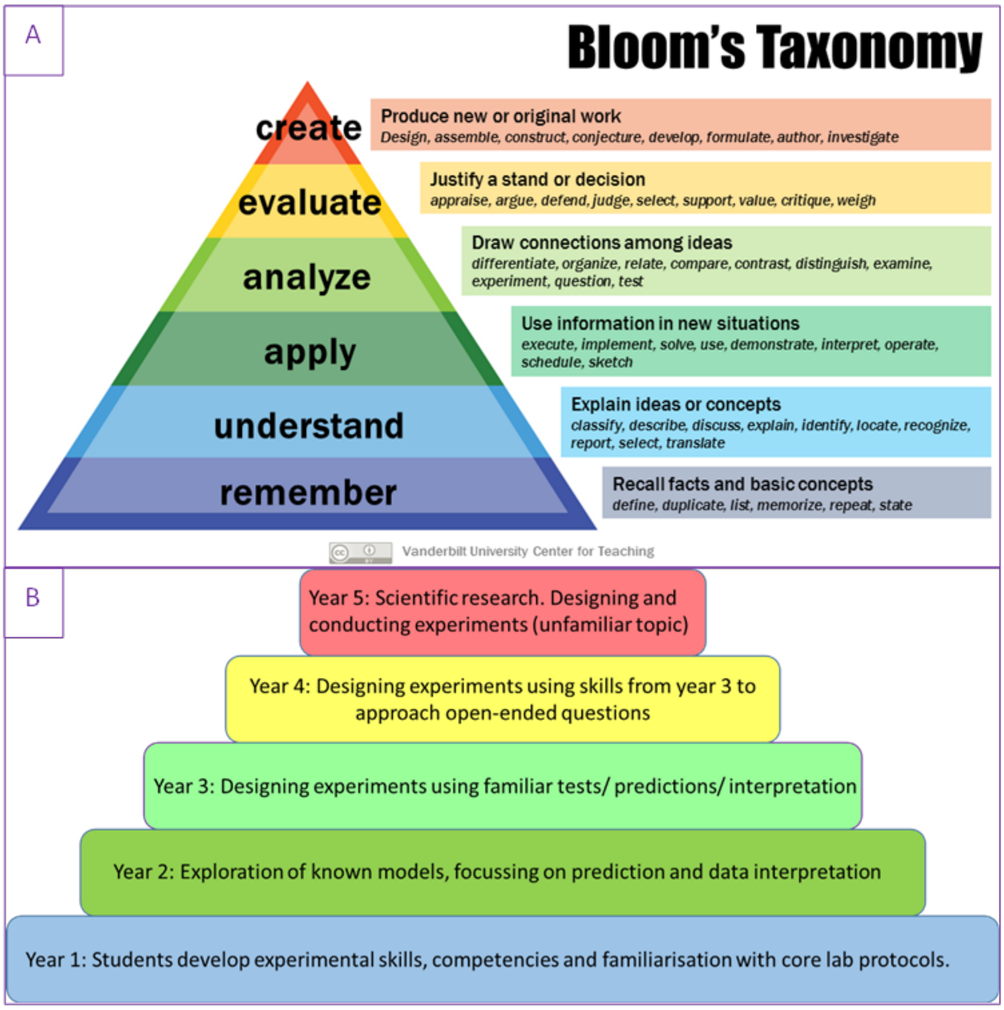


Figure 2: maps of the revised Bloom's taxonomy (2A; used under creative commons (Armstrong, 2010), and proposed undergraduate lab framework (2B); adapted from Seery et al. (2019)

The next step in Blooms' taxonomy as shown in Figure 2A (evaluate) is implicit in the description of Seery's fourth-year lab classes where students are building on their skills from the previous year to be able to design experiments to open-ended questions. To be able to do this, students will have had to rationalise their approach; and how the experiment will address the question. In doing so they will be able to support and justify their approach, although it is arguably not until the 5th year of study that students would reach the final domain in being able to create new and original work.

It should be noted that the 5-year undergraduate system described in this paper is indicative of courses used by universities in Scotland which are longer than those in unive rsities that use the NQF system and so aligning this framework with these courses would requires condensing these objectives into a shorter timeframe.

Whilst much of the research discussed applies to chemistry laboratories, as described in section 1.1, there is considerable overlap in the aims of practical work in both bioscience and chemistry and so it would be reasonable to propose that the models and frameworks described for chemistry students would be applicable in the study of bioscience, at least to some degree. Certainly, the introduction of short research projects aimed at developing undergraduate bioscience students' cognitive and metacognitive skills reported advances in their ability to think more deeply when faced with open-ended problems even though in many cases the students themselves did not recognise this development (Dahlberg et al. 2019). However, use of the Science Laboratory Environment Inventory (SLEI) which is designed to investigate student experience as well as attitude to labs have shown differences (albeit in secondary school pupils) between biology and chemistry (Hofstein et al. 1996). This study highlighted differences in the sections of the survey relating to the integration of theory and practice, and open enquiry. Chemistry student responses indicated a higher degree of integration of theoretical concepts in their practical work; whereas bioscience student responded more positively about the opportunity for open investigation where they have an input in directing what is going on in the practical class (open-endedness).

1.4 Cognition vs metacognition

When considering how students learn, it is important to recognise that metacognitive as well as cognitive processes occur. Cognitive processes such as problem-solving, memory and decision-making (as described above) are focussed on knowledge acquisition and application. By comparison, metacognition is considered a higher order process, dealing with a person's awareness of their understanding of a topic, skill, or concept (and its limitations). Whilst there has been considerable development of the theory around metacognition since it was described by Flavell (1979), it is generally accepted that metacognition is a process that has several phases which give rise to an individual's ability to plan, monitor and evaluate their own understanding (self-regulated learning; SRL). Two types of metacognition have been described, with both required for effective learning (Winne, Azevedo 2014). The two types of metacognition are:

1) Metacognitive forms of knowledge. This enables individuals to be aware of what they know (described as declarative knowledge) such as in the case of task understanding where individuals may be aware of how to achieve a task (described as procedural knowledge); and conditional knowledge that identifies when and where to use these to achieve a task.
2) Metacognitive forms of thinking. These are centred on the application of metacognitive forms of knowledge to a specific task. Metacognitive monitoring and control use awareness of an individual's knowledge to direct their thinking towards the intended goal or completion of a task; with SRL using monitoring and control events to adapt an individual's thinking.

Taken together, these provide a process of self-regulation that, in an educational setting, allows learners to take greater responsibility for their learning. This supposition is supported by a study of chemistry undergraduates who were taught about metacognition and a range of learning strategies that use a metacognitive approach and showed that those who attended this lecture gained higher grades than those who did not (Cook et al. 2013).

A number of models of learning that take into account metacognitive processes have developed and, a meta-analysis of this self-regulated learning which reviewed a variety of these models demonstrated that all agreed that metacognition was a cyclic process with

3 main processes that could be applied - although for some models there were considerably more than 3 processes (Panadero 2017). An example of this is the first SRL model proposed by Boekaerts, which had 6 components organised under two mechanisms and was strongly influenced by the incorporation of motivational factors in students learning (Boekaerts 1996). By comparison, the model proposed by Zimmerman, which according to Panadero (2017) is the most frequently cited model of SRL, consists of 3 processes and is consistent with the main processes identified in other models (Zimmerman 2000). The main processes Panadero (2017) identified across models were:

1) Preparatory phase: common descriptions of this phase across different models include planning, goal setting and forethought (which is a combination of task analysis and self-motivation).

2) Performance phase: In this phase the models describe goal striving, application of strategies, cognitive processing, and monitoring/control.

3) Appraisal phase: this phase focusses on the use of appraisal or self-reflection/ judgement for adaptation.

An important factor to consider in studying laboratory education is the relationship between cognitive load and metacognition, and the impact that a relatively high cognitive load (as may be expected from working in a complex learning environment) may have on students' ability to regulate their learning. The literature in this area provides conflicting information in this regard. On the one hand, metacognition has been suggested to be impacted by cognitive load (Pieschl et al. 2013). Whereas interviews with 20 students who studied chemistry using inquiry-based laboratory classes in an Israeli school described using metacognitive practices during their activities which suggested that if laboratories are appropriately scaffolded towards inquiry-based learning, it may support the development and practice of metacognitive process rather than inhibit them (Kipnis, Hofstein 2008). This outcome is supported by the more recent study by Dahlberg et al. (2019) who implemented a short research-based module in their undergraduate bioscience programme and observed that participants in the module showed more sophisticated problem-solving abilities and engagement compared to a standard laboratory approach. Similarly, a study of 109 undergraduates which used a variety of techniques for problem-solving found that those who were "metacognitive solvers" produced more sophisticated solutions than those who were not (Berardi-Coletta et al. 1995).

1.4.1 Collaborative and socially shared metacognition

The literature described so far highlights metacognition as being integrated into the thought processes and awareness of an individual, however more recent theories and studies have highlighted that metacognition can be a shared process within a group where collective changes in understanding occur based on individual's willingness to commit to group goals and tasks (socially shared regulation of learning: SSRL) or that social interactions can support an individual's SRL (Co-regulation of learning: CoRL), and that this is likely to provide improved learning outcomes (Hadwin et al. 2011; Järvelä, Hadwin 2013).

This model of learning has been recognised in a number of studies including that by Smith and Mancy (2018) which analysed video recordings of groups of students who were discussing a maths problem, using a coding scheme for cognitive, metacognitive and socially shared metacognition. In their study, metacognition was more likely to form part of the collaborative talk and suggested that this collaborative metacognition came about through group and individual processes. This study is not the only one which has investigated metacognition within the context of maths. The study by Iiskala et al. (2011), which preceded the study by Smith and Mancy, similarly demonstrated SSRL in children (aged 10) undertaking problem-solving in maths. In this case, the study reported that the more complex the problem, the more likely it was that individuals would engage in SSRL to solve that particular problem. This type of observation is not exclusive to maths education but has also been reported in a range of activities and age groups; from 5–7-year-olds undertaking collaborative writing tasks (Larkin 2009), to project group work in pharmacy graduates (Lobczowski et al. 2021). In the latter study, analysis of a series of meetings held by 6 different groups to discuss project work further demonstrated the benefits of socially shared metacognition. In this study, those groups who self-identified as having a high collaborative metacognitive experience were more likely to exhibit use of deliberate and targeted strategies than those with self-reported low collaborative metacognitive experience.

1.5 Measuring metacognition in the laboratory

With one of the aims of this thesis being to gain a better understanding of how students use technology to support their laboratory learning, it was important to consider the range of tools and methodologies that have been used to explore metacognitive practices in other studies in this area of research. As described in the previous section, analysis of recorded events such as collaborative maths problem solving to investigate metacognitive experiences are one avenue for exploration of these learning theories. Such data requires coding that is clearly linked to metacognitive theory and so can generate models of the cognitive and metacognitive processes – such as that described by Lobczowski et al. (2021). Such methodologies rely upon "observable" phenomenon e.g., recording collaborative work during a class session which can either be directly analysed or used as the basis for discussion in interviews with participants. Examples of this latter approach can be found both in the study of bioscience and chemistry undergraduates whose video recordings were used in interviews that discussed their thoughts and feelings about their lab course learning (Taylor-Robertson 1984; Galloway, Bretz 2016). Such an approach could be similar to the retrospective think-aloud method (which will be discussed further in section 1.5.1). Interview protocols, such as in the case of the study into inquiry laboratories in Israel (Kipnis, Hofstein 2008) can also be effective at providing supportive evidence of participants' perspective when the activity, experience or impact of the experience cannot be directly observed.

The Meaningful Learning in the Laboratory Instrument (MLLI) which is a survey-based tool, is another approach that has been used to evaluate lab learning (Galloway, Bretz 2015a). This survey-based tool was developed as a way of evaluating the domains described in Novak's model of meaningful learning and has been used to explore the expectations and experiences of chemistry students in the laboratory both cross-nationally and longitudinally (Galloway, Bretz 2015; Galloway, Bretz 2015b; Galloway, Bretz 2015c; Galloway et al. 2015; Galloway et al. 2016) as well as evaluating the effectiveness of pre-laboratory videos in supporting lab learning (Schmidt-McCormack et al. 2017). The data derived from these studies primarily focuses on cluster analysis which considers student expectations and if/how these have been met.

In addition to the methodologies described, further approaches are available to researchers in the domain of "observable" phenomena. These are the use of the think-aloud method or researcher observations. The use of observations has a widespread appeal because of the versatility of the approach. Observation protocols can use either overt or covert sampling; can be undertaken in a wide range of environments (such as naturalistic environments or spaces dedicated for this purpose – such as a psychology laboratory); and can record instances of specific behaviour, behaviour at set time intervals of all behaviour over a given time (McLeod 2015).

1.5.1 Think-aloud protocol.

The think-aloud methodology requires participants to verbalise their thoughts either as they occur to them (concurrent) or at a later point (retrospective). This type of methodology has been applied in a range of contexts and has been extensively used in understanding learning processes, and approaches to problem-solving, such as the study by Randles and Overton (2015) which compared strategies used by chemistry students and professionals to solve problems. Their findings suggested that students proposed novice strategies for problem-solving which often resulted in a failure to reach the successful end point, whereas industrial chemists were more likely to use expert level strategies that had a much greater chance of success (with chemistry academics somewhere in between these).

The work by Ericsson and Simon (1980), which was subsequently revised in 1993 (Ericsson, Simon 1993), described the use and analytical considerations of the think-aloud methodology as verbal data. Their work described that the verbal data collected was formed from information in use in participants' short-term memory and provided that the verbalisation drew on this information and avoided asking for information that was not in use (e.g., their motivation for taking an action) then the cognitive processes were unaffected. This latter argument has seen considerable discussion but to date, there is no evidence that supports the use of the think-aloud methodology impacting cognitive processes although it is possible for cognitive processes to occur more rapidly than the verbalisation is made which does have the potential to slow down cognitive processes (for a review see the book on think-aloud protocols by van Someren et al. 1994).

As outlined below, the think-aloud method has been applied to studies in science and healthcare disciplines to investigate problem-solving and decision-making. Both the study by Bowen (1994), and study by Randles and Overton (2015) used think-aloud methodologies in the field of problem-solving in chemistry. Bowen (1994) focussed on chemistry student problem-solving, whereas Randles and Overton (2015) showed that under controlled conditions, participants at different career stages/ paths in chemistry approached problem-solving in different ways and that some of these were more effective in providing a successful outcome than others.

The think-aloud method has also been used *in situ* to investigate the decision-making processes of critical care nursing staff and physicians in acute situations (Lundgrén-Laine, Salanterä 2010). On this occasion the data was collected concurrently which eliminated the possibility of false remembering that may have impacted previous studies in this area (which had predominantly used a retrospective approach). However, it did require a degree of compromise in the methodological approach as the researcher was more involved in prompting or talking to the participant than would ordinarily happen. Unlike the examples described above which applied a think-aloud method for chemistry or healthcare disciplines, no published accounts of problem-solving or decision-making thought processes have been found in the field of bioscience education.

Whilst decision-making and problem-solving are the most common applications for the think-aloud methodology in a science education context, it has also been used to evaluate online resources (i.e., to evaluate the interaction between a human and a computer). An example of this was an electronic resource developed to support the early stages of nursing and healthcare student's understanding of biology (Cotton, Gresty 2007). This approach not only allowed the researchers to investigate the navigational decisions that students made in using the software but also how they were feeling about what they were doing at the time.

1.6 Measuring student experience of the lab

Whilst the discussion so far has focussed primarily on learning theories and why academics consider practical classes to have value for students, it is also important to explore how students experience these classes and their perception of the laboratory as a learning environment.

Over the last 50 years a range of different tools have been used to investigate the learning environment that students experience. Early tools, such as the learning environment inventory (LEI) and the classroom environment scale (CES) were primarily focussed on the secondary school classroom. These survey tools were designed to investigate various aspects of the students' perception and satisfaction with the classroom environment.

The CES as used by Trickett and Moos (1974) was designed to measure 9 different dimensions of the classroom (with 10 items per scale) which could be classified into three broad categories: Relationships, Personal development and Maintenance/change (as can be seen in Table 2). This classroom evaluation tool came about independently of the LEI which was developed by Walberg as a result of the Harvard project physics initiative (Walberg & Anderson 1968; Welch & Walberg 1972; Walberg (Ed.) 1979). The LEI had a total of 15 scales (with 7 items on each scale) which covered a range of aspects of the classroom which can be categorised in the same way as the CES (see Table 2).

Both the CES and LEI were developed using the high school classroom as the environment under investigation. Recognising that this may not be directly applicable to a further and higher education environment, Treagust and Fraser (1986) developed the college and university classroom environment inventory (CUCEI). Validation of this tool revised the scales used to only 7 scales (each with 7 items in them) which, as can be seen in Table 2, can be mapped to the same categories as the CES and LEI. Whilst the CUCEI may be appropriate for the classroom, the laboratory represents a specialist environment which means that general classroom tools will not fully represent this learning environment. To study student experience of the laboratory as a learning environment, the scientific laboratory environment inventory (SLEI) was designed.

Table 2: comparison of the scales used in different classroom evaluation tools.

Tool	Context used	Relationship scales	Personal development	Maintenance/change scales
CES	High school	involvement, affiliation, teacher support	task orientation, competition	order and organisation, rule clarity, teacher control, teacher innovation
LEI	High school	cohesiveness, friction, cliqueness, favouritism, apathy, satisfaction	speed, difficulty, competitiveness	democracy, formality, goal direction, disorganisation, diversity, environment
CUCEI	Higher education	Personalisation, Involvement, student cohesiveness, satisfaction	Task orientation	Innovation, individualisation

1.6.1. Scientific Laboratory Environment Inventory (SLEI)

As with the CES, LEI and CUCEI, the SLEI scales can be categorised into personal relationships (social cohesiveness), personal development (Open-endedness and Integration) and maintenance/change (rule clarity and material environment): and in fact, in designing and validating the SLEI it was acknowledged that all of those domains were important for gaining an understanding of the students' experience (Fraser et al. 1992; Fraser & Wilkinson 1993). A total of 5447 students at 53 sites across 269 classes were surveyed using either a class (Fraser et al. 1992) or personal (Fraser & Wilkinson 1993) form of the survey to validate the SLEI: noting that the outcome of the class form was more favourable than the outcome of the personal form. These sites were spread across both universities and high schools in England, Canada, Australia, USA, Israel and Nigeria and were supported by further studies that cross-validated these findings with an additional 1,594 Australian-based senior high school participants from 92 different classes (Fraser & McRobbie 1995; Fraser et al. 1995). In each case, the studies noted the capacity of the SLEI to discriminate between the experiences of students in different classes. This was true of both the school and the university samples: the SLEI was able to discriminate between the 71 university science laboratory classes (spread over 13 sites) that contributed a total of 1720 participants to the study (Fraser et al. 1992). Within this university group, 108 participants from 6 different classes on one site in England took part and in line with the rest of the observations, the SLEI was able to discriminate between these classes. Further testing of a modified version of the SLEI took place in a University in Thailand where all scales were positively correlated to students' attitudes (Santiboon et al. 2012). To date no studies specific to bioscience or comparing the way that two different degree subjects utilise the same physical laboratory space, have been carried out at university level.

As with the LEI and CUCEI, the SLEI has 7 items per scale and uses a 5-point Likert-like scale with answer options of 'Never', 'Seldom', 'Sometimes', 'Often' and 'Very Often'. Importantly, the SLEI uses an *actual* and a *preferred* version of the question. The "*actual*" version is designed for students to be able comment on their experiences whereas the "preferred" version allows them to comment on how they would like that experience to be. As can be seen in Table 3, questions can either be positively worded (as in the social cohesiveness example) or negatively worded (as in the material environment example).

Since it's validation, the SLEI has predominantly been used in a school rather than higher education setting, although as previously noted higher education institutions were instrumental in the validation of this tool. Within schools the SLEI has successfully been used to show that there are differences in the experiences of students in different science classes across a number of different countries; with studies taking place in Singapore, Australia, Israel, Korea and Spain (Wong & Fraser 1995; Henderson et al. 1998; Hofstein et al. 2001a; Fraser & Lee 2009; Membiela & Vidal 2017).

Table 3: example of questions used in the SLEI survey actual form. Example questions shown are those given in (Fraser & Wilkinson, 1993)

	Domain	Description	Example question for the scale
Social cohesiveness	Personal relationships	Interaction between students	"Students in this laboratory class get along well as a group."
Open-endedness	Personal development	Independent exploration	"We know the results that we are supposed to get before we commence a laboratory activity."
Integration	Personal development	Link between theory and practical	"We use the theory from our regular science class sessions during laboratory activities."
Rule clarity	Maintenance/change	Rules within the lab	"There is a recognised way of doing things safely in this laboratory."
Material environment	Maintenance/change	Physical laboratory space	"The laboratory is too crowded when we are doing experiments"

Whilst most studies describe the classrooms as general science, some have specified science disciplines. For example the study by Wong and Fraser (1994), which validated a modified version of the SLEI (renamed as the chemistry laboratory environment inventory), used 1592 10th grade chemistry students as participants: in their subsequent study, they had 1450 Grade 10 chemistry and physics student participants (Wong & Fraser 1996). In the 1994 study, the authors cross-validated their findings against the sample used by Fraser and Wilkinson (1993). Within the Singapore cohort, the SLEI was able to discriminate between preferred outcomes for different streams of students as well as identifying that student's attitude to chemistry was associated with their actual perceived environment; with responses from female students being generally more positive than their male counterparts.

A number of studies have focussed on Biology classes, however these focussed on secondary education, as opposed to higher education. Studies by Fisher, Henderson and Fraser (1997) and Henderson, Fisher and Fraser (2000) focussed on 489 students across 28 biology classes in Tasmania, Australia. The 1997 study highlighted that students tended to prefer a more positive environment than they perceived themselves to have but equally outcomes were linked to strong integration of theory and practice and a degree of open-endedness (independent exploration): conversely a high degree of open-endedness and emphasis on rule clarity were perceived to negatively impact student outcome. In Henderson, Fisher and Fraser (2000) the SLEI data was reported alongside attitudinal surveys (attitudinal surveys will be discussed in more depth below in section 1.6.3). In this study, students' attitudes were shown to correlate with their perception of social cohesiveness, integration of theory and practice, rule clarity and material environment: the more positive these aspects were, the more positive their attitude was towards their laboratory work.

More recent research by Lightburn & Fraser (2007) used the SLEI in conjunction with attitudinal surveys alongside interviews to investigate perceptions of 761 students across 25 biology classes in the USA. In their version of the SLEI, the open-endedness scale was removed with 6 items being included in the remaining scales, which were validated as part of the study. This modified SLEI was able to discriminate between the perceptions of students in different classes. As observed in the studies of Fisher et al. (1997) and Henderson et al. (2000) students' attitudes to their laboratory classes were more positive if they felt that there was a strong link between their practical work and the underlying theory (i.e., scored highly on the integration scale).

Using the SLEI within a high school setting in Israel, there were recorded differences in biology and chemistry students in terms of integration, open-endedness and rule clarity which were theorised to relate to the nature of the curriculum (Hofstein et al. 1996). This results in biology students receiving more inquiry-based laboratories including continuous and intensive projects than chemistry students, which would lend itself to a more positive response to the open-endedness (and possibly also the integration) scale.

1.6.2 Technology-rich outcomes-focussed Laboratory Environment Inventory (TROFLEI)

In more recent years, there has been an awareness that technology is increasingly playing a role in classrooms and laboratories and so there has been further development of the learning environment inventory to be able to capture this. The TROFLEI is an environment inventory tool made up of 10 scales each with 10 items including a scale dedicated to computer use. The survey scales can also be categorised into the same domains as described by Trickett & Moos (1974): see Table 4.

Table 4: distribution of TROFLEI scales within the three domains as defined by Trickett and Moos (1974)

Relationship scales	Personal development	Maintenance/change scales
Social cohesiveness	Investigation	Equity
Teacher support	Task orientation	Differentiation
Involvement	Co-operation	Computer usage
Young adult ethos		

The inclusion of scales such as teacher support and young person ethos clearly indicate that this tool has been specifically designed to function within a school setting. To date, all studies involving the use of the TROFLEI have taken place in schools. The initial validation of the TROFLEI took place in Australia with a pool of 1249 high school students (Aldridge et al. 2004) with the full scales subsequently being made available for use (Aldridge & Fraser 2008). This was followed by further study of the school learning environment in Australia when the same research group tested a further 2317 school pupils across 166 classes (Aldridge & Fraser 2011). The reliability and validity of the TROFLEI has also been tested within 30 high schools in New Zealand (with a total of 1027 participants (Koul et al. 2011). This study reported differences between students' perception of their class environment and how they would prefer it to be, with an added observation that female participants perceived their current classroom more positively than their male counterparts. Whilst Welch et al. (2012) collected data on the gender of its participants, this was not a feature of the analysis. Their paper was the first to publish a cross-cultural validation of the TROFLEI by studying students in grades 9-12: 980 students were surveyed in Turkey; 130 students participated in USA. Analysis of the TROFLEI data showed that the tool was reliable in both contexts, with Cronbach-α (a test for scale reliability) values ranging between 0.778 and 0.939 (see section 2.4.2 for more information on the Cronbach-α test).

1.6.3 Attitude surveys

To be able to effectively address the question of how technology impacts student lab experience, an important insight is to understand if or how their attitude to technology influences this. As with exploration of learning environments, a range of survey tools have developed over the last 40 years.

Perhaps the most influential of the attitude surveys within the scope of this project is the test of science related attitudes (TOSRA) developed by Fraser (1981). The TOSRA is based on the attitudinal aims described by Klopfer (1971) and uses a 5-point Likert-like scale (which ranges from strongly agree to strongly disagree) to test various aspects of students' attitude to science within the school context. These scales are categorised as: social implications of science; normality of scientists; attitude to scientific inquiry; adoption of scientific attitude; enjoyment of science lessons; leisure interest in science and career interest in science. Initial validation used 1337 participants from Australia, spanning 44 classes in years 7-10 (Fraser 1981). The TOSRA handbook also cross-validated the published responses of other studies using this tool with students in Australia or the USA showing good internal consistency and reliability: as indicated by the α coefficients which ranged from 0.62 to 0.92. This suggested that the TOSRA was broadly applicable: not only within Australia but across other countries as well.

More recently, attitude scales have been used alongside an LEI type tool, rather than in isolation, to give a broader picture of students' experiences coupled to their attitudes to science. A summary of studies using these tools can be seen in Table 5.

Table 5: summary of different attitude scales used to investigate student attitudes.

Tools developed	Scales	Author
SLEI and 4 out of the 7 TOSRA scales	social implications of science; normality of scientists; attitude to scientific inquiry; interest in science	(Fraser & Lee 2009)
QOCRA and CLEI (modified TOSRA and SLEI)	attitude to scientific inquiry in chemistry, adoption of scientific attitudes in chemistry, and enjoyment of chemistry lessons and perceptions of chemistry	(Wong & Fraser 1994)
attitudinal and efficacy questionnaire (for use alongside TROFLEI)	student attitude to subject, student attitude to computers and academic efficacy	(Aldridge & Fraser, 2008)

The attitudinal and efficacy questionnaire developed by Aldridge and Fraser (2008) made use of existing tools when creating their scales. Their student attitude to subject scale consisted of a modified version of the enjoyment of science lessons scale found in the TOSRA; the student attitude to computers scale was created by taking 8 of the 30 items in the computer attitude survey (CAS) developed by Loyd and Gressard (1984) to test students' attitude to computers and computer programming; the final aspect (academic efficacy) was adapted the Morgan-Jinks Student Efficacy Scale (Jinks & Morgan 1999) which draws on the idea that students' sense of their own academic competence could impact their perception of their learning environment.

These scales were used in a longitudinal study to monitor how successful a technology rich outcomes-focussed high school learning environment was between 2001 and 2004, using a total participant pool of 1918 students (Aldridge & Fraser 2008; Aldridge & Fraser 2011). These students were split into two learning environments with different teachers. The impact of teachers on student's attitude and motivation were evident, as statistically significant differences were seen in the academic efficacy scale in the two environments. According to the aims of the project, it is important to be able to compare the student laboratory experience and attitude to technology with their digital skills.

1.7 Research project context: Superlab

In 2012, Nottingham Trent University (NTU) opened a large, multidisciplinary technology-rich laboratory in the Rosalind Franklin building that is known as "Superlab" (Kirk et al. 2013). At the start of this project, it was one of only a few "state of the art" laboratory spaces for bioscience in the UK alongside University of Bradford's STEM centre and University of Liverpool's central teaching hub – the latter of which caters for predominantly physics and chemistry students but also those studying environmental science (Hernández-de-Menéndez et al. 2019). The laboratory can hold a maximum of 194 students simultaneously with a floor area of 2441m^2: a further 226m^2 adjoining the lab is a dedicated preparation area (Kirk et al. 2013). Staff have access to a number of computer terminals throughout the laboratory to project material onto the wall-mounted screens (as shown in Figure 3).

The lab itself is classified as a containment level II facility because microbiological agents that can cause mild disease (such as species of Herpes virus) are used by students in their lab practicals. This means that students need to adhere to strict health and safety guidelines when entering and leaving the laboratory. Students leave their possessions locked in lockers outside of the laboratory before entering and then collect their lab equipment (lab coat, safety glasses and earpiece (as described in section 1.7.2) from their designated locker in an antechamber connected to the laboratory, which contains hand washing facilities for use before leaving the laboratory.

The Superlab laboratory space is utilised primarily by students taking undergraduate or postgraduate courses in biosciences, chemistry, or forensic science. Most undergraduate bioscience students will have practical classes in this laboratory space throughout their course to a lesser or greater extent, but all bioscience students entering the university at level 4 (first year undergraduate) will have every first term practical class in this laboratory space. There are a number of features of the laboratory that explain why the laboratory was selected as the research setting for this project.

Figure 3: Images showing the length of main lab area with numerous benches (above) and across the lab (below) to show one of the bays containing fume cupboards (centre right of image) and the cell culture cabinets (to the back and left)

1.7.1 Tablet technology

To work within safety guidelines for a category II containment facility means that the lab is "paperless" – in other words students are not able to bring items into the lab such as lab-books to work with. Students use a technological solution to this problem by accessing files and materials that are needed for the lab via tablet technology (see Figure 4).

Figure 4: Bioscience students at NTU using tablet technology to photograph gel images during a practical class in Superlab (Nottingham Trent University, 2016)

The tablets serve a number of functions, not only allowing access to material (such as protocols and digital media) provided by lecturers via the university's virtual learning environment (VLE) but also access to cloud stored files and provide the opportunity to access the internet to research supporting information.

1.7.2 Using technology to communicate with students.

With a laboratory space capable of running practical classes of 100 or more bioscience students, technological solutions have been applied to ensure that students are able to hear information provided by their academics as well as see resources (be that informative slides, videos or real-time demonstrations) through wall mounted video screens. The lead academic is provided with a headset microphone through which they can speak to the students, who receive this through earpieces as can clearly be seen in Figure 4. The earpieces also provide a way for students to listen to videos independently while they are working if they plug their tablets directly into the earpiece. The advantage from a staff perspective is that with a large class, they repeat the material fewer times and provide better consistency in the student experience (Kirk, et al. 2013). However, this raises concerns over accessibility for students who are deaf or have a hearing impairment who may not be able to use the ear piece effectively, if at all. In these instances, students can make use of subtitles on the videos; can choose where they want to work (e.g., if they are able to lip-read, students may choose a lab bench with good visibility of the lecturer; alternatively, some students may have a British sign language interpreter work alongside them in the laboratory. Similarly, visually impaired students can make use of the accessibility functionality of the tablets to aid their learning and where necessary specialist equipment (e.g., fitting eye piece cameras to microscopes so that images are displayed on the tablet screen rather than having to look down the microscope) may be used to support their laboratory learning.

1.7.3 Advanced technology equipment

With a laboratory as large, and with such varied use, as Superlab there is provision of a range of equipment that the students can use, much of which is computer driven. As the students' progress, they will often take responsibility for the use of this equipment independently. In some cases, this only comes to the forefront when students are undertaking their research project and so are using highly advanced equipment. The combination of the space, equipment and IT infrastructure is thought by staff to provide students with a learning environment that gives them the feel of what it would be like to work in a modern professional laboratory setting (Kirk et al. 2013). It should be noted, however, that over the time scale of the project, increasing numbers of bioscience laboratories have developed their laboratory spaces to use a similar range of technological equipment in their laboratories to the extent that this is now expected; although fewer may adopt a paperless approach that requires students to use tablets. As such the Superlab is increasingly representative of university laboratories used for bioscience students and as such, the findings from this study will be more broadly applicable than in the early stages of the project.

1.7.4 Technology changes within Superlab

It is important to acknowledge that tablet and other education technologies are rapidly changing and those used in the Superlab have not remained static over the duration of the project. Table 6 below shows how these changes have been implemented over the course of the project during the data collection phase.

Table 6: summary of technology changes in the Superlab over the project duration

Academic year	Tablet hardware	Tablet software for recording data	Other technology changes
2014-2015	Samsung Galaxy Tablet 1&2	Android OS; Evernote	HP SFF PC for instruments and teaching
2015-2019	Lenovo ThinkTab 10	Microsoft Office	Lenovo SFF PC for teaching and instruments

1.7.5 Understanding our student cohort.

As with many higher education institutions, the students who enter NTU bioscience courses at level 4 come from a wide range of educational backgrounds including some who are re-entering formal education as mature students after a break in their learning. In addition, bioscience students come from numerous different countries and diverse cultural backgrounds; in many cases, English is not the first language for these international students and the use of technical/scientific language may present an additional barrier in their learning.

As already discussed, practical classes are a challenging environment for learning, with a real risk of cognitive overload. The key theme of this project is to gain a better understanding of the impact that providing the students with a laboratory environment that is both technology rich and technology dependent has on their learning journey. The dependence on technology does, in itself, raise the question of whether the Superlab environment will add to student cognitive load, reducing their capacity to learn in this environment. An important factor in this equation is student familiarity with technology.

1.8 Digital literacy and digital fluency

1.8.1 Digital literacy

Whilst there is little doubt that technology is becoming increasingly pervasive throughout our lives, including learner journeys, at the start of this project there was little literature that evaluated the extent of student "digital literacy" (defined by the joint information systems committee (JISC) as the "capabilities which fit someone for living, learning, and working in a digital society; JISC, 2014).

Prior to the start of this project, the JISC Learners' Experiences of e-Learning project (Beetham 2011; Jisc 2013) which was part of early JISC projects investigating student digital literacy (see Beetham (2014) for details of the broader scope of the project), resulted in the creation of a learner profile (based on data collected from 7 institutions). This tool was made publicly available to institutions wishing to investigate the base digital literacy of their students and considered both the types of technologies that students owned, as well as the frequency with which they undertook a range of activities e.g., using email. During the course of the project, a number of reports were generated by JISC based on the findings of the student digital experience surveys that have been developed since 2014. However, these are generalised findings featuring data from both further and higher education, and not specific to science disciplines (or more specifically bioscience student experience). For example, in 2016, JISC conducted a closed pilot of a survey for evaluating student digital literacy (called the digital experience tracker; Jisc 2016). The digital experience tracker was completed by 10,753 students (that comprised of both further education and higher education students) from 24 institutions. Amongst higher education institutions, the most frequently cited reasons for institutions to participate in the pilot were to obtain a baseline for further comparison, to inform digital infrastructure development and to understand their learner's perspective. This was followed by another pilot (this time an open pilot) that was completed by 22,593 FE and HE learners across 74 institutions (JISC 2017).

Following the pilot studies, the digital experience insight survey was released in subsequent years with uptake in HE shown in Table 7.

Table 7: summary of the numbers of HE participants in the digital experience insight survey

Year	Total number of participants	Total number of HE participants	Number of HE institutions represented	Reference to outcome report
2018	37720	23386	30% (number not stated)	(Jisc 2018)
2019	29531	14525	19	(Jisc 2019)
2020	20575	20575	28	(Jisc 2020)

The relationships between the JISC digital experience survey outcomes and those of the digital history survey will be explored in chapter 3.

1.8.2 Digital frameworks

Reflecting on the JISC description of digital literacy, it is clear that a wide range of skills and competencies could be incorporated under this definition, and so researchers have proposed a number of different frameworks to describe the different aspects of digital literacy. Hobbs (2008) defined digital literacy as having 4 aspects, which they used to create a framework with the following categories: media literacy, information literacy, critical literacy, and media management. Whereas the Joint information systems committee (JISC) initially proposed a framework of 7 categories: ICT literacy; digital scholarship; learning skills; career and identity management; information literacy; media literacy; communication and collaboration (JISC 2014). The JISC framework has subsequently been refined into 6 capabilities by combining information and media literacy (JISC 2018a). At a similar time to the 2014 JISC digital literacies framework, NTU created its own digital framework to support staff in identifying levels and types of digital skills: ranked from enquiring, to upskilling, followed by experienced and finally up to creative level (NTU Digital Practice 2014). This system is a practical measure that allows staff to not only assess their own digital skills and reflect on their continuing professional development, but also enable them to integrate appropriate digital skills (at an appropriate level) into their courses. The NTU digital framework, similarly to the 2014 JISC framework, consisted of 7 areas of practice: communication and collaboration; learning to learn/becoming self-supporting; learning technologies; information literacy; media literacy; information and communications technologies/computer literacy; and digital identity and employability.

As digital technologies continue to develop, it is clear that they have an ever-increasing role in higher education with the most recent developments being in the field of artificial intelligence (AI). There is much discussion about how higher education in the UK should address the emergence of openly accessible platforms such as Chat GPT and Google's Bard, but it is clear that graduate employers already see this as a desirable digital skill (Lacey, Smith 2023). However, this project and the development of the tools used for the research took place prior to the emergence of AI and so this is not the focus of this discussion.

Studies with tertiary education students which were conducted prior to this project, have described participants as adept in using a range of technologies and having honed their skills at extracting information from a range of sources to complete their studies (Lea, Jones 2011). The researchers in this study acknowledged that the task of integrating both of these aspects into their learning was a more complex task than that experienced by previous generations that did not have access to these technologies. Not only this but emerging from the data was the concept of the changing status of knowledge, suggesting that academic institutions could have a greater impact on the approaches and practices that students use to attain it. With this in mind, it was timely that the production of a bespoke framework was created for NTU staff to use to prompt academics to consider reviewing how digital skills are used and developed in their courses and also how this prepares graduates for the world of work. Whilst the examples of appropriate digital skills may evolve over time (e.g., to include the application of AI), the framework itself retains validity as a tool for evaluating and mapping skill progression.

A significant feature in the rationale for studying the digital skills needed by bioscience graduates was a report commissioned by the UK government that highlighted that shortages in key digital skills were a risk factor with the potential to restrict business growth and innovation as well as social mobility (Department for Culture 2016). This report came after a review identified 16 characteristics needed by 21st century students which they categorised into three groups as shown below (World Economic Forum 2015):

Foundation literacies (How students apply core skills to everyday tasks). These include literacy (scientific, ICT and financial literacy); numeracy; and cultural and civic literacy.

Competencies (How students approach complex challenges). These covered: Critical thinking/ problem-solving; creativity; and communication and collaboration.

Character qualities (How students approach their changing environment). These are curiosity; persistence/grit; adaptability; leadership; and social and cultural awareness.

Additionally, their review of a range of digital skills frameworks across a number of sectors categorised digital literacy into three broad levels:

"Empowering individuals": these are the basic skills needed for everyday life and applicable to everyone. This includes skills such as carrying out internet searches and cyber security.

"Upskilling for the Digital Economy": these are the skills needed by the general workforce which build on the basic skills in everyday life with a greater focus on information processing.

"Digital skills for ICT professions": within this bracket are digital creators such as those who develop new technologies, products and services.

Whilst the NTU digital framework does not directly translate to the levels described in the white paper, there are commonalities. Enquiry level skills across all the areas of practice in the NTU digital framework would be consistent with the "empowering individuals" category since they relate to activities such as accessing email, being able to search for information, use word processing packages and being aware of the need to use passwords for security. Similarly, the creative level skills would be in keeping with the digital skills for ICT professions description. The difficulty is in mapping where the upskilling and experienced practice levels fit. This may be dependent on the sector and job role. In addition, the NTU framework is specifically tailored to a learning environment rather than the world of work in general (as in the digital skills report) and so some of the areas of practice would potentially be applicable only in specific circumstances: for example, the "learning to learn" and "learning technologies" areas of practice are likely to only be of interest to staff in the education sector and their students as they relate to activities such as creating assessments, as opposed to facilitating students to become life-long learners.

The survey undertaken in the digital skills report indicates that in all job roles, the most frequent reason for being digitally under-skilled is because it is a new job role or training is not complete (Department for Culture 2016). This suggests that employees are universally lacking the digital skills for starting new job roles and this insufficiency is addressed through the employer. Stakeholders who participated in the research perceived that the main skills gaps were in higher level skills where too few individuals were provided with the relevant training opportunities in the education system given the pace of change in the technology. Whilst situated outside of the data collection period of this project, as recently as 2021, the Department for digital, culture, media and sport has invested in pilot projects to enhance data skills at 7 universities throughout the UK, clearly demonstrating the need to upskill graduates in preparation for employment remains (Department for Digital culture and sport 2022).

From a project perspective it was important, therefore, to understand not only the student experience and their range of digital skills but also employer expectations of our graduates.

1.8.3 Benchmark statements and graduate digital skill outcomes

To give further context to the design and data generated by the digital history survey (DHS; sections 2.4 and 3.1) and employer survey (section 2.6 and chapter 4) described in chapters 2-4, it is important to acknowledge that these tools factored in the digital requirements of existing benchmark criteria that needed to be met for Bioscience degrees in the UK.

At the time when the tools were designed, the 2015 benchmark statements were the most recent version available (QAA 2015). In the introductory statements, it was acknowledged that students were learning in a rapidly changing technological environment, however there was only one instance of specific mention of digital skills. This was in section 4.4 (iii) which states that graduates in bioscience should be able to "*use the internet and other electronic sources critically as a means of communication and a source of information*."

Other than this, the statements provided were generic and could be inferred to use technology. For example, they mention the need to be able to write reports or essays but do not stipulate how to achieve this: theoretically this could be a handwritten report, but it seems unlikely that this would be the case.

Since then, there has been additional guidance in the form of revision of the benchmark statements (QAA 2019). In addition, since NTU bioscience degrees have now been accredited to by the Royal Society of Biology, the standards in their accreditation handbook (which are underpinned by the benchmark statements) would also apply to subsequent discussion of digital skills in NTU bioscience degrees (Royal Society of Biology 2019).

The 2019 benchmark statements reflect on the need for bioscience programmes to address the needs of employers and encourages the involvement of local businesses to make use of specialist knowledge and to ensure the relevance of their programmes to employers. There is also more specific mention of digital skills as can be seen in Table 8.

This table shows how the requirements laid out in the benchmark statements can be mapped to the NTU digital framework and an example of how this is applied in practice within bioscience programmes at NTU.

Table 8: mapping of digital skills in bioscience benchmark statements to NTU digital framework with practice examples.

Digital skill	Section in QAA report (2019)	Mapping to NTU digital framework (2014)	Example in NTU practice
use the internet and other electronic sources to: communicate with others; Source information	4.4 (iii). Communication, presentation and information technology skills	Media literacy; Information technology; computer literacy	Presentation of research via word processed reports and as oral presentations
peer and collaborative learning, including the use of social media	6.5: Teaching learning and assessment	Collaboration and communication; Media literacy	Use of SCALE-UP sessions (Beichner, Saul n.d.) to provide second years with co-created revision resources that they can share
use of electronic multimedia, videos, recordings and broadcasts	6.5: Teaching learning and assessment	Media literacy	Use of lecture capture and embedding of technical video resources in the VLE (see chapter 3)
Ability to search for information and use learning resources in an electronic format	6.6: Teaching learning and assessment	Information technology; computer literacy	Level 5 word processed laboratory reports that require discussion and contextualisation of findings from self-directed research
Assessment using online activities	6.12: Teaching learning and assessment	Information technology; computer literacy	Bespoke biochemistry kinetics smart worksheet (created by Learning Science Ltd, Bristol)
Computer based examinations	6.12: Teaching learning and assessment	Information technology; computer literacy	Online open book exams have been in widespread use since 2019

1.8.4 Digital fluency

The concept of digital fluency has many similarities with digital literacy but primarily focusses on describing competencies in terms of working in an online environment. Digital fluency proposes net savviness, critical evaluative techniques, and diversity as the key competencies (Miller, Bartlett 2012). Net savviness involves understanding how the internet works e.g., generating a search result or generating personas; critical evaluative techniques is centred on the ability to identify the trustworthiness of information and diversity a measure the breadth of information consumption and ability to identify its wider context.

The definition of digital fluency focusses primarily on the online environment and is not as inclusive of aspects of digital tools that are not online tools (such as using laboratory equipment) unlike the frameworks around digital literacy. For this reason, digital literacy rather than digital fluency will be used to support our understanding of students' digital experiences.

1.8.5 Digital inequality

Whilst the discussion so far has highlighted the relevance and importance of digital skills in learning and life in general, it is important to recognise that there is digital inequality, which may play a role in further entrenching the divide between socio-economic groups (Katz et al. 2017). Katz's study indicated that those children (aged 6-13) in low-income households have constrained access to digital devices or the internet, which may limit the opportunities they have for social or emotional development (via peer and teacher interaction online) or to make full use of learning resources that are more freely available to their more privileged peers. This is compounded by the lack of opportunity for these children to explore and find out about information they are interested in independently: 35% of children in low-income households had the opportunity to do this compared to

52% in other groups. This is thought to be particularly problematic as exploration is important in building children's self-confidence and motivation for learning. The recent pandemic has shown in sharp relief the breadth of this issue in the UK, where access to digital technologies was needed for remote education during periods of school closure. An example of scale of digital inequality can be seen in a contemporary report of home education during the first UK lockdown (March-May 2020) which showed that children from low-income families typically spent 30% less time on home learning than higher income families (Andrew et al. 2020).

One of the considerations in a project aimed at evaluating the impact of technology on student learning is therefore to acknowledge that students entering the course will have had, and may continue to have, a range of experience in accessing and using digital technologies. For those students who have had limited access to these types of resource, a technology-rich laboratory environment may present a greater challenge than to others in their peer group, with a correspondingly greater potential risk of cognitive overload and loss of learning gains. Currently there are no minimum digital skill requirements for students entering the university on bioscience courses and there are no systems in place at the university to assess student digital skills (except through the Digital history survey described in chapters 2 and 3). As a result, whether students are particularly at risk of cognitive overload due to poor digital literacy was unknown at the start of the project.

1.9 The impact of the COVID-19 pandemic on laboratory education

Whilst the data collected during this project precedes the beginning of the COVID-19 pandemic, it is important to view its findings through this lens and reflect on the impact that this has had on laboratory education. The pandemic placed the UK higher education sector into a position where, at times, it was not possible for students to access laboratories and even when it was, this was restricted due to the need for social distancing. This required organisations, including Nottingham Trent University, to rationalise its' approach to laboratory classes across all stages of all degree programmes: balancing the need to meet QAA benchmark statements and requirements of degree accreditation organisations such as the Royal society of Biology and Institute of Biomedical Sciences, for all student cohorts. A systematic review of literature highlighted that five alternative strategies for STEM practical education had emerged during the pandemic and noted that these could also be incorporated into return-to-campus teaching (Tsakeni, 2022). These included: use of home lab kits; use of VR or AR environments; use of remote laboratories; and in some cases, use of robotics.

When considering the impact of the pandemic on higher education, it is also important to remember that the cohorts of students during, and for a number of years after, the pandemic will have received a disrupted education in secondary and further education and as a result will likely have lower skill and confidence in the laboratory than in previous years (Francis, McClure and Willmott, 2021).

1.9.1 Lab skills in a home environment

During the pandemic, individual organisations designed initiatives to support laboratory skill development when students were unable to access labs: for example, the Bioskills at home kit which NTU academics designed to give students an opportunity to undertake experiments remotely and practice core skills such as pipetting (Rayment et al. 2022). This approach was not unique within the UK but was specifically aimed at targeting the skills gap and ensuring students could gain confidence in skills that were fundamental to their course. Academics at Hull university also created experiments that students could undertake at home: these were designed to simulate a spectrophotometry methodology using a mobile phone (Hubbard *et al*., 2022). In both scenarios the ability to carry out experiments and practice skills outside of the laboratory are ones that transcend the pandemic and have the potential to create a more inclusive learning environment given the range of academic experiences that students coming to higher education may have. These approaches were not used in isolation as some organisations combined the use of home lab kits with virtual simulations to support student lab learning (Nischal, Zulema Cabail, & Poon, 2022). Simultaneously, the use of video content (either as technical videos to support laboratory learning – see chapter 5 (and Rayment et al., 2022a), or as a way to support development of subject knowledge increased (this thesis alone reports a three to four-fold increase in technical video use). In the latter case, the embedding of video resources for blended learning and inclusion of active learning components in immunology topics alongside this was considered to be an important factor in ensuring the videos fulfilled their potential as a way to bridge the gap between learning environments as well as theory and practice, giving students the ability to personalise their learning (Smith & Francis, 2022). The authors later showcased this approach by development of carefully scaffolded branched video resources which were a more engaging approach than standard linear video creation (Lacey, Francis and Smith, 2024). In the former case, comparison of providing biomedical science students with live instructor-led demonstrations or video demonstrations on lab techniques showed equal benefit in allowing them to subsequently complete a practical test (plasmid DNA extraction); which in each case was more beneficial to student outcomes than not providing these resources (Heng et al., 2022). This highlighted that resources created for remote working when lab access was restricted, impacted student performance when restrictions were lifted and have the potential to continue to benefit future student cohorts through continued use of video resources.

At the same time as individual institutions were formulating their strategies to respond to the learning environment imposed by the pandemic which required a substantive, and during lockdown periods a complete, shift to learning in an online environment collaborative groups such as the DryLab network were created. These networks provided academics across the sector with an opportunity to share resources and strategies for dry laboratory approaches, including those that would provide an alternative for capstone projects (Campbell et al. 2020; Stafford et al., 2020; Cramman et al. 2021a). These networks were able to showcase how Labster and LearnScience virtual laboratories could be used to support student understanding of techniques and experiments; as well as individual academics presenting their own resources and dry lab alternatives. Resources from this network are hosted via the Lecturemotely website (Rushworth et al. 2021) meaning that these remain freely available despite the return to on-campus activities. The presentations delivered by academics at DryLab network meetings spanned a wide range of activities in line with those categories described by (Tsakeni, 2022). Not only this but importantly, the networks empowered academics to be able to affect change within their own practice (building their confidence in being able to apply a broader range of skills) and also potentially across their institution (Cramman et al., 2021). This aspect was especially important as prior to the pandemic, resistance to use of tools such as virtual simulations had previously been observed amongst some educators based on concerns about their efficacy, but was overcome to a large extent by the need to change resulting from the pandemic (Choate et al., 2021).

1.9.2 Changes to laboratory provision

Discussions of the lasting impact of the pandemic are ongoing, however there is an increasing body of literature that supports a shift in how practical education is supported to more widely incorporate the use of videos and simulations, as well as the more recently developed augmented and virtual reality (Wilkinson, Nibbs and Francis, 2021). A recent study used a mixed methods approach to highlight that student perception of a blended approach to learning was broadly positive with aspects such as flexibility for learners being particularly noteworthy, without negative impacting learning outcomes and student attainment (Tahir et al., 2022). Having said this, a study carried out at the University of Wisconsin Madison described how comparison of survey data from before, during and after pandemic teaching showed an increased appreciation (through the level of engagement and practice of experiments) when returning to on campus classes than prior to the pandemic (de los Santos et al., 2023). Although there were differences in these areas, student perception of their ability to analyse present and discuss data, and critical thinking skills were unaffected. These observations aligned well with a study at Taylor's University of Malaysia which described the integration of virtual laboratory simulations across different cohorts and demonstrated that these enhanced student confidence in practical skills and gave real world context to their studies (Yap et al., 2021).

In practice, this means that students will experience an approach to laboratory education that integrates a wider variety of mediums and skills than prior to the pandemic. An example of this can be seen in the study by Li et al. (2023) which shows curriculum development to include both a wet and dry lab component to the generation and study of a transgenic mouse model.

The discussion in chapter 5 (and Rayment *et al.*, 2022a) highlights that prior to the pandemic, bioscience modules typically had fewer pre-lab activities than in chemistry modules, and so it would be interesting to revisit this post- pandemic to explore how this has changed. Further, chapter 6 (Rayment *et al.*, 2023) highlight the important role that pre-and post-laboratory activities can have in student lab experience and understanding of their laboratory classes: a factor that is arguably more of even greater importance to pandemic affected cohorts who have had a more limited exposure to practical skills than previous cohorts.

In addition to the evidence seen in biosciences, broader discussion of the changes brought about to the education of students in higher education has highlighted that the pandemic has brought about a significant shift in their student model. A recent paper described this as moving from a “factory model” where the approach assumes that “one size fits all”, to a more personalised approach to learning that empowers students and focusses on application of knowledge to explore real world scenarios (Conn *et al*., 2021). Such a philosophy is typified by the strategic direction of Nottingham Trent University whose goals, presented as “University, Reimagined”, describe creating opportunity for students to personalise their learning journey as a core value of the institution (Nottingham Trent University, 2021). In a similar way to the discussion earlier in this section, Conn et al. (2021) recognises the increasingly important role that technology plays in this approach to education where not only job opportunities within their sector (health care) utilise a broad range of technological tools and interfaces but also that this can be used to personalise students learning journey. Taken together, the pandemic could be viewed as a catalyst for change, increasing the rate at which HE institutions’ move in the direction of personalised learning and diversification of approaches to laboratory education.

1.9.3 Capstone projects

One area of the bioscience undergraduate practical experience that merits specific discussion is the capstone project. Traditionally, the capstone project completed by NQF level 6 students was most likely to be undertaken within a practical environment. Both within and beyond the drylabs network, additional resources and support in the form of “how to” guides and database of open access datasets have supported upskilling of academics in this area of capstone project delivery: which could be considered challenging for those who had previously provided wet lab projects (Jones, Lewis & Payne, 2023). A recent pilot study from Ulster university demonstrated that whilst students’ perception and experience of dry lab projects varied, students identified having developed employer relevant skills such as critical thinking and analytical skills (McKenna, 2023). However, students in this study described concerns about a lack of opportunity to develop practical skills, which they considered desirable. Whilst this may, at some level, stem from their prior expectation about what a project is, the pandemic has provided an opportunity for both staff and students to reflect on the purpose of a capstone project and to evaluate how this can be achieved in a variety of ways rather than just the more traditional lab-based project.

Whilst the idea of dry laboratories is not new to the pandemic (see review by Lewis (2014), the availability of openly accessible databases and molecular modelling tools has made bioinformatics and "big data" data analysis type projects more widely accessible. Commentary from the Open university highlighted that during the pandemic, students on their programmes successfully moved to more data-driven projects without their achievements being negatively impacted (Gauci et al., 2022). In addition, a recently published study highlighted that 87.9% bioscience students at the university of Western Ontario had dry projects in the academic year 2020-21 compared to 16.4% 5 years previously, although their study found that students were overall less satisfied with their experience (Chaplin, Kohalmi and Simon, 2024).

Whilst the literature produced based on projects undertaken during the pandemic broadly demonstrates that staff successfully adapted to the rapidly shifting academic landscape, the resulting student experience appears to have been less satisfying. When evaluating why this could be, there are a few questions that should be considered.

- In the study by Chaplin, Kohalmi and Simon (2024) the areas which were consistently least positive centred around areas such as communication, and a feeling of "disconnect" with others on their course. In both cases, these experiences led to feelings of isolation and a lack of support. The question is then, to what extent these reflected students feelings during the pandemic in general and to what extent they specifically related to the project they were doing.

- Another question is whether providing a variety of different project types fulfils the expectations that staff and students have of this significant part of an undergraduates' course. Even before the pandemic, surveys of staff and students across 16 universities in the UK showed a misalignment in expectations of the project with staff considering them as a means for students to gain research experience and skills and build competency in skills looked for by graduate employers. By comparison, the student's focus was on building understanding and increasing their knowledge in a particular field (Lewis et al., 2017).

If students account for the attributes that they are looking to develop for their future career when choosing their project, then providing a variety of project formats will likely increase student satisfaction since graduate roles vary widely (see Blackford et al., 2011) and only a small number of students actually continue working in the laboratory. This perspective has been reinforced by observation at the University of Leeds which highlights that up to a third of students would opt for non-traditional capstone projects (Lewis, 2020). Examples of these types of projects includes virtual laboratory or fieldwork studies; bioinformatics; grant proposals; systemic reviews and meta-analysis; technical or commercial reports; education-based projects that make use of surveys and focus groups; and making resources for student use, or to engage the public (Lewis 2020a).

1.10 Research Paradigm

In disciplines such as bioscience, where practical classes form an integral part of student learning, it is clear that their higher education courses fit within the constructivist paradigm. This framework as originally proposed by Piaget (1964) tenets that individuals gain or construct new knowledge and meaning for themselves as an active process. This new knowledge is integrated into their existing knowledge and may be evaluated and re-evaluated in the face of new knowledge being added; the inference being that an individual's experience will be unique because it is constructed from their experience over time. The published work in meaningful learning by Novak (1980) and Ausubel (1963) as described in section 1.1 are both in keeping with this constructivism framework.

Within constructivist theory there are a number of different types of proposed constructivism: these are described as cognitive, social, radical, critical and contextual constructivism. In the context of this project, the aspects of the constructivist framework that most closely aligns with the approach taken are cognitive (as proposed by Piaget) and social constructivist theory. Social constructivism, founded on Vygotsky's writings, differs from cognitive constructivism by developing the idea that construction of an individual's knowledge can also be influenced by peer and societal influences (Vygotsky 1986). This theory acknowledges the "more knowledgeable other" (which in a learning setting is most often the instructor/academic but can also be a more knowledgeable peer) as influential in moving a learner from the position of attempting to achieve a problem-solving task independently, to being able to successfully complete it: a phenomenon known as the zone of proximal development (ZPD). Such an idea has given rise to the concept of scaffolding (the provision of activities by an educator or more knowledgeable peer to support a learner through the ZPD) that is a common method applied in teaching practice (Wood et al. 1976).

The increasing role of technology in educational settings has given rise to the argument that connectivism, which also has its roots in constructivism, may be better aligned with current practice. Like constructivism, this paradigm is centred on construction of the individual's own knowledge but acknowledges the potential of the outside influence that enables individuals to construct new knowledge for themselves to be technological, rather than just being a "significant other person" as described by Vygotsky (Siemens 2005; Siemens 2017). The recent COVID-19 pandemic has emphasised just how integrated technology is to all stages of student learning. Further, it describes the ability to relate concepts to one another as a key skill (as in Novak's model of meaningful learning) but describes how an individual can utilise a network of connections which can include other people, and appliances to do this.

In this respect, a technology-rich laboratory, such as the Superlab, which provides an environment where students can make use of social connections, academic support, and non-human appliances (such as tablets) to facilitate construction of their own knowledge may be more accurately described as being aligned with the connectivist philosophy.

This research seeks to understand the role of technology in the student lab learning experience and so be better able to comment on whether the Superlab provides a social constructivist or connectivist framework for learning as well as reflecting on the impact that the pandemic has had on this argument.

1.11 Approach to research design

The research methods and case studies described in this project include a range of investigative techniques that generate both quantitative and qualitative data. Taking a mixed methods approach allows for the integration of different types of data, enhancing our understanding at both a cohort level (for example using survey tools where responses are given on Likert-like scales) as well as qualitative data (such as interviews and focus groups) which expand on individual student experiences. In more recent years, the mixed methods approach has become more widely used, with literature extending beyond individual research papers to the creation of handbooks such as those by Teddlie and

Tashakkori (2011) which supports researchers in development of their research programs. As a whole, the project takes two approaches to mixed methods.

- As can be seen in chapter 5, a sequential explanatory design (Creswell et al. 2003) has been adopted where initial data collection was quantitative with qualitative methods being used after this initial phase to gain more in depth understanding.
- When taking an overview of the project, mixed methods have been applied to address specific aims. For example, the Student Laboratory Environment Inventory (SLEI) described in chapters 2 & 3 is a survey-based tool (quantitative methodology) and the think-aloud protocol with supplementary semi-structured interviews (a qualitative approach described in chapter 6) are both used to investigate the second aim of the project but do so independently of each other (see Figure 5).

When considering the research approach taken by the researcher to encapsulate the project research aims and objectives, the most appropriate choice was phenomenographic. This approach focusses on investigating the differences in individual's perception of the world by trying to describe all the different ways that they experience a shared phenomenon (rather than trying to describe the phenomenon itself) (Bodner, Orgill 2007; Marton 1986). In the context of this project, this enables consideration of questions such as "what are students' experiences of Superlab" as opposed to trying to address "what is Superlab?"

Whilst this project seeks to address the impact of technology on the experiences of bioscience students, Jennifer Evans is similarly investigating the impact of Superlab but amongst the chemistry and forensic science undergraduate cohorts. Where cited, tools have been developed collaboratively with the intention of cross-discipline comparison.

All aspects of this project involving participants have been approved by the NTU School of Science and Technology non-invasive ethics committee and meet the ethical guidelines indicated by BERA (British Educational Research Association, 2011).

1.12 Project Aims.

Whilst the JISC surveys give a sector overview (bearing in mind the limited participation in the early phases of the survey development), there is little literature that describes the experiences of a student cohorts' attitude and comfort with technology in different learning environments/institutions, or how they use the tools available to them to aid their learning. The intent of this project is to investigate these aspects of the student experience within our context and, where relevant, how it specifically applies to the Superlab environment. Figure 5 summarises how the studies described in this thesis address the research aims described below.

1.12.1 Digital literacy

As described in section 1.8, although we can make assumptions that students entering tertiary education are familiar with using a range of different technologies, it is important to understand the experiences of the students entering Superlab to be able to evaluate the impact that technology has on their learning experience. So, the first aim of this project is to investigate the digital literacy of bioscience students, whether this impacts their laboratory experience, and how it fits with employer expectation of bioscience graduates. Given the observations that students were expected to use technology even more extensively during the pandemic, this aim is particularly pertinent to consider in the current academic climate.

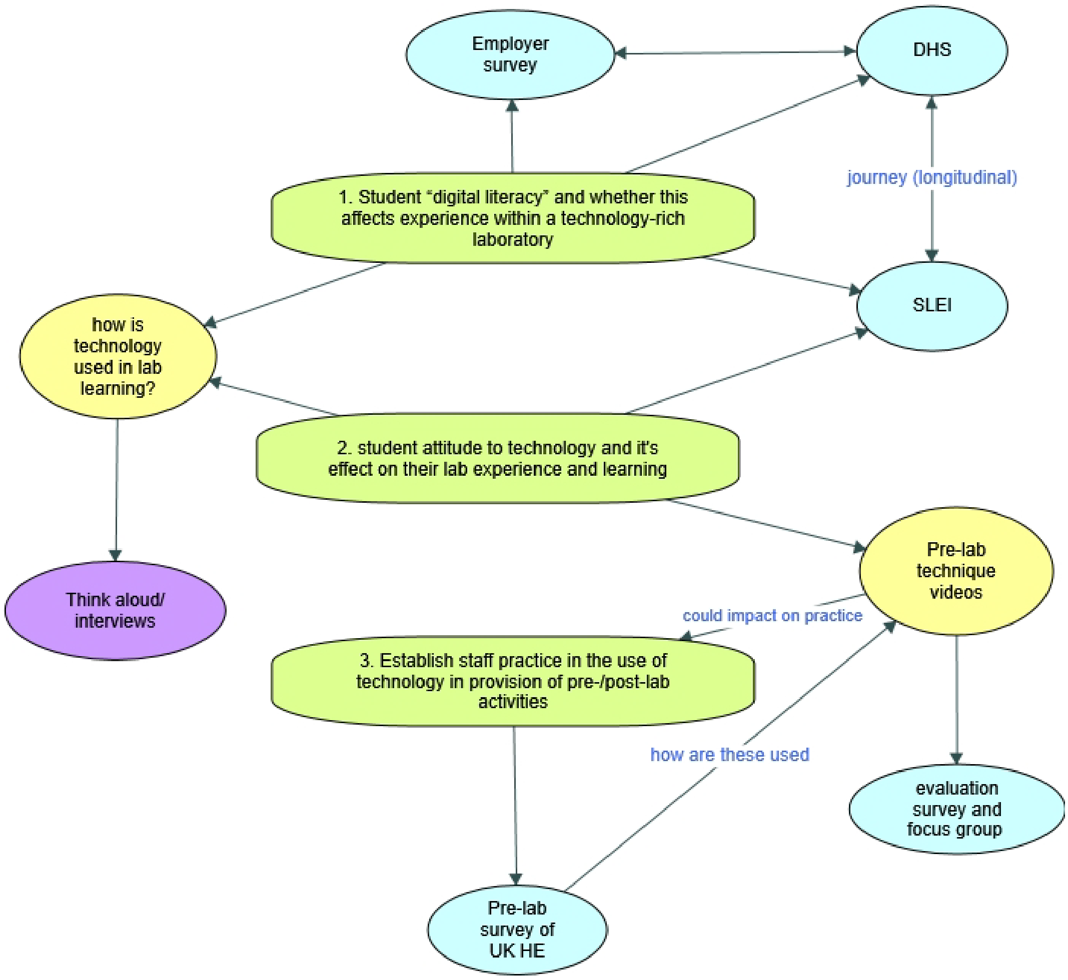


Figure 5: A map showing how the aims for this project link to the studies that have been undertaken. Green is used to show the aims; yellow is used to describe a key aspect that is then linked to a method of investigation (shown in blue or purple). Blue is used for primarily quantitative studies, purple for qualitative studies.

1.12.2: Student attitude to technology

As discussed in section 1.1, the emotional/motivational aspect is an important consideration for meaningful learning and whilst it is broadly presumed that students will have a positive attitude towards technology, the project aims to specifically investigate this in respect of practical work, alongside evaluating whether this impacts their lab experience and learning (in Superlab). Initially this involved the validation and use of a modified version of Fraser's SLEI survey tool, before moving on to qualitative methods (a concurrent think-aloud method, supplemented with semi-structured interviews).

1.12.3: Pre- and Post-laboratory scaffolding in biosciences.

As described in section 1.2, reducing cognitive load could have potential benefits in terms of enhancing lab learning. By familiarising students with aspects of the practical class prior to the session itself, cognitive theory would hold that they would form memories of this and when subsequently encountering it in the lab, would be able to focus on the important aspects of the task through the action of their perception filter.

Whilst a systematic review of pre-laboratory scaffolding in chemistry departments has been undertaken (Carnduff and Reid 2003), there is no equivalent for bioscience undergraduate departments in the UK. With this in mind, the final aim of this project is to establish staff practice in the provision of pre- and post- lab activities and whether technology has a role in this. As highlighted in section 1.9, this is a particularly important discussion point since the COVID-19 pandemic has caused a re-imagining of laboratory provision and support.

1.13 Acknowledgement of the role of the researcher in the research

When designing tools for assessment of digital literacy and influence of technology on lab experience, it has been necessary to acknowledge the position of the researcher and the influence that this may have had. Whilst undertaking the project I have been employed by Nottingham Trent University in a teaching role that has meant that I have both taught and assessed students on the biology courses particularly at levels 4 and 6. As a result of this it has been necessary to consider steps to mitigate the potential for students to be influenced by the position of the researcher. The key issues are shown below.

- **Assessment points**: Across all the studies that form part of this project, the timing of recruitment and study elements were conducted to ensure they did not overlap with periods when I was actively assessing these cohorts of students.
- **Recruitment**: For the student survey-based studies (DHS and modified SLEI) these invitations were sent out through Surveymonkey links so that there was not a direct link to the researcher. Recruitment for the think-aloud/interview-based studies were done in person through taught sessions, however the think-aloud/interview studies recruited second year students, who I generally am not involved in teaching or assessing.
- **Response Bias**: It is important to acknowledge the possibility that participants would feel that they should answer questions in a specific way (the way that they perceived the instructor wanted them to answer). An example of how this was dealt with, can be seen in the video case study (chapter 5) where the focus group was led by a colleague who was familiar with the project but not known to the students (Jennifer Evans) to reduce this risk.

Chapter 2: Survey tool method development.

This chapter describes the development of 3 surveys to investigate Aims 1 and 2 as shown in Figure 5. Data generated by these tools will be described in chapter 3.

The survey tools described in this chapter are:

- The **digital history survey (DHS)**: designed to establish student digital literacy, digital experiences and preferences (linked to Aim 1). This was developed with inspiration from the Jisc "Getting to know your learners survey" (Beetham 2011). The aim of this survey was to investigate the availability and use of technology by first and final year students (including aspects of their digital literacy).
- A modified version of the SLEI (referred to as the **modified -SLEI** throughout): this tool is designed to evaluate student laboratory experience and preferences including technology use (linked to Aim 2).To do this, the modified-SLEI was developed by combining questions from Fraser's SLEI (Fraser et al. 1992), the TROFLEI (Aldridge & Fraser 2008) and attitude to technology scales (Aldridge & Fraser 2011).
- **Employer survey**: designed to investigate the expectation of graduate digital skills (linked to Aim 1).

2.1 Participant Terminology

For the purposes of the surveys described in this chapter student participants are described in one of two ways. First year students are described as new students: students completing a survey as a final year student are described as returning students. It should be noted that during the first two iterations of the DHS and modified SLEI (2014-15 and 2015-6), data was collected from other student cohorts (e.g. second year students) as the original intention was to compare across all year groups. However poor uptake in the second-year cohorts resulted in the decision to cease collecting data for year 2 students and prioritise first and final year students. Where possible only final year data will be presented for returning students to ensure consistency throughout, however if it is not possible to remove data from non-final year returning students this will be clearly stated.

2.2 Data collection

As described in section 1.12.2, to be able to address whether student digital literacy (using the DHS) impacts on student lab experience (using the modified-SLEI) it was necessary to set up a system by which participant responses in different surveys could be identified as being from the same individual whilst maintaining their anonymity. This was achieved by setting up participant address lists that sent participants an individual participant identifier in the recruitment email.

All iterations of the DHS and modified-SLEI were hosted in Surveymonkey (Momentive PLC, California, USA) as it facilitated this type of recruitment. To create an address list for Surveymonkey, a spreadsheet of email addresses for actively enrolled new first year and final year students was created for bioscience, chemistry, and forensics science students: these were then assigned an 8-digit participant number. Students invited to participate in the DHS retained the same participant number in the modified-SLEI (to be described in section 2.5) of the same year. This ensured that individual survey responses could be correlated across survey tools. Survey participants could also be tracked across different academic years, as participants retained their participant identifier for both first year and final year surveys. By doing this, participant responses could be compared longitudinally.

In academic years 2015-6 and 2016-7, the opportunity became available to recruit new students from other course areas within the School of Science and Technology at NTU to participate in the DHS: these students were not assigned participant numbers in their recruitment emails as they were not participating in any other DHS or SLEI surveys. These surveys gave an opportunity to compare the digital literacy of new bioscience students with those in other STEM disciplines.

For all DHS and modified-SLEI surveys, students were emailed with an invitation to participate as described above. In 2014-15, DHS survey responses were also collected on paper copies that were completed during personal tutorials and then inputted online by the researcher. In all subsequent years, participants were provided with an opportunity to complete this survey online as part of their induction activities.

2.3 Ethical considerations

The digital history survey, modified-SLEI and Employer survey were independently subjected to scrutiny and approved by the SST non-invasive ethics committee. Where amendments were made following initial approvals, the study was returned to the ethics committee for approval of amendments. Use of the research tool did not commence until ethical approval was in place.

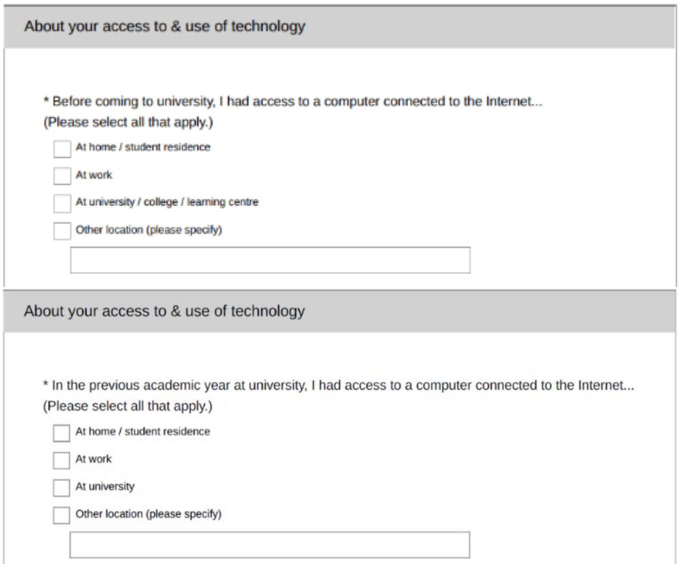
2.4 Digital history survey

2.4.1 Initial survey design

The initial DHS survey development was carried out by Jennifer Evans prior to this researcher joining the project. It was based on two survey tools: an internal survey developed by Jane Harper (NTU) to evaluate the Superlab when it first opened, and the JISC Learner profile survey (Beetham 2011; JISC 2013).

A copy of the Digital history survey as it would have been seen by a new student in the 2017-18 cohort can be seen in Appendix 1. It should be noted that this appendix is based on a PDF version of the survey and so does not show the conditional formatting available in the online platform that hosted the survey. The conditional formatting meant that if students selected bioscience as their course area, they would then only be given the list of bioscience course options to choose from rather than all of those listed in the appendix. Similarly, only students who selected yes to the question about disability would be directed to give more specific details: if selecting "no" then participants were directed to the next question.

Two versions of the survey were created: one for new students and one for returning students. It was necessary to create separate versions of the questions to ensure that the context of the question made sense for each group. An example is shown in Figure 6. The difference in the surveys relates to the way that the previous year's activities are referred to. So, for first years that activity will have occurred prior to starting university, whereas for returning students, it will have been in the previous academic year.


About your access to & use of technology

* Before coming to university, I had access to a computer connected to the Internet...
(Please select all that apply.)

- At home / student residence
- At work
- At university / college / learning centre
- Other location (please specify)

About your access to & use of technology

* In the previous academic year at university, I had access to a computer connected to the Internet...
(Please select all that apply.)

- At home / student residence
- At work
- At university
- Other location (please specify)

Figure 6: comparison of wording for questions in the DHS as constructed for new (top panel) and returning students (lower panel).

This survey was first used with students in Term 1 of academic year 2014-5 and every subsequent year, ending with the 2017-8 cohort.

2.4.2 Further development of the DHS survey

Starting from the 2016-7 version of the survey, additional questions were included in the survey for both new and returning students. These questions (shown on pages 22-23 of the survey in appendix 1) were designed to better understand platforms that students would prefer to use to communicate with members of staff.

The rationale for this was an awareness that communication with students can extend beyond traditional routes such as email, into social media spaces. These spaces can be professional networking sites such as LinkedIn; or more social spaces such as Twitter or Facebook which can be appropriate for professional use.

In addition to this, starting in the 2016-7 version of the survey, the format of the question on page 18 of appendix 1 that asked about the activities that participants undertook in their personal and social was amended to a frequency question in line with the question on pages 20 of appendix 1 that asked how often participants performed specific activities as part of their course. This question previously only asked participants to select those activities that they used. The purpose of this change was to extend the level of detail provided by the answers.

2.4.3 Access to technology analysis and outcomes

Survey questions from pages 13 of appendix 1 onwards were designed to gain insight into what types of technologies students had access to and their use of technology/ways of working with technology. Descriptive analysis was carried out on questions that were not linked to digital literacy scoring, with comparison across the different years of the survey. The process and analysis of digital literacy scoring will be discussed in 2.4.4.

For surveys containing the questions on pages 22-23 (surveys in 2016 onwards) which focused on use of social media, responses were evaluated in the same way as described above for other survey questions which did not contribute to digital literacy scoring.

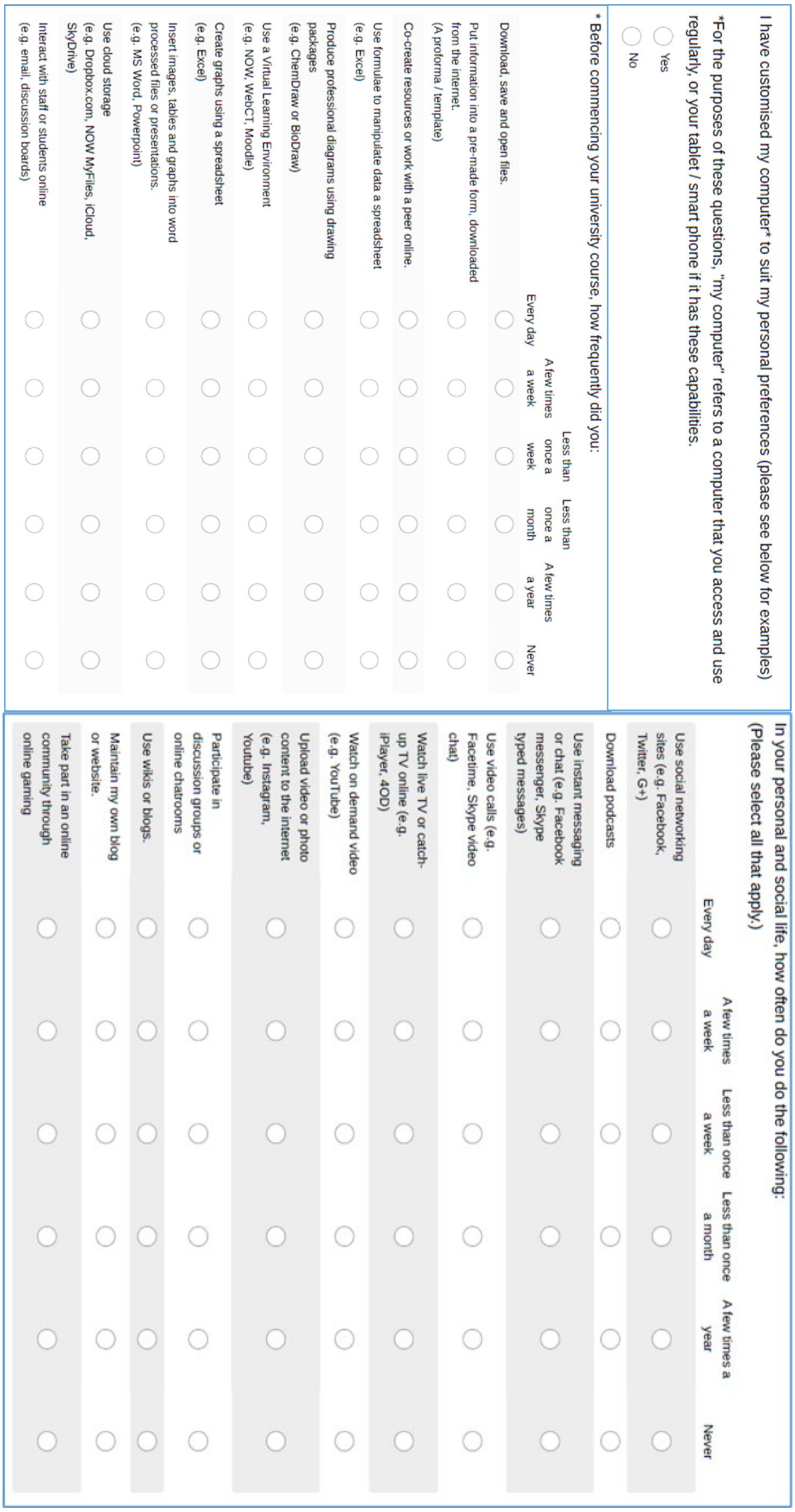
The last question in the DHS was an open-ended question that asked students whether they thought technology had a positive or negative effect on their learning and to explain their reasoning for this. Responses to this question were analysed in two ways. The first was to calculate the numbers of participants who said that technology had a positive, negative or both a positive and negative effect on their learning. For those participants who gave a rationale for their perspective, answers were coded into themes (Saldaña 2015) and the frequency with which each theme appeared in each survey cohort recorded. The outcome of this analysis is shown in chapter 3 in the form of research questions (see 3.1.3).

2.4.4 Digital literacy scoring

A digital literacy score was generated using the questions as shown in Figure *7* for all surveys and course groups to whom the survey was administered. This scoring system utilised the NTU digital framework (Practice 2014) competencies and skill levels as the basis for ascribing each activity a points value which would be summed to give the participant's overall digital literacy score. The framework has 4 levels: enquiring, upskilling, experienced and creative. Enquiring level activities were scored with 1 point as these were the least complex tasks with points increasing to 4 for the most complex activities (creative level). An example of the scoring can be seen in Table 9. A complete list of scoring for digital literacy can be found in appendix 2. Participants were allocated the points for questions using a frequency scale if they selected an answer that was not "never". Adding together individual points values generated, a digital literacy score for each participant with a value between 0-40. Incomplete participant records were excluded from further analysis, but complete records were included irrespective of overall digital literacy score. In the 2014-15 survey, one record was incomplete in the chemistry returning student data; one incomplete record was removed from each of the new bioscience, chemistry, physics and computing new student data for 2015-16; 7 incomplete computing students records, and one incomplete maths record were removed from the 2016-17 new student data; and, ten bioscience incomplete records were removed from the digital literacy calculation for the 2017-18 data.

Table 9: Example of how activities in one of the DHS questions are ascribed digital literacy points values.

Activity	Framework competency	Level	Point value	Description
In personal and social life, how often do you…				
Watching live TV or catch-up TV online	Information literacy	Enquiring	1	Can identify and access digital resources
Using instant messaging or chat	Communication and Collaboration	Upskilling	2	Can identify and use different communication tools including social media tools
Upload video or photo content to the internet	Media literacy	Experienced	3	Create or derive new multimedia content
Maintain my own blog or website	Media literacy	Creative	4	Understand how to design, produce and disseminate information using a variety of digital media that is appropriate to the audience and use hypertext to link across media



I have customised my computer* to suit my personal preferences (please see below for examples)

*For the purposes of these questions, "my computer" refers to a computer that you access and use regularly, or your tablet / smart phone if it has these capabilities.

- Yes
- No

* Before commencing your university course, how frequently did you:

	Every day	A few times a week	Less than once a week	Less than once a month	A few times a year	Never
Download, save and open files.						
Put information into a pre-made form, downloaded from the internet. (A proforma / template)						
Co-create resources or work with a peer online.						
Use formulae to manipulate data a spreadsheet (e.g. Excel)						
Produce professional diagrams using drawing packages (e.g. ChemDraw or BioDraw)						
Use a Virtual Learning Environment (e.g. NOW, WebCT, Moodle)						
Create graphs using a spreadsheet (e.g. Excel)						
Insert images, tables and graphs into word processed files or presentations. (e.g. MS Word, Powerpoint)						
Use cloud storage (e.g. Dropbox.com, NOW MyFiles, iCloud, SkyDrive)						
Interact with staff or students online (e.g. email, discussion boards)						

In your personal and social life, how often do you do the following:
(Please select all that apply.)

	Every day	A few times a week	Less than once a week	Less than once a month	A few times a year	Never
Use social networking sites (e.g. Facebook, Twitter, G+)						
Download podcasts						
Use instant messaging or chat (e.g. Facebook messenger, Skype typed messages)						
Use video calls (e.g. Facetime, Skype video chat)						
Watch live TV or catch-up TV online (e.g. iPlayer, 4OD)						
Watch on demand video (e.g. YouTube)						
Upload video or photo content to the internet (e.g. Instagram, Youtube)						
Participate in discussion groups or online chatrooms						
Use wikis or blogs.						
Maintain my own blog or website.						
Take part in an online community through online gaming						

Figure 7: DHS questions used in the calculation of the digital literacy score

2.4.5 Digital literacy statistical testing

Before statistical tests could be carried out, digital literacy scores were tested for normality using a Shapiro-Wilk test using SPSS software (IBM, New York, USA). This test was chosen over other types of normality test, such as Kolmogorov-Smirnov (K-S), as it has greater power and so is less likely to produce a type II error (i.e. producing a false negative) when working with small data sets (Ghasemi, Zahediasl 2012).

The outcome of Shapiro-Wilk tests on digital literacy score data are shown below in Table 10. Due to the low numbers of participants in returning students groups, digital literacy scores were not further analysed by statistical tests for these cohorts.

As can be seen from the p-values generated, except for the data for 2016-17 new computing students, all data sets have p-values that are greater than 0.05. Since the null hypothesis for the Shapiro-Wilk test is that the data is normally distributed, this means that the null hypothesis is only rejected and the alternative hypothesis (that data is not normally distributed) accepted for 2016-17 new computing students.

Table 10: P value outcomes of Shapiro-Wilk normality testing. Data sets that deviated from normal distribution (by having a p value of less than 0.05) are shown in bold

Survey year		survey type	Shapiro-Wilk p value	Is data parametric ?
2017-8	Bioscience	New	0.807	Yes
2016-7	Bioscience	New	0.568	Yes
	Chemistry/ Forensics	New	0.331	Yes
	Maths	New	0.707	Yes
	Physics	New	0.583	Yes
	Computing	**New**	**0.007**	**No**
2015-6	Bioscience	New	0.119	Yes
	Chemistry/ Forensics	New	0.318	Yes
	Maths	New	0.488	Yes
	Physics	New	0.908	Yes
	computing	New	0.290	Yes
2014-5	Bioscience	New	0.855	Yes

As there were both parametric and non-parametric data as shown above, it is appropriate for the descriptive statistics shown to include both mean and median as measures of central tendency. Choice of statistical test to address specific research questions is discussed in chapter 3.

2.5 SLEI survey validation

To investigate students' perception of their lab experience, parts or all of the SLEI, TROFLEI and attitude surveys were combined to create a single survey tool that was named the modified-SLEI. The final version of the survey can be seen in appendix 3. It was named this as the main tool used was the SLEI developed by Fraser et al. (1992). The SLEI scales used in the initial development of this tool were social cohesion, open-endedness, integration, rule clarity and material environment. This study is not the first to adapt the SLEI: Wong and Fraser (1994) previously customised the SLEI to be context specific for use in chemistry classes. For this study, the SLEI scales and questions were used in their entirety (both *actual* and *preferred* scales) and laid out as previously published: with one question from each scale per page. However, questions were reviewed for clarity within the NTU context, and the wording of questions adjusted if needed. An example of an adjustment made is shown below in this question from the Integration scale:

Original wording (Fraser & McRobbie 1995): "the laboratory work is unrelated to the topics I am studying in my science class".

Adapted wording (appendix 3): "The laboratory work is unrelated to the topics that we are studying in our lectures/seminars".

As the SLEI did not have any questions that related specifically to the use of technology, the computer use scale from the TROFLEI (Aldridge & Fraser 2008) was used to investigate this aspect of the study. As there were only 5 questions compared to the 7 questions in the SLEI scale and in the TROFLEI questions on the same scale are presented together, the computer use scale was kept separate to the SLEI questions. As for the SLEI questions, the computer use questions were specifically adapted to be appropriate for the tablet technology available in the laboratory. An example of an adjustment made is shown in the question below.

Original wording (Aldridge & Fraser 2008): “I use the computer to obtain information from the Internet”.

Adapted wording (see Appendix 3): “Whilst in the laboratory I access further reading using the tablets to help my understanding”.

As an important part of the study was to evaluate whether attitude to technology affected student lab experience, the attitude to technology scale described by Aldridge and Fraser (2008) was used to investigate this. As for the SLEI and computer use questions, these were specifically tailored to the context (an example is shown below) acknowledging that the students use tablet technology rather than computers when they are in the Superlab.

Original wording (Aldridge & Fraser 2008): “Working with computers is motivating”.

Adapted wording (see appendix 3): “Working with tablets is motivating”.

As this scale only had one version of the question (unlike the *actual* and *preferred* versions of the question used in the SLEI and TROFLEI scales), questions were administered together: this is in keeping with the survey structure described by (Aldridge & Fraser 2008).

2.5.1 SLEI participants

As described in section 2.2, participant data was collected for bioscience, chemistry and forensic science students for both the DHS and modified-SLEI. Within the context of survey validation, reliability testing was performed using all data relating to that environment for each scale as described in the literature (Aldridge, Fraser 2008; Fraser et al. 1993). As bioscience, chemistry and forensic science students all have classes in the Superlab environment, and data has been collected by Jennifer Evans for a parallel study to this one for chemistry and forensic science students, all subject data has been used to validate and develop the survey into its final form as shown in appendix 3. The table below (Table 11), shows the number of participants for each survey and cohort of students.

Table 11: Summary of SLEI participant numbers for each cohort for subject group. The number of potential participants is shown in brackets as well as the percentage response rate.

	2014-5	2015-6	2016-7	2017-8
New Bioscience Students	36 (310) 11.6%	41 (319) 12.9%	34 (228) 14.9%	30 (321) 9.3%
New Chemistry/ Forensic science students	48 (268) 17.9%	77 (201) 38.3%	60 (106) 56.7%	20 (136) 14.7%
Returning Bioscience students	20 (423) 4.7%	11 (185) 5.9%	10 (237) 4.2%	11 (268) 4.1%
Returning chem	8 (290) 2.8%	19 (139) 13.7%	28 (170) 16.5%	11 (122) 9.0%

Students were invited to participate in the study as outlined in section 2.2: these invitations were not highlighted to students in taught sessions as this survey was open from the latter part of term 2 and through the start of the third term.

2.5.2 Validation of modified SLEI: Survey development and reliability testing

The analysis strategy for the modified-SLEI data followed the same approach as that used in the literature, for the most part. The first step in this is to convert the Likert-like scale data for each participant into a scale score.

For the SLEI-based questions, this meant adding together the weighted values (as outlined in Fraser, Wilkinson 1993). However unlike the reported analysis method, this study does not add a value of '3' to unanswered questions: instead those scales were removed from the analysis. Similarly, the technology use scale that was adapted from the TROFLEI, summed response values to create scale total (Aldridge 2012), so this approach was used in the current analysis. The attitude to technology scale, which was derived from the CES developed by Loyd, Gressard (1984), also summed question values to generate scale totals for individual participants and so this was the method used for the modified-SLEI data.

Using the data sets as described above, Cronbach-α analysis was carried out using SPSS software (IBM, New York, USA) for each scale within the survey (both *actual* and *preferred* forms), in each year. This analysis tests the similarity of groups of data and therefore tests reliability of data within a scale (Field 2009). This type of reliability testing has been used throughout the published literature that evaluates the use of the SLEI and is an established method for testing reliability of this type of data (Lang et al. 2005). According to Field (2009) an ideal Cronbach- α value would be 0.7 with values between 0.6-0.8 being considered within an acceptable range but higher than 0.8 indicating that the items in the scale are too similar. Since it is comparing items on a scale, the fewer items there are on a scale, the less precise the Cronbach- α value will be. This analysis was carried out before the modified-SLEI survey was conducted in the subsequent year to ensure that if any changes needed to be made, these could be incorporated. When calculating the Cronbach-α value for each scale, the inter-item correlations (how similar two individual questions are to one another) and corrected item total correlations were also calculated. Values below 0.3 suggest that questions are not related and therefore are not measuring the same characteristic/scale. Given that the questions in the SLEI are grouped into scales that address specific areas, questions with an inter-item correlation or corrected item total correlation below 0.3 would be undesirable as it suggests that it is not measuring the same thing as other items on that scale. The Cronbach-α value, inter-item correlation and corrected item total correlations were evaluated alongside the “Cronbach-α values for if the item is removed” values to see if there was an overall improvement in reliability if the question was removed. As the analytical picture could be complex due to the use of both an *actual* and *preferred* scale which did not necessarily support the same approach, decision-making gave greater weight to changes that improved the reliability of the *actual* scale. This was thought to be of more significance given the later reliance on the *actual* scale for correlation with digital literacy scores generated in the DHS.

Potential decisions that could be made for each question in a scale were:

- Reword question to ensure that it is not an issue with clarity of wording that is causing poor reliability. In this instance, the assumption is that some participants have interpreted the question differently than expected, so rewording it may help to ensure that all participants have interpreted the question in the same way and provided answers accordingly. The question would be specifically reviewed in the following year to evaluate whether there has been a change in the reliability of the question/scale.
- Remove question from the scale. This approach was most commonly used if rewording a question did not resolve issues with the reliability of scale/question. It could also be used in the first instance if the question had very poor inter-item correlations with all items and removing it improved the overall reliability of the scale, particularly if this was true for both *actual* and *preferred* version of the scale.
- Retain question with current wording as there are no identified issues with the question's reliability or its relationship with other questions in the scale.

Examples of the different outcomes and rationale for those choices are shown in appendix 4. In the first instance it was preferred to attempt to reword rather than remove questions where possible (particularly if multiple items were affected in the scale). A complete breakdown of the analysis for the removal and rewording of questions is available on request: questions that were reworded and retained are highlighted in appendix 3.

To be able to carry out longitudinal testing required all participants in all years have to have answered the same questions. As some questions in the open-endedness and

Integration scales were reworded after the first cycle and then retained, 2014-15 data for scales that retained re-worded questions could not be included in the final data analysis.

2.5.3 Summary of modified-SLEI validation (reliability and discriminant validity)

In addition to calculating scale reliability (Cronbach-α test), discriminant validity testing was carried out to confirm that each of the scales was discrete and not measuring the same parameter. This took the form of calculating the mean item correlation of each scale with the other scales in the modified-SLEI based on mean item score. By calculating and using the mean item values for each participant (rather than total scale scores), the impact of scales having a different number of items (and therefore different maximum values) was negated. Discriminant validity testing requires a type of multivariate analysis known as correlation matrix analysis: as the data was a mixture of parametric and non-parametrically distributed data (based on Shapiro-Wilk's test observations), this analysis used Spearman Rho rather than Pearson product moment correlations and was carried out using Graphpad Prism (Graphpad holdings LLC, California, USA).

The outcome of the reliability and discriminant validity testing is shown in Table 12. The Cronbach-α value varies from 0.422 to 0.924, with the rule clarity scale performing the least well of any of the scales. In terms of discriminant validity, the values for the mean correlation with other scales varies from 0.09 to 0.44.

Table 12: Summary of key characteristics for expressing the reliability and discriminant validity (mean correlation with other scales) is shown for each scale (actual and preferred) and each year.

scale	no. items in the scale	Year	Cronbach- α		Mean correlation with other scales	
			actual	preferred	actual	preferred
social cohesion	6	17/18	0.817	0.530	0.24	0.26
		16/17	0.772	0.719	0.27	0.18
		15/16	0.763	0.803	0.18	0.23
		14/15	0.764	0.734	0.26	0.22
Open-endedness	6	17/18	0.643	0.753	0.40	0.34
		16/17	0.650	0.540	0.26	0.31
		15/16	0.673	0.598	0.32	0.23
		14/15	0.556	0.583	N/A	N/A
Integration	6	17/18	0.900	0.695	0.32	0.40
		16/17	0.859	0.709	0.27	0.26
		15/16	0.864	0.708	0.17	0.11
		14/15	0.872	0.674	N/A	N/A
rule clarity	4	17/18	0.422	0.511	0.28	0.44
		16/17	0.554	0.745	0.29	0.36
		15/16	0.615	0.560	0.09	0.20
		14/15	0.625	0.486	0.22	0.23
technology use	5	17/18	0.679	0.829	0.11	0.26
		16/17	0.745	0.768	0.43	0.35
		15/16	0.672	0.757	0.20	0.18
		14/15	0.819	0.867	0.09	0.14
attitude to technology	7	17/18	0.833		0.16	0.22
		16/17	0.865		0.27	0.24
		15/16	0.901		0.15	0.23
		14/15	0.924		0.09	0.14

2.5.4 Normality testing

Before statistical tests could be performed on the SLEI scale data, the data distribution was examined to determine whether the data was parametric or non-parametric. Since the Open-endedness and Integration scales in 2014-15 did not have the same data set as later iterations (due to reworded questions that were first implemented in the 2015-16 survey being retained) no comparisons could be made using with those scales for 2014-15 and so these were excluded from the Shapiro-Wilk tests. The outcome of these test can be seen in Table 13 and shows that the outcome for each scale (i.e., whether the p-value is equal to or less than 0.05) does not produce the same outcome for every year for every scale. For example, the data shows that the Integration scale (*preferred*) has a p value of less than 0.05 (indicating the data is not parametrically distributed) in 2015-16 but not in 2016-17 or 2017-18.

Table 13: Outcome of Shapiro-Wilks normality test for bioscience data for all scales in all years. Data with an orange infilled box show places where data is non- parametric (i.e. the p value is less than 0.05).

Scale	SLEI 14-15 p values (df)	SLEI 15-16 p values (df)	SLEI 16-17 p values (df)	SLEI 17-18 p values (df)
Social cohesiveness (actual)	.4092 (28)	0.1035 (27)	0.1084 (27)	0.1158 (10)
Social cohesiveness (preferred)	.2402 (27)	0.009 (27)	0.2238 (24)	0.4060 (12)
Open-endedness (actual)	N/A	0.167 (27)	0.0597 (27)	0.8359 (10)
Open-endedness (Preferred)	N/A	0.2368 (26)	0.3693 (25)	0.4458 (34)
Integration (actual)	N/A	0.258 (27)	0.4802 (27)	0.0896 (10)
Integration (preferred)	N/A	0.0408 (26)	0.4861 (25)	0.1031 (10)
Rule clarity (actual)	.0056 (29)	0.003 (27)	0.0020 (29)	0.3890 (10)
Rule clarity (preferred)	<0.0001 (28)	0.0008 (27)	0.0003 (27)	0.0623 (10)
Technology use (actual)	.3195 (27)	0.4561 (30)	0.0046 (31)	0.5904 (14)
Technology use (preferred)	.2653 (27)	0.0182 (26)	0.1206 (92)	0.6280 (14)
Attitude to technology	.6412 (27)	0.3424 (34)	0.3917 (32)	0.2550 (15)

2.5.5 Summary of survey validation

The modified-SLEI survey scales showed a range of Cronbach-α values that ranged from 0.422-0.924 although only the openendedness and rule clarity scales produced values of less than 0.6. With the exception of those data sets that were lower than the suggested 0.6 score, this suggests that the scales were reliable.

For the openendedness *actual* scale, the data that had a reliability score of less than 0.6 was found in the first iteration of the survey. As outlined in section 2.5.2, the scale was modified by removing or adapting questions in an attempt to improve their clarity and as a result the Cronbach-α scores for the actual scale increased to a value above 0.6 in the next iteration: the scores for the preferred scales did not increase to a value above 0.6 except in the 2017-18 survey but remained at 0.540 or above.

The Cronbach-α scores for both the actual and preferred scales of the rule clarity metric had values below 0.6. The lowest values were seen in the 2017-18 data which was 0.422 for the actual data and 0.511 for the preferred scale. Critically there are features unique to this scale which means that the Cronbach-α value may not be a good measure for reliability in this case. A report on the use of Cronbach-α as a measure of reliability suggested that scales where there were few participants or few questions were likely to report low reliability scores using this test (Tavakol, Dennick 2011). The participant numbers in 2017-18 were much lower than in previous iterations of the survey (N=13) but the rule clarity scale also differed from the other scales by having fewer questions: there were 4 questions for rule clarity but 6 or more for the other scales in the survey. This suggests a combination of these two factors may contribute to make the outcome of the Cronbach analysis less robust in this case.

With the exception of the rule clarity scale as described above, the Cronbach-α values in this study are in keeping with those reported in other uses of the SLEI survey (see Table 14). Whilst 3 studies report Cronbach-α values below 0.6, in a similar way to the current study, the paper by Wong and Fraser (1996) showed their lowest scores in the openendedness and rule clarity scales.

Table 14: A sample of the Cronbach-α and discriminant validity values from papers using the tools that the modified SLEI was based on (*ND mean not determined)

Reference	Tool	Cronbach-α values	Discriminant validity (range of mean correlation values)
(Lightburn, Fraser 2007)	SLEI	0.67-0.93	ND*
(Henderson et al. 2000)	SLEI	0.58-0.92	0.10-0.57
(Fraser, Wilkinson 1993)	SLEI	0.6-0.92	0.07-0.45
(Fraser, Lee 2009)	SLEI	0.58-0.97	0.16-0.46
(Fraser et al. 1995)	SLEI	0.64-0.92	0.11-0.44
(Wong, Fraser 1996)	SLEI	0.414-0.914	0.028-0.550
(Aldridge, Fraser 2008)	TROFLEI	0.85-0.98	0.15-0.48
	Attitude	0.78-0.92	0.09-0.21

Calculation of the mean correlation between scales has been used in numerous SLEI-based publications to evaluate how distinct the different scales are from one another (described as discriminant validity). Table 14 shows the published ranges for this analysis across the different scales in the SLEI, TROFLEI and attitude scales. In this study, the mean correlation between scales ranged from 0.09-0.43 on the actual scale and preferred scale 0.11-0.44. This is in keeping with published values and so similarly confirms that the scales used in the modified-SLEI are distinct but overlapping.

2.5.6 Statistical testing of research questions

Once the normality testing had been completed (section 2.5.4), this could be used to inform the choice of which statistical test was most appropriate for analysing the data to address the research questions described in chapter 3.

2.6 Employer survey

2.6.1 Survey development

To be able to assess whether NTU is providing students with digital skills that match the expectation of graduate employers, a survey tool was designed to investigate the skills that employers in a variety of sectors were looking for in graduate roles. Knowing that some roles may be filled by graduates from a variety of disciplines, the survey was designed to be broadly applicable across the school. To ensure that the data would be of benefit to different disciplines, the following actions were taken:

- The benchmark statements for all disciplines were investigated to be able to outline the provision covered by this subject specific documentation and ensure it was represented.
- Subject specific experts, such as course leaders, in each discipline were consulted to confirm that the survey would meet their benchmarks and that the wording of technical phrases made sense within the context of the discipline. This latter point was particularly relevant to computer science benchmarks and courses which had specific technical language associated with them.

The questions included in the employer survey (the final version, post-pilot, can be seen in appendix 5) can be broadly fitted into 3 categories:

1) Demographic type data designed to identify the type of graduate role and also which disciplines were recruited to this role. The answers listed for question 3 (which area the employer's business focusses on) were based on the employer categories used by NTU employability team. As the initial intention was to disseminate the survey via approximately 2000 employer contacts that were known to the university, it was appropriate to use a format that they would already be familiar with when dealing with the university.

2) Whilst it was important for the survey to give an understanding of the digital skills that graduate employers were looking for, it was also important to gain an appreciation of how important employers consider these skills to be when compared to other skills that they would be looking for. This was particularly relevant as it was anticipated that the survey may lead to recommendation of curriculum changes and so responses needed to be put into perspective.
3) Digital competencies. As described for the DHS (section 2.4.1), the competencies stated in each of a series of Likert-like scaled questions were mapped against the NTU digital framework (NTU Digital Practice 2014). A full listing for all questions can be seen in appendix 6: a sample of the mapping can be seen in Table 15 which also shows where there was an equivalent in the DHS. Some statements mapped to one or more DHS statement; some statements did not have a direct statement to compare to in the DHS as this survey was more comprehensive of the knowledges and competencies included in the digital framework than the DHS. In part this related to the need to include benchmark statements across disciplines, which was not a requirement in the DHS.

Table 15: Example of mapping of employer survey to NTU digital framework competencies and whether an equivalent question can be found in the digital history survey

Activity	**Framework competency**	**Level**	**Mapping to DHS statements**
In graduate roles, how often would you expect individuals to do the following:			
Create a presentation using a digital tool such as MS powerpoint, or prezzi	Communication and collaboration	Enquiring	
Embed images or multimedia objects such as videos into a file	Media literacy	Upskilling	Insert images, tables and graphs into word processed files or presentations
Construct or manage a database	Computer literacy	Experienced	
Use analysis tools (e.g Excel, SPSS) to record and analyse data	Information literacy	Upskilling	Create graphs using a spreadsheet; Use formulae to manipulate data in a spreadsheet
Specify, design and write computer programmes	Computer literacy	Creative	

2.6.2 Pilot study

To ensure that the study was appropriate for all disciplines, a pilot study was undertaken in which a small number of employers who were known to recruit graduates in specific disciplines were invited to participate. For each discipline, 2-3 employers were invited by email to take part in the survey; the survey itself was hosted in Surveymonkey (Momentive PLC, California, USA). In the pilot version of the survey, specific questions were included so that pilot participants could provide feedback (see appendix 7). These questions were designed to solicit feedback on whether questions were clear, concise and easily understood as well as covering all relevant areas to their business/graduate role.

Participants were also given open text boxes so that they could provide additional or explanatory feedback if required.

2.6.3 Pilot data and feedback

Whilst the aim of the pilot study was to establish whether there were any subject specific elements missing and to check for clarity, examination of the data showed some consistency in responses despite the varied backgrounds of the participants. Of those participants invited to take part in the pilot study, 14 participated in the survey with their area of business covering: chemicals; environment and conservation; government and public sector; health, social care and counselling; IT software and multimedia communications; pharmaceuticals and life sciences; and scientific, technical and research. Eight participants answered the question of what disciplines they recruited from and in many cases indicated more than one discipline: biological and computer science graduates were recruited by 50% of respondents; Forensic science and mathematics graduates recruited by 25% of respondents and Chemistry and physics graduates recruited by 12.5% of respondents. The 10 most important skills for graduates according to the pilot participants as well as the 5 most important digital skills are shown in Table 16.

Most participants answering the relevant questions expected graduates to have awareness of e-security (6/7), data protection (5/7); copyright and intellectual property rights (4/7). All participants expected graduates to use passwords for security and to be aware of security risks of downloading files and apps from the internet; 5 of the 7 respondents also expected graduates to be aware of how to manage security of multiple accounts/digital identities online. In addition to this, most participants (6/7) expected graduates to be able to distinguish between social and professional networks; whereas only 4/7 expected graduates to be able to identify legal and ethical security risks in data/information storage, enhance privacy settings online, manage several digital identities or support and develop others through use of professional networks.

Table 16: summary of the top 10 skills and the 5 most important digital skills chosen by pilot participants as being key graduate skills

Skill	Proportion of respondents selecting this answer
Overall 10 most important skills	
Teamwork	8/8
Initiative	8/8
Ability to solve problems	8/8
Time management	8/8
Relevant practical skills	7/8
Effective oral communication skills	6/8
Subject specific knowledge	5/8
Computer literacy	5/8
Data analysis skills	4/8
Digital communication skills	4/8
Overall 5 most important digital skills	
Computer literacy	6/7
Analyse data using suitable tools	6/7
Effective use of media	5/7
Digital communication skills	5/7
Use of resources such as shared calendars for time management	4/7

Examination of the frequency of use of a variety of digital skills is shown in Table 17. As can be seen in this table there is variation in how often different digital skills are used. For example, all graduate employers expected that those entering graduate roles would manage their time using shared calendars on a daily basis; most (85.7%) expected them to search online for information or use email on a daily basis. Whereas, over half of employers described that creating a presentation (5/7) or using EXCEL or similar for analysis (4/7) was a task that was carried out on a monthly basis. In addition, a number of activities were not required in all roles: construction or maintenance of a webpage or database were not required in 3/7 and 2/7 of roles respectively.

Table 17: Summary of the response of participants showing the frequency that different activities would be expected to be used in graduate roles expressed as a percentage of responses (n=7 throughout)

Activity	Daily	Weekly	Monthly	Quarterly	As required	N/A
Use information and communication technologies:						
Create a document or report using a word processing package e.g.MS Word	57.1%	28.6%	0.0%	0.0%	14.3%	0.0%
Create a presentation using a digital tool such as MS powerpoint, or prezzi	0.0%	0.0%	71.4%	0.0%	28.6%	0.0%
Embed images or multimedia objects such as videos into a file	14.3%	71.4%	0.0%	0.0%	14.3%	0.0%
Construct or manage a database	14.3%	14.3%	14.3%	0.0%	28.6%	28.6%
Use analysis tools (e.g Excel, SPSS) to record and analyse data	0.0%	28.6%	57.1%	0.0%	14.3%	0.0%
Use specialist software	57.1%	14.3%	0.0%	0.0%	28.6%	0.0%
Manage their own time/organise meetings using shared calendars or other digital tools	100%	0.0%	0.0%	0.0%	0.0%	0.0%
Select and use appropriate file storage options	42.9%	28.6%	0.0%	0.0%	28.6%	0.0%
Construct and maintain webpages	14.3%	0.0%	0.0%	0.0%	42.9%	42.9%
use relevant tools to plan projects individually or as a group	28.6%	28.6%	14.3%	0.0%	28.6%	0.0%
Use digital communication and collaborative working:						
Use email to communicate with individuals or groups both within the organisation and externally	85.7%	14.3%	0.0%	0.0%	0.0%	0.0%
Use online conferencing software (e.g. skype) to hold meetings	28.6%	14.3%	28.6%	0.0%	14.3%	14.3%
Use social media (such as facebook or twitter), or professional networks (e.g. LinkedIn, researchgate)	14.3%	28.6%	0.0%	0.0%	42.9%	14.3%
Work collaboratively or share information using digital tools such as googledocs, dropbox or onedrive	42.9%	14.3%	14.3%	0.0%	14.3%	14.3%
Using Virtual Private Networks (VPNs) to securely connect to work network from remote locations e.g. home	28.6%	0.0%	0.0%	0.0%	42.9%	28.6%

Accessing, evaluating and sharing information:						
Search online for resources or information	85.7%	14.3%	0.0%	0.0%	0.0%	0.0%
Critically evaluate the validity and reliability of source material	42.9%	57.1%	0.0%	0.0%	0.0%	0.0%
Use digital tools to design assessments	0.0%	28.6%	14.3%	0.0%	42.9%	14.3%
Use digital tools for professional development e.g. reflection or identifying development points	14.3%	28.6%	28.6%	14.3%	14.3%	0.0%
construct bibliographies or collate references in a management tool (e.g. Refworks)	0.0%	0.0%	14.3%	0.0%	57.1%	28.6%

All participants that answered pilot feedback questions (n=7) agreed that question and answer options were concise, that the questions were easy to follow, and the answer statements were clear. Six out of the seven respondents answered the question about whether the survey covered all the digital skills applicable to their organisation, all respondents stated that it did.

2.6.3 Amendments for final survey

Before the survey was released, two changes were made. Feedback from the pilot study had not given any indication that amendments were needed, or additional information needed to be included, however further consultation with subject specialists suggested some additions would benefit recent course changes. These were:

- In questions 8-10, inclusion of the statement "specify, design or write programmes" on the advice of a subject expert (personal communication, P Fitzgerald).
- Addition of question 7: this was designed to investigate whether those who had workplace experience had additional or more in-depth skills.

This final version of the survey was hosted in Surveymonkey (Momentive PLC, California, USA) and participants were invited to participate through mailing lists and newsletters sent out by the NTU employability team. Due to lack of responses using this route of dissemination, this was extended to include social media platforms (Facebook and Twitter) as a way to advertise the survey.

Chapter 3: Understanding bioscience student laboratory experience.

The data described in this chapter seeks to address aspects of both the first and second aim in the project (sections 1.12.1 and section 1.12.2) through the creation and use of survey tools to investigate the student perspective of digital skills and laboratory experience. Creation and validation of these surveys are described in chapter 2.4 (DHS) and 2.5 (modified-SLEI).

3.1 Digital history survey

3.1.1 DHS Participant numbers

A summary of the number of participating students participating in the DHS from each course area is shown in Table 18. As can be seen, the response rate is consistently lower in the returning student cohorts.

Table 18: summary of participant numbers for digital history survey. Total participant pool is shown in brackets with response rates shown as a percentage for each. N/A has been entered where no data was not collected.

	2014-5	2015-6	2016-7	2017-8
New Bioscience Students	92 (310) 29.7%	98 (319) 30.7%	90 (228) 39.5%	94 (321) 29.3%
New Chemistry/ Forensic science students	151 (268) 56.3%	76 (201) 37.8%	69 (106) 65.1%	54 (136) 39.7%
New computing students	N/A	57 (318) 17.9%	118 (241) 49.0%	N/A
New Maths students	N/A	55 (123) 44.7%	81 (112) 72.3%	N/A
New Physics students	N/A	15 (105) 14.3%	20 (73) 27.4%	N/A
Returning Bioscience students	0 (227) 0.0%	4 (231) 1.7%	0 (237) 0.0%	6 (268) 2.2%

3.1.2 DHS survey outcome

Do our students receive formal training in IT skills?

Comparison of the responses of new students across different academic years to the question asking what formal IT qualifications they have are shown in Table 19.

Whilst many of the skills vary by year and do not have a clear pattern, there are clear trends in the levels of students with GCSE IT and those with no relevant IT qualifications. The numbers of students with no IT qualifications increases from the 2014-15 cohort (26.5%) to the final group (2017-18; 48.6%); the percentage of students with GCSE IT is similar in the 2014-15 and 2015-16 cohorts (47.9% and 49.0% respectively): this successively reduces in the 2016-17 (42.2%) and 2014-15 cohorts (30.5%).

Table 19: summary of formal IT qualifications that are held by students entering university

	2017-18 (n=105)	2016-17 (n=90)	2015-16 (n=98)	2014-15 (n=121)
GCSE IT (Grade C or above)	30.5%	42.2%	49.0%	47.9%
IT Key Skills Level 2 (Pass grade)	3.8%	6. 7%	3.1%	13.2%
IT Key Skills Level 3 (Pass grade)	1.0%	5.6%	2.0%	8.3%
IT A-Level (Grade C or above)	1.9%	1.1%	1.0%	1.7%
European Computer Driving License (ECDL) - Pass grade	8.6%	0.0%	3.1%	5.0%
No relevant IT qualification	48.6%	40.0%	35.7%	26.5%
Other relevant qualification	10.5%	14.4%	11.2%	9.9%

How often and where do students access the internet?

When asked how often students accessed the internet, all participants in all surveys who answered the question stated that they accessed the internet every day (2014-15 new students n=121; 2015-16 new students n=97; 2015-16 returning students n=4; 2016-17 new students n=89; 2017-18 new students n=104; 2017-8 returning students n=5).

Where students had access to a computer with internet, data from both their previous and current year of study is shown in Table 20.

Table 20: summary of proportion of students who have access to computers with internet in various locations. Responses are shown as a percentage of respondents. The n number in each case is shown in the row with the survey date.

		At home / student residence	At work	At university / college / learning centre	Other location
2017-8 new (n=104)	Current	96.2%	6.7%	91.4%	0.0%
	Previous	98.1%	19.2%	70.2%	2.9%
2016-7 new (n=89)	Current	97.8%	12.4%	87.6%	1.1%
	Previous	98.9%	36.0%	84.3%	2.3%
2015-6 new (n=97)	Current	96.9%	7.2%	91.8%	2.1%
	Previous	99.1%	27.8%	81.4%	1.0%
2014-5 new (n=121)	Current	98.4%	16.5%	94.2%	0.8%
	Previous	100.0%	29.8%	80.2%	0.8%
2017-8 returning (n=6)	Current	100.0%	16.7%	100.0%	0.0%
	Previous	100.0%	50.0%	100.0%	0.0%
2015 -6 returning (n=4)	Current	100.0%	75.0%	75.0%	0.0%
	Previous	100.0%	25.0%	100.0%	0.0%

How often do students use different technologies and what technologies do they own?

Students were asked how frequently they used three different types of technologies: desktop/computers, tablets and smartphones. As can be seen in Figure 8, the most frequently used technology was the smartphone with at least 95% of participants using it every day. Having said this, for a small number of participants, this is a technology that they rarely or never use. Conversely all participants used computers at least once a month with at least 70% of participants in all cases using this on daily basis.

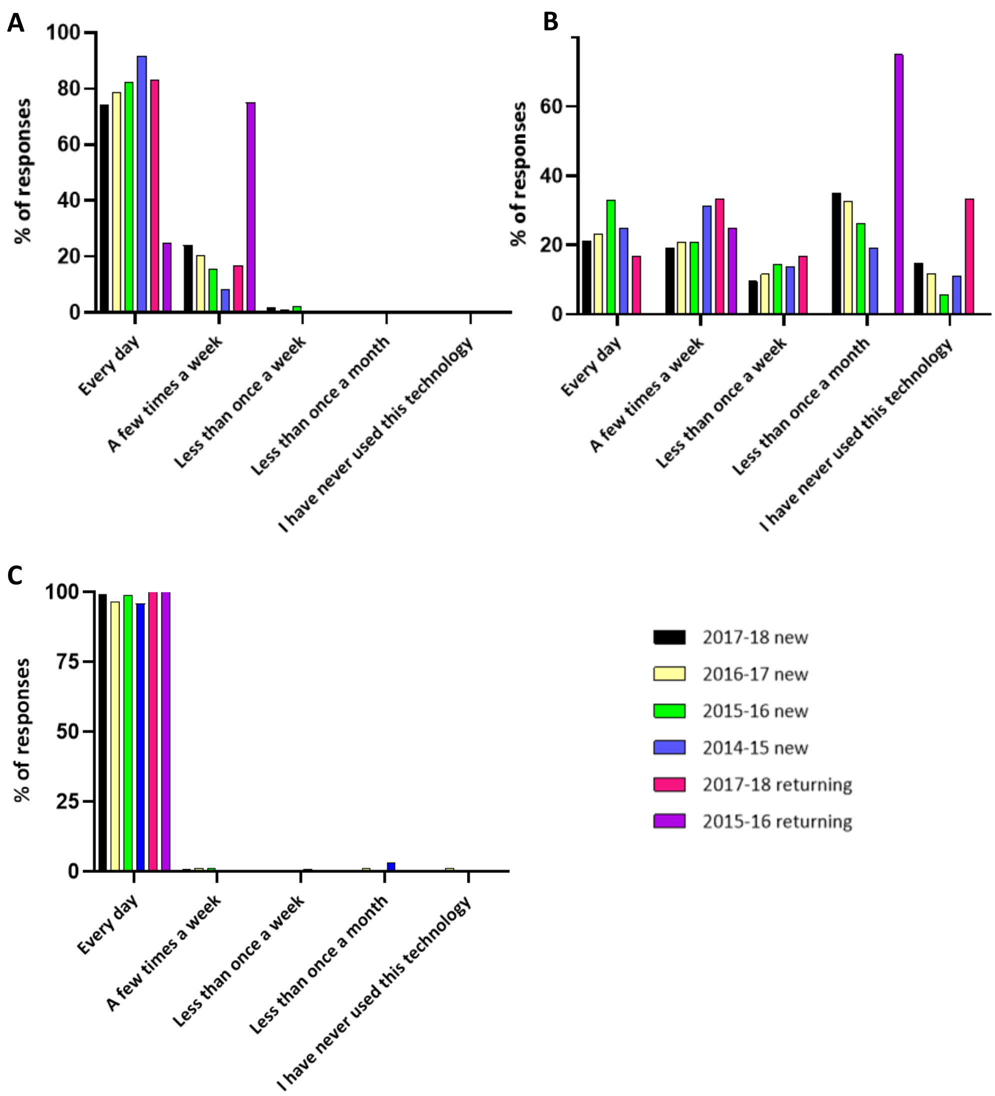


Figure 8: Summary of frequency of use of desktops/computers (A), tablets (B) and smartphones (C) and a key to survey responses

The use of tablets was more varied with answers spread across all options and no discernible pattern across the cohorts. A higher proportion of students stated that they had never used this technology than for other types of technology.

As shown in Table 21 the most frequent answer for which operating system participants were most familiar with was Microsoft; whereas for tablets and smartphones they were most familiar with the iOS system used by Apple devices.

Table 21: summary of the percentage of participants who chose the most commonly selected option for their most familiar platform across different devices.

	Microsoft: computer	Apple: tablet	Apple: smartphone
2017-8 new (n=104)	73.1%	57.3%	63.5%
2016-7 new (n=89)	83.2%	54.6%	57.3%
2015-6 new (n=97)	81.3%	52.1%	63.5%
2014-5 new (n=121)	82.5%	52.9%	52.5%
2017-8 returning (n=6)	50.0%	66.7%	66.7%
2015 -6 returning (n=4)	100%	75.0%	50.0%

Whilst these questions indicate the type of technologies that students are familiar with, it does not infer what technologies students own. When DHS participants were asked this, responses showed that in almost all cases, students owned a mobile phone with a small proportion of students also owning another mobile phone that was not a smart phone (see Table 22). At least 90% of students owned a laptop or netbook and at least 40% owned a tablet. When asked whether they would bring their technology to campus with them, most participants answering this question said that they would (2017-8 new students 90.8%, n=98; 2016-17 new students 89.9%, n=89; 2015-16 new students 97.9%, n=96; 2014-5 new students 94.1%, n=119; 2017-18 returning students 80.0%, n=5; 2015-6 returning students 100.0%, n=4).

Table 22: Summary of the technologies owned by different cohorts of new and returning students expressed as a percentage of the number of survey respondents (shown in brackets under the survey information).

	2017-8 new (n=101)	2016-7 new (n=88)	2015-6 new (n=97)	2014 -5 new (n=121)	2017-8 returning (n=5)	2015-6 returning (n=4)
Smart phone	100.0%	97.7%	99.0%	95.9%	100.0%	100.0%
Other mobile phone (not smart phone)	1.9%	4.6%	5.2%	9.1%	20.0%	0.0%
iPod or mp3 player	40.6%	48.9%	65.0%	71.9%	60.0%	50.0%
Tablet	44.6%	44.3%	48.5%	43.8%	40.0%	50.0%
Laptop or netbook	91.1%	90.9%	94.9%	91.7%	100.0%	100.0%
Digital camera	31.7%	47.7%	48.5%	57.0%	60.0%	75.0%
Digital video camera	15.8%	18.2%	19.6%	31.4%	60.0%	25.0%
Webcam	32.7%	37.5%	37.1%	59.5%	20.0%	50.0%
Digital audio recorder	19.8%	17.1%	16.5%	22.3%	40.0%	50.0%
Assistive technology : hardware or software (screen readers etc.)	2.0%	1.1%	1.0%	5.8%	0.0%	0.0%

How do students prefer to study?

The survey included a number of questions designed to better understand how students' study. In the first instance, participants were asked where they planned to do most of their study in the upcoming year. At least 50% of participants across all surveys stated they would primarily study at their home (2017-8 new students 63.6%; 2016-17 new students 58.4%; 2015-16 new students 65.6%; 2014-5 new students 52.5%; 2017-18 returning students 80.0%; 2015-6 returning students 75.0%) with a significant proportion choosing the university/library option (2017-8 new students 35.4%; 2016-17 new students 41.6%; 2015-16 new students 33.3%; 2014-5 new students 27.5%; 2017-18 returning students 20.0%; 2015-6 returning students 25.0%). A significant number of participants in the 2014-5 new students survey (20% of the 120 participants) selected that they would study both at home and university.

When asked whether they ensure they work with devices that have internet access and if so which devices, most students indicated that they would use a desktop, laptop or netbook with internet access (as shown in Table 23). There was also an increasing number of participants in the new student groups who selected that they liked to have their smartphone available: as can be seen in the table: this increased from 42.5% in 2014's new students to 70.7% in 2017's new students. The percentage of returning students who liked to have their smartphone available was less than for the new students in the same academic year (e.g., 40% of returning students in 2017-18 compared to 70.7% of new students in 2017-18). It should be noted that participants were able to select more than one answer and so the high percentage of responses in more than one category indicate that some participants are using more than one device (i.e., survey percentages would have a sum of greater than 100%).

Table 23: percentage of respondents answering whether they like to work with the internet available on different devices

	2017-8 new (n=99)	2016-7 new (n=89)	2015-6 new (n=96)	2014-5 new (n=120)	2017-8 return (n=5)	2015-6 return (n=4)
Yes, I like to have my smart phone available with the internet available.	70.7%	65.2%	67.7%	42.5%	40.0%	0.0%
Yes, I like to have a desktop computer, laptop or netbook with the internet available.	84.5%	92.1%	90.6%	95.8%	100.0%	100.0%
Yes, I like to have my tablet available with the internet available.	16.2%	18.0%	20.8%	15.0%	40.0%	0.0%
No, I do not ensure I have the internet available when I study.	0.0%	2.3%	1.0%	0.0%	0.0%	0.0%

How do students view social media and communication networks?

When asked about which social media platforms students used in their personal/social lives and for professional networking, students gave a range of answers as can be seen in Table 24. The most used platform in the student's personal/social life was Facebook with WhatsApp and snapchat also being frequently used. Participants were able to select more than one answer and the high percentages are indicative that participants are selecting two or more answers. When considering professional networking, all groups used both Facebook and LinkedIn with new students also using additional social media platforms for professional communication. In the new student groups, Facebook was a more commonly used platform than LinkedIn for professional networking, but the reverse was true for the returning students. As for personal social media use, the percentage responses seen for professional networks indicates that students use more than one platform for professional communication. For participants that selected the "Other" category, the most specified platforms for personal use were Instagram and Tumblr. In the professional category, the most cited alternative was to use email.

Table 24: summary of the social media platforms used by students for personal and professional networking

	2017-8 new		2016-7 new		2017-8 returning	
	Personal (n=92)	Professional (n=81)	Personal (n=89)	Professional (n=78)	Personal (n=5)	Professional (n=4)
Facebook	87.0%	64.2%	93.3%	59.0%	100.0%	50.0%
Twitter	46.7%	19.8%	56.2%	21.8%	60.0%	0.0%
LinkedIn	2.2%	33.3%	1.1%	34.6%	40.0%	100.0%
YikYak	0.0%	0.0%	2.3%	1.3%	0.0%	0.0%
WhatsApp	77.2%	35.8%	68.5%	29.5%	60.0%	0.0%
Snapchat	82.6%	11.1%	73.0%	2.6%	80.0%	0.0%
Other	25.0%	2.5%	14.6%	10.3%	0.0%	0.0%

High responses rates were returned for the use of email and NOW (the university's virtual learning environment) as mechanisms for students to communicate with academics and academics to communicate with students (as seen in Table 25). Additional platforms were considered acceptable by new students with the highest responses observed for Facebook and WhatsApp.

Table 25: summary of communication platforms that students would like to use to contact or be contacted by academic members of staff

		2017-18 new (n=91)	2016-17 new (n=89)	2017-8 return (n=5)
Email	to contact academics	100.0%	100.0%	80.0%
	to be contacted by academics	89.0%	89. 9%	80.0%
NOW	to contact academics	71.4%	74.2%	100.0%
	to be contacted by academics	70.3%	65.2%	66. 7%
Facebook	to contact academics	16.5%	14.6%	0.0%
	to be contacted by academics	15.4%	5.6%	0.0%
Twitter	to contact academics	6.6%	5.6%	0.0%
	to be contacted by academics	2.2%	2.3%	0.0%
LinkedIn	to contact academics	2.2%	1.1%	0.0%
	to be contacted by academics	1.1%	2.3%	0.0%
YikYak	to contact academics	2.2%	0.0%	0.0%
	to be contacted by academics	0.0%	0.0%	0.0%
WhatsApp	to contact academics	14.3%	15.7%	0.0%
	to be contacted by academics	13.2%	13.5%	0.0%
Snapchat	to contact academics	4.4%	4.5%	0.0%
	to be contacted by academics	3.3%	0.0%	0.0%

<u>What do student perceive effect of technology on their learning to be?</u>

As a part of the digital history survey, participants were asked whether they felt that technology had a positive or negative effect on their learning and why. The numbers of participants answering this question with a positive, negative or combination of positive and negative responses can be seen in Table 26. Very few participants stated that technology only had negative effects on their learning: more commonly participants would indicate that there were both positive and negative effects although these responses were lower in number than positive only responses.

Table 26: summary of the number of participants citing the technology had a positive or negative impact on their learning

	2017-18 new	2016-17 new	2015-16 new	2014-15 new	2017-8 returning	2015-16 returning
Positive only	65	62	69	80	3	3
Positive and negative	14	15	9	18	0	1
Negative only	0	3	1	2	0	0

When participant explanations for their positive or negative impact were coded it generated a list of themes which could be categorised into 4 groups: technology as a source of information; developing professional skills; flexibility; and accessibility (Table 27).

Table 27: categories and themes generated for open responses when participants were asked whether technology has a positive or negative impact on their learning. Data generated from positive responses is shown in green; negative responses are shown in red.

Technology as an information source	Developing professional skills	Flexibility	Accessibility (level playing field)
Extends understanding	Assessment	Mobility	Accessibility
Immersive	Collaboration	Multi-task	Confidence
Increases knowledge	Communication	Storage	Easier
Information accessible	Create documents		Improved focus
Interactive	Organisation		Learning style
Internet	Professional		Opportunities
Revision	Research		Variety of formats
Addictive	Scientific advances		Accessibility
Barriers			Barriers
Difficult to use	Skill development		Confusing
Dislike format	Time management		
Distraction	Skill loss		Poor focus
Over-reliance			
Unreliable			Socialising

Technology as a source of information

This category generated a range of both positive and negative themes. The positive themes frequently centred around how readily available information was and therefore how it was able to either increase participants knowledge on a given topic (i.e., that they could learn something that they did not current know about) or that they could extend their understanding of a topic (i.e., that they could learn more about a topic they were already familiar with). However, participants also noted that technology could be a distraction from their study (particularly the availability of social media); could provide conflicting information; that it could be unreliable or difficult to use and that it could be a barrier to their learning as shown by the participant response from 2017-18 below:

“I don't like e-textbooks and this could make doing work more difficult”

It is important to consider how often these responses occurred as this gives a better understanding of the participants’ experiences. A comparison of the positive and negative responses for 2 cohorts is shown in Figure 8. As can be seen for both cohorts, the most common positive aspect in this category is that technology makes information more accessible, with the most negative being that it can be a distraction. However, comparison of the data from 2014-15 cohort showed a number of other features which participants considered negative aspects of technology on their learning which are absent or less prominent in the 2017-18 cohort. These were that it was unreliable or difficult to use. This observation could reflect that advances in technology have made technology more reliable, or easier to use; or that students are becoming more comfortable with technology in their learning.

Developing professional skills

Another theme which was present in the 2014-15 data but absent in the 2017-18 group was skills loss. Students who described a loss of skills typically referenced the ability to

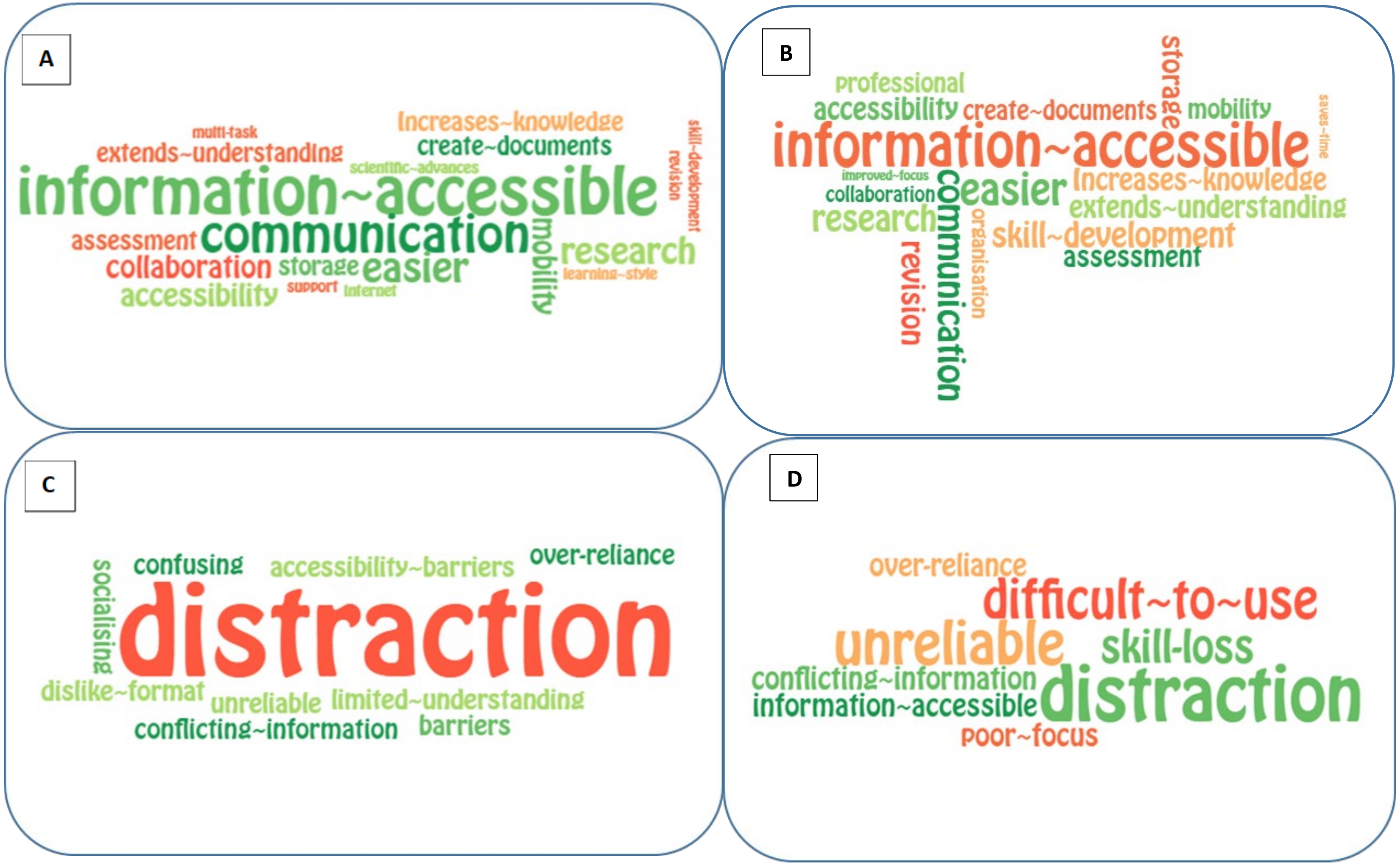


Figure 9: Visual representation of the positive (A&B) and negative responses (C&D) in response to open question “Do you think technology has a positive or negative effect on your learning? Please explain your thoughts.”. Responses are shown for the new student data

draw graphs by hand which was perceived as a professional skill. The themes described in this category describe a range of professional skills in a positive way such as collaboration, communication (both of which were more prominent in the 2017-18 data than the 2014-5 data), time management and ability to carry out research.

An example of this can be seen in the quotation from one of the 2017-8 participants:

"…it helps to develop necessary skills as we enter a paperless age."

Flexibility

The category of flexibility encompassed three different themes which did not fit into either of the first two categories. These themes centred around the portability of technology. In particular the theme of mobility was used to describe the ability of technology to allow for participants to be flexible in where and when they use technology as shown in the quote from a 2017-18 participant below:

"Technology makes it easier to access resources and to be able to do your work on the move easily."

This category also encompassed the ability to store information and files for future access and the ability of technology to allow participants to carry out multiple tasks at a time.

Accessibility

As in the *technology as a source of information* category, the accessibility category contained themes which were viewed both positively and negatively. This can be seen in the themes of accessibility/accessibility barriers and improved focus/poor focus. The participants who generated themes in this category indicated that variety in formats gave them the ability to learn in a way that suited their needs but also that it provided them with avenues of support and made it easier for them to make progress. Conversely others expressed that lack of familiarity created barriers to learning such as seen in the quote below from a 2017-18 participant:

"I feel it would be difficult for those who are not familiar with certain aspects of technology".

Whilst there is no addition detail, the description of difficulties being linked to a lack of familiarity with the technology, is suggestive of a possible link to the inherent increased cognitive load for these individuals.

3.1.3 Digital literacy analysis and outcomes

The summary descriptive statistics for the data collected during this study can be found in Table 28.

3.1.3.1 Statistical tests

The DHS study aimed to address three questions by carrying statistical tests on the digital literacy scores. These were:

- Is there a difference in the digital literacy of different cohorts of new bioscience students?
- Does the digital literacy of bioscience students differ from that of other STEM disciplines?
- Does the digital literacy of students change over the time that they are on their course?

To address these questions required a statistical test to be performed with the comparison of 3 or more data sets. The outcome of the Shapiro-Wilk test in chapter 2 (section 2.4.5) was used to inform whether a one-way ANOVA or a Kruskal-Wallis test was performed as these are the most appropriate tests depending on whether or not the data is parametric.

Table 28: Summary descriptive statistics showing both mean and median for central tendency of data as is appropriate for mixed parametric and non-parametric data.

Survey year		survey type	Mean	SD	SEM	Min.	25% Percentile	Median	75% Percentile	Max.	Range	N
2017-8	Bioscience	New	27.63	5.433	0.5634	13	24	27	31.5	40	27	93
2016-7	Bioscience	New	26.93	5.964	0.6321	12	22.5	27	31.5	40	28	89
	Chemistry/ Forensics	New	28.74	5.503	0.6674	15	25	28.5	33	40	25	68
	Maths	New	26.9	5.281	0.5904	14	24	27	30	40	26	80
	Physics	New	25.79	6.391	1.466	10	23	27	30	38	28	19
	Computing	New	30.76	5.916	0.5469	11	27	31	35	40	29	117
2015-6	Bioscience	New	22.62	6.061	0.6154	6	19	23	27	37	31	97
	Chemistry/ Forensics	New	23.25	6.779	0.7827	10	19	23	28	40	30	75
	Maths	New	23.07	5.775	0.7859	7	19.75	24	27	37	30	54
	Physics	New	22.93	6.911	1.847	11	17.5	24.5	28	35	24	14
	computing	New	25	6.677	0.8922	13	20	25	29	39	26	56
2014-5	Bioscience	New	21.44	5.246	0.5499	7	18	22	25	36	29	91

The one-way ANOVA is a viable test to use, even with non-parametric data included in the dataset, if there are equal variances between samples and that there are at least 15-20 samples (Minitab blog editor 2016).

To test for equal variance, Levene's test for homogeneity of variance was carried out in SPSS using the sample groupings to be tested by one-way ANOVA/Kruskal-Wallis test. As all groups were shown to have equal variance between samples (see below), these were then subject to a one-way ANOVA with a Tukey's post-hoc test using Graphpad Prism (Graphpad holdings LLC, California, USA). The one-way ANOVA with Tukey's post-hoc tested whether there was a statistically significant (α=0.05) difference in a single variable between multiple samples and compared all pairs of samples to establish which of these were significant. These tests provided multiplicity adjusted P-values that accounted for the multiple comparisons being conducted simultaneously: thereby reducing the likelihood of a type I error (i.e., a false positive result; Dytham 2011).

The outcome of this analysis is shown below for each of the research questions (questions shown in bold). When considering the outcomes of the one-way ANOVAs across STEM disciplines, it became important to establish whether there was a difference between the literacy scores for disciplines over the two years that data was collected. To achieve this, two-way unpaired T-tests were carried out on discipline data.

Is there a difference in the digital literacy of different cohorts of new bioscience students?

This analysis used all four of the new bioscience cohort datasets. The results from the Levene's test for homogeneity of variance generated a p value of 0.443 using these datasets. This means that the null hypothesis is not rejected. The null hypothesis for this test states that there is no difference in the variation of samples: this means that a one-way ANOVA can be used as the sample variance does not violate the test assumptions.

The graph in Figure 10A shows the plot generated by the Levene's test. In some cases, there are datapoints which are identified as potential outliers because of the Levene's test. In the subsequent analysis these potential outliers were not removed because they were confirmed as a genuine recorded measure of digital literacy for that participant and removing it would mean eliminating a valid entry.

The one-way ANOVA produced a p value of <0.0001, meaning that the null hypothesis is rejected, and the alternative hypothesis can be accepted: this indicated that there is a significant difference in the digital literacy scores of the different bioscience cohorts. Tukey's post-hoc test identified that there were significant differences between a number of pairs of data. The pairwise comparisons showed that there were no significant differences between the 2014-15 and 2015-16 cohorts ($p=0.4877$) and the 2016-17 and 2017-18 cohorts ($p=0.8393$); but there was a significant difference in the digital literacy scores of the 2014-15 and 2016-17, 2014-15 and 2017-18, 2015-16 and 2016-17 and, 2015-16 and 2017-18 pairs as indicated by a p value of less than 0.0001 in each case (as shown in Figure 10B).

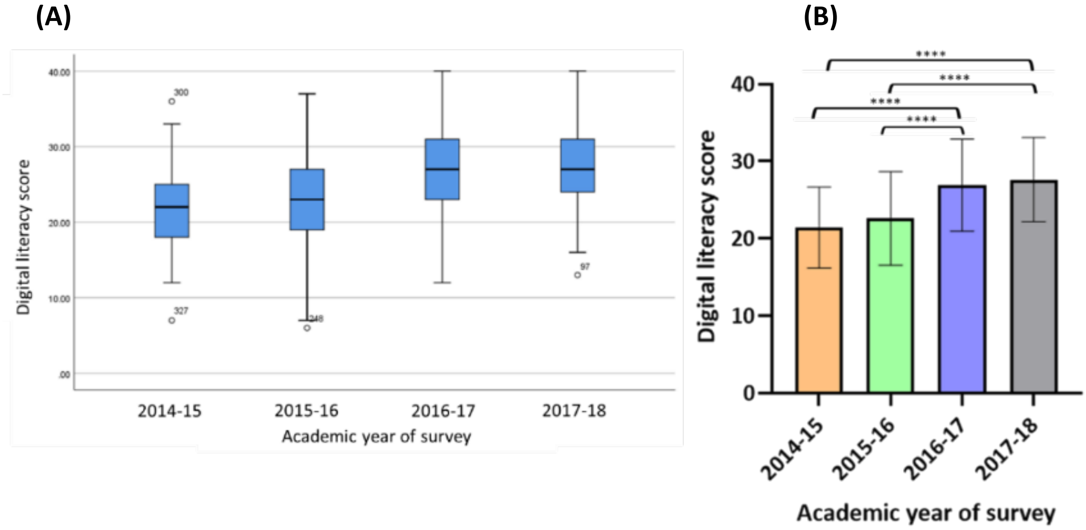


Figure 10: graphical representation of (A) digital literacy scores for different cohorts of bioscience students with potential outliers indicated as individual data points and, (B) the mean digital literacy score for each cohort (+/- SD) (**** denotes statistical significance of p<0.0001)

Does the digital literacy of bioscience students differ from that of other STEM disciplines?

Data on the digital literacy of a range of disciplines was collected for two separate cohorts of students (2015-16 and 2016-17). To be able to establish whether there was a difference in the digital literacy of bioscience first year students compared to their counterparts in other STEM subjects, it was proposed to perform a one-way ANOVA with Tukey's post-hoc test on all new student data from 2015-16, and a separate test for the equivalent 2016-17 data. As with the bioscience new student data, a Levene's test was undertaken to establish whether the samples for comparison had equal variance. The outcome of the test showed that both the 2015-16 and 2016-17 data sets had equal variance across the different disciplines (as can be seen in Figure 11) as they both produced a p value which was greater than 0.05 ($p=0.182$ for 2015-16 data; $p=0.652$ for 2016-17 data).

The one-way ANOVA that was performed on the 2015-16 data was not statistically significant ($p=0.2672$), showing that there was no difference in the means of the data sets: as can been seen in Figure 11(C). By comparison, the one-way ANOVA of the 2016-17 data produced a p value of less than 0.0001. As can be seen in Figure 11(D), the post-hoc Tukey tests showed that significant differences in the mean digital literacy scores of number of discipline pairs. Notably, there was a significant difference ($p<0.001$) between bioscience and computing scores but not with physics ($p=0.9343$), maths ($p>0.9999$), or chemistry ($p=0.2943$).

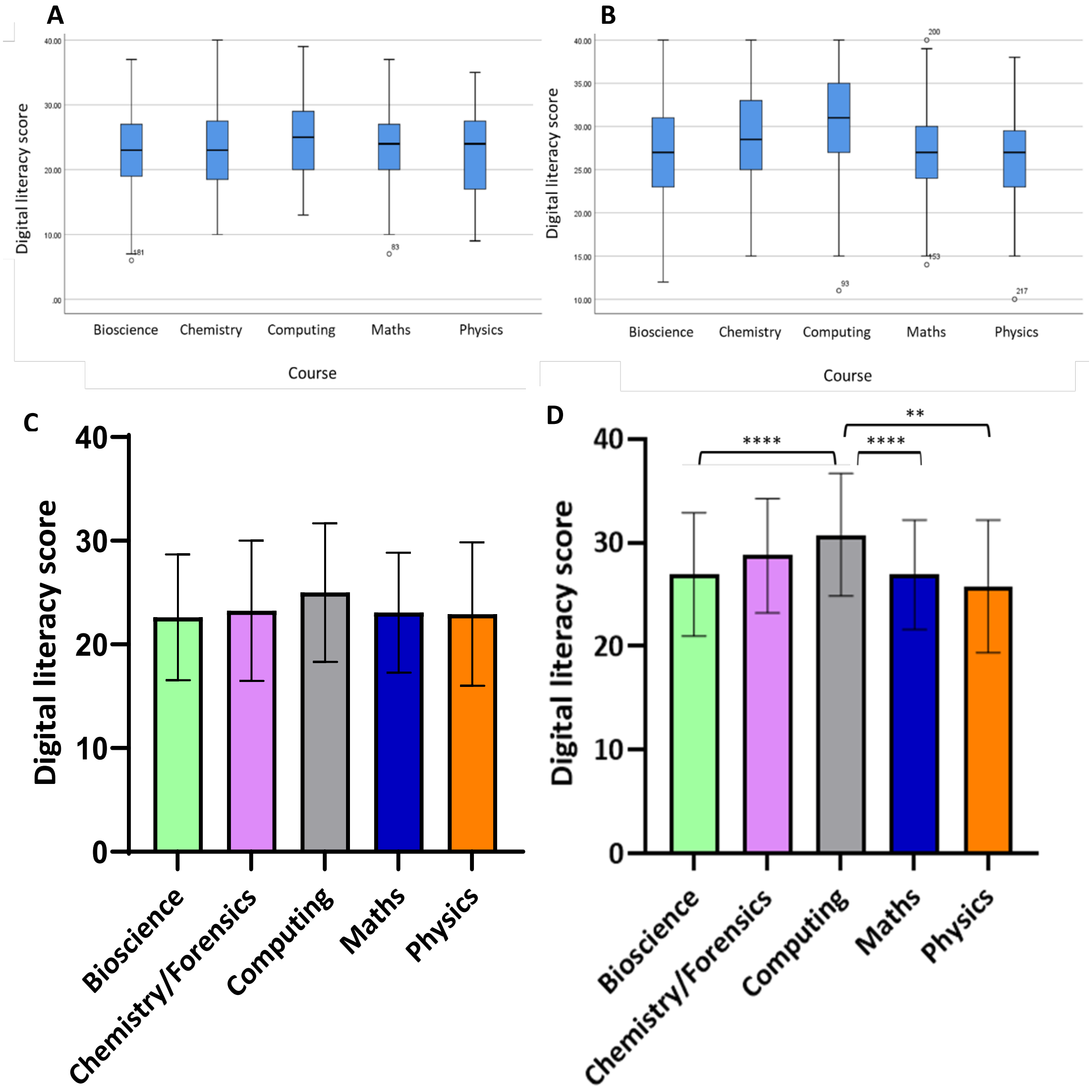


Figure 11: graphical representation of digital literacy scores for students enrolled on different courses in the school of science and technology in (A) 2015-16 or (B) 2016-7 with potential outliers indicated as individual data points. The mean digital literacy score (+/-SD) are shown in C (2015-6) and D (2016-17) with statistical significance shown being based on the outcome of a one-way ANOVA with Tukey's post-hoc test, **$p<0.01$; ****$p<0.0001$

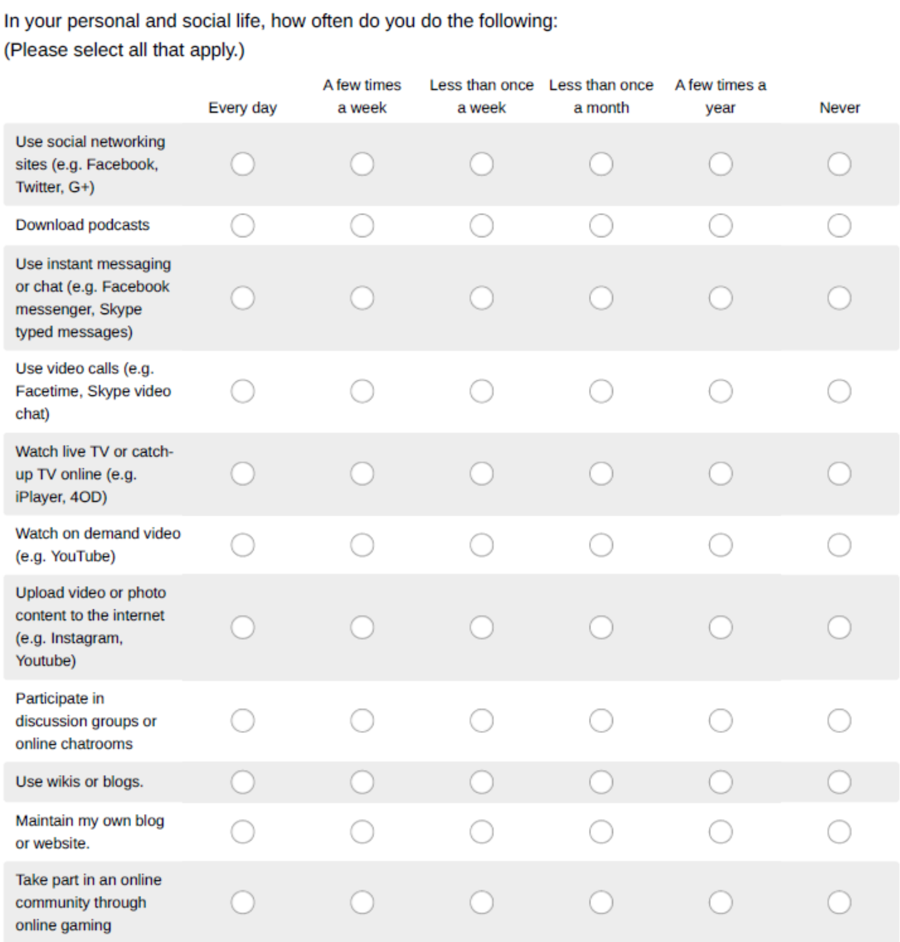
The mean scores for all disciplines increased for the 2016-17 cohort compared to their previous year group: in all cases, except for Physics ($p=0.2287$), this was a statistically significant increase based on the outcome of unpaired T-tests ($p \leq 0.0001$ for computing, chemistry/forensics and maths).

Does the digital literacy of students change over the time that they are on their course?

To address this question required a comparison of new students with their respective cohort data as returning students. Given that there were no surveys completed by 2016-17 returning students, this meant that there was only one pairwise comparison that could be made: that of 2015-16 new students with 2017-8 returning students. Data was investigated to determine how many of the 2017-8 returning students had also completed the original survey as new students in 2015-6 to establish if there were sufficient participants to make the pairwise comparison. Out of the 6 participants in the returning survey of 2017-8, 3 had also participated as a new student in the 2015-6 DHS survey. Given the low sample number and therefore high likelihood of a type I or type II error in statistical testing, the data from these 3 participants were evaluated as case studies. This approach also beneficial as it allowed a more in-depth investigation of how the student profiles changed during their course. Digital literacy scores were interrogated to establish where differences were recorded between the student's first and second surveys. In addition, as the use of technology question on page 18 of appendix 1 (as shown in Figure 12) asked participants to state not only whether they undertook a range of activities but how frequently they did them, this section of the digital literacy scoring was further investigated. The options given to the students are shown in the table below (Table 29). These were converted to a numbered scale (as per the table) to enable mapping of increases and decreases in the frequency of each of the activities. In a similar way to the way that analysis of Likert-type scale data converts ordinal data to ranked numbers which should not be presumed to be equidistant (Sullivan, Artino 2013), so the conversion of the frequency of activity to numeric values should not assume the ranked numbers in Table 29 to reflect equidistant values.

Table 29: summary of conversion of activity frequency to a numeric score

Frequency	Frequency numeric score
Every day	5
A few times a week	4
Less than once a week	3
Less than once a month	2
A few times a year	1
Never	0



In your personal and social life, how often do you do the following:
(Please select all that apply.)

	Every day	A few times a week	Less than once a week	Less than once a month	A few times a year	Never
Use social networking sites (e.g. Facebook, Twitter, G+)						
Download podcasts						
Use instant messaging or chat (e.g. Facebook messenger, Skype typed messages)						
Use video calls (e.g. Facetime, Skype video chat)						
Watch live TV or catch-up TV online (e.g. iPlayer, 4OD)						
Watch on demand video (e.g. YouTube)						
Upload video or photo content to the internet (e.g. Instagram, Youtube)						
Participate in discussion groups or online chatrooms						
Use wikis or blogs.						
Maintain my own blog or website.						
Take part in an online community through online gaming						

Figure 12: question included in the DHS which asked students how frequently they undertook a variety of activities

As can be seen in Table 30, the digital literacy score for all three participants increased from their first-year survey to the final year survey. In three instances participants reported no longer undertaking an activity in their final year survey (shown in the table as returning) which they did in their first survey (shown in the table as new). Two of these activities were activities in their personal and social life with the remaining being whether they customised their computer. There were a number of activities both within the participants personal and social life as well as related to their course that were performed in the final survey but were not undertaken prior to university. Student's experiences prior to university varied so not all participants showed a change in whether or not they undertook a specific activity. For example, in case study 1 and 3, the participant had used a virtual learning environment (VLE) prior to university whereas participant 2 had not and so theirs was the only response that increased their digital literacy score.

Table 30: breakdown of the changes in case study participant answers for digital literacy scored questions in their first year at university compared to their final year. Ticks are used to indicate that a participant has performed that activity; a cross indicates that they have not. Grey shading is used to indicate activities that participant stopped doing between first and final year; green shading is used to show activities that participants have started doing since the first survey (therefore increasing their digital literacy score)

Activity	Point value	Case study 1		Case study 2		Case study 3	
		new	returning	new	returning	new	Returning
Total digital literacy score		22	34	16	20	22	29
General questions							
Customise computer	2	✓	✓	✓	✓	✓	X
In personal and social life							
Use social networking sites	2	✓	✓	✓	✓	✓	✓
Download podcasts	1	✓	✓	X	✓	X	✓
Using instant messaging or chat	2	✓	✓	✓	✓	✓	✓
Using video calls	2	X	X	X	✓	X	✓
Watching live TV or catch up TV online	1	✓	X	✓	✓	✓	✓
Watch on demand video	1	✓	✓	✓	✓	✓	✓
Upload video or photo content to the internet	3	X	X	✓	X	✓	✓
Participate in group discussion groups or online chatrooms	3	✓	✓	X	X	X	✓
Use wikis/blogs	1	✓	✓	X	X	✓	✓
Maintain my own blog or website	4	X	✓	X	X	X	X

Take part in an online community through online gaming	2	✓	✓	X	X	X	X
Before starting the course/ in previous year of course							
Download and save data	1	✓	✓	✓	✓	✓	✓
Put information into a pre-made form	1	X	✓	X	X	X	✓
Co-create resources or work with a peer online	3	X	✓	X	X	✓	✓
Use formulae to manipulate data in a spreadsheet	2	✓	✓	✓	✓	✓	✓
Producing professional diagrams	3	X	✓	X	X	X	X
Using a VLE	1	✓	✓	X	✓	✓	✓
Create graphs using a spreadsheet	1	✓	✓	✓	✓	✓	✓
Insert images, tables and graphs into word processed files or presentations	1	✓	✓	✓	✓	✓	✓
Use cloud storage	2	X	✓	X	✓	X	✓
Interact with staff or students online	1	✓	✓	X	✓	✓	✓

Noticeably there were some activities which were commonly undertaken by all participants in both surveys: these were downloading and saving files, creating graphs as well as inserting graphs/images into other files prior to university. Similarly, some - such as using cloud storage, using pre-made forms and professional drawing - were not undertaken by any of the participants prior to starting their course. Whether these were subsequently undertaken at the end of the course varied according to activity: all participants reported using cloud storage, 2 case studies showed participants using premade forms, but only one of the three examples performed professional drawing.

Data collected for the activities that students undertook before starting or in the previous year of their course was collected as frequencies: in other words, students were asked how often they undertook an activity with the option of "never" given to mean that it was not used. Given that there were a number of activities which were positive in both surveys, comparison of the frequency that these activities were used at gave insight into specific changes that the students experienced. The outcome of this analysis can be seen in Figure 13.

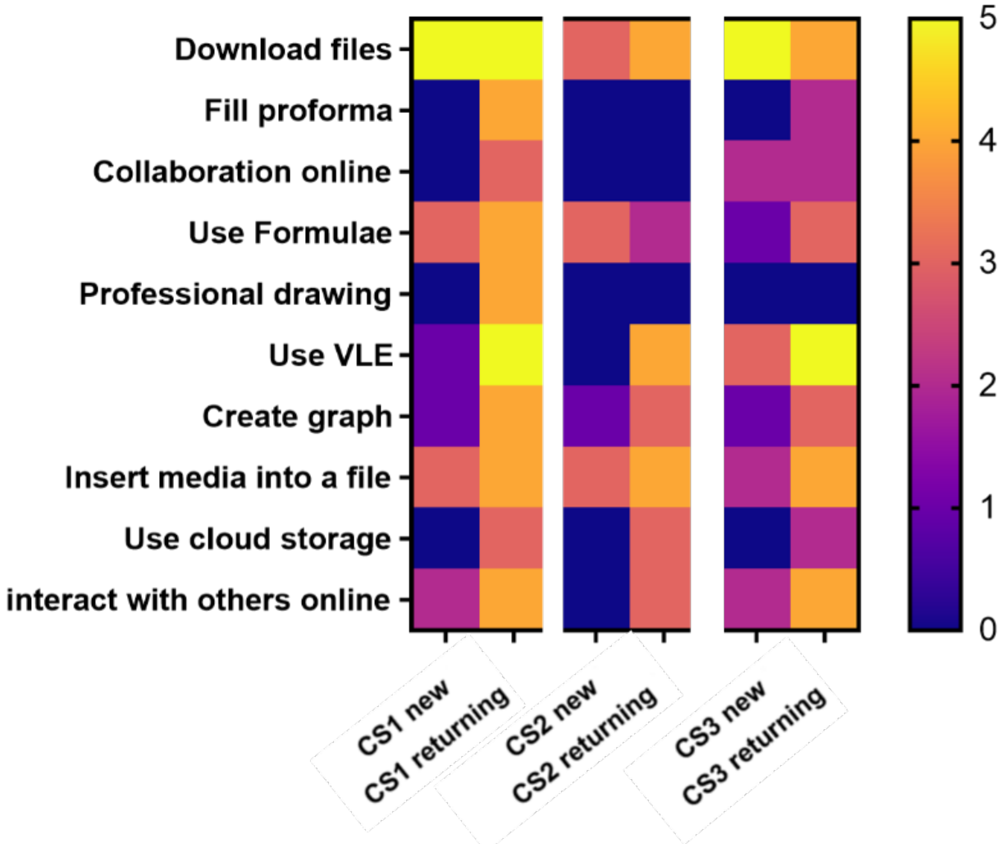


Figure 13: a heatmap comparing frequencies of digital activities undertaken by 3 students prior to university and during their course.

As can be seen in the heatmap, use of a VLE and cloud storage, online interaction with staff and peers as well as creation of graphs and insertion of media in files were more frequently used in the final year of study than the first year for each of the case studies. Use of proformas, online collaborative tools and professional drawing either remained the same or increased in frequency over the course depending on the case study. The remaining activities were more variable with some such as the frequency of downloading files increasing, decreasing, or remaining unchanged depending on the case study.

3.1.4 Discussion of DHS findings

3.1.4.1 Profile of NTU bioscience student use of technology

The outcome of the DHS showed that the number of students with formal IT qualifications reduced over the duration of the study: in 2014-15 26.5% of bioscience students had no formal IT qualifications compared to 48.6% in 2017-18. Despite this, the survey showed a statistically significant increase in the digital literacy scores of bioscience students over the duration of the survey suggesting that IT qualifications are not responsible for the increase in digital literacy score of level 4 students entering the university.

Every cohort of student participants at NTU accessed the internet everyday although there were some variations in where students accessed the internet. Looking back at Figure 9**,** it is clear to see that participants describe the largest positive benefits of technology as the accessibility of information and also communication and collaboration. The observation relating to accessing information is in keeping with findings from JISC surveys which showed that at least 65% of higher education students used digital tools to access material related to the course (but not provided by their lecturers: JISC 2016; JISC 2017; JISC 2018; JISC 2019; JISC 2020). Collaboration with others online was less common, with 62.8% of HE students saying that they had worked with other online in the previous six weeks in the 2016 survey (JISC 2016) but the 2019 showing that 24 % of HE students had never worked with others online (JISC 2019).

In the current research, at least 96% of students used the internet in their home environment but the proportion of students stating that that they used the internet at university fluctuated between 70% and 100% depending on the cohort. Perhaps one explanation can be seen in the data for what types of devices students use to access the internet: 95% of students use a smartphone on a daily basis whereas only 70% use a computer on a daily basis despite 90% of students owning their own laptop. The proportion of students owning laptops in this study was similar to those observed in the 2017 JISC digital experience survey which suggested that 88% of students owned personal laptops but that whilst they owned laptops, smartphones or tablets, desktop computers were more likely to be based in their institution (JISC 2017) .

The potential significance of these findings can be seen in the students working pattern: 84.5- 100% of students agreed that they preferred to work with internet available and increasingly the desire to have their smartphone available whilst working (42.5% students indicated this preference in the 2014-15 survey compared to 70.8% in 2017-18). Given the high proportion of students positively responding to these questions, it is clear that for many students there is a preference for having access to the internet on multiple devices while they study. Irrespective of this, for new students, the likelihood that they would study at university compared to their previous year increased throughout.

Insight into the students' perspective of technology as a learning tool can be seen by looking further into their responses to the question of the impact of technology in their learning. The responses to this question showed that students found technology to have a broadly positive effect with many students indicating that the breadth and accessibility of information was beneficial to their learning. Other themes that were categorised with this aspect was the benefits felt from having an interactive or more immersive learning experience. This is in keeping with observations that more recent technological advances such as simulations and augmented/virtual reality offer students an immersive and interactive experience that has cognitive realism and therefore offers an authentic experience despite not having a physical element to them (Herrington et al. 2007). Not only this but the interactive nature of activities online can provide collaborative opportunities as well as being a flexible student-led approach to learning.

Another aspect that students viewed positively was that technology would help them to develop professional skills with particularly emphasis on transferrable skills in collaboration, communication, time management and ability to research information. These are all transferrable skills that are valued by graduate employers (as will be discussed in chapter 4).

When considering communication and collaboration, student responses indicated that they make use of multiple social networks. In their personal lives, Facebook, WhatsApp, and Snapchat were the most used networks although Facebook was also perceived as a network that could be used professionally (alongside LinkedIn). It is perhaps interesting to note that whilst both new and returning students described Facebook and LinkedIn as professional networks the relative proportion of students using each platform varied between new and returning students: a higher proportion of returning students used LinkedIn for professional networking than new students and a lower percentage used Facebook in this capacity.

As can be seen in Figure 9, there were differences in how students in later surveys viewed the negative aspect of technology compared to at the start of data collection. Themes such as “unreliable” and “difficult to use” were mentioned by multiple participants in 2014-15 survey (Figure 9d) but were much less frequent or absent in the 2017-18 survey (Figure 9c) suggesting that either developments in technology or their familiarity with them (as suggested by the increasing digital literacy score) reduce some of these barriers.

In the survey iterations that asked students about their preferred communication methods, email and VLE scored the most highly: as may be expected. New students also listed Facebook and WhatsApp: this is perhaps not entirely surprising since university administered Facebook groups are used pre-arrival on some courses to help students with questions they may have and so there is potentially the expectation that this will continue once on their course.

3.1.4.2 Student digital literacy

In chapter 1, the definition of digital literacy was described as the capabilities required for an individual to be able to live, learn and work in a "digital society" (JISC 2014).

As noted above, there was a significant increase in the digital literacy of bioscience students from 2016-17 onwards (there was no significant difference between 2016-17 and 2017-18). Similarly, comparison of the mean digital literacy scores in 2015-16 and 2016-7 showed a significant increase for all other STEM disciplines examined except for Physics. The number of physics students participating in the surveys was less than half of the number in the next lowest cohort (2015-16 n=19; 2016-17 n=14) and so it is possible that with such low numbers, the data is more at risk of suffering from a type II statistical error.

Given that this increase in digital literacy appears independent of formal qualifications, it suggests that students are either increasingly gaining experience of using digital tools through application in a classroom environment prior to university or through independent use. One study that may give some insight into this was a survey of level 4-6 students in conducted in 2017 which indicated that approximately half (53.4%) of students felt that their FE experience prepared them with the IT skills they needed for higher education (Bashir et al. 2017): a similar proportion to that reported in the JISC digital experience tracker of 2016-7 (JISC 2017). However, since there is no comparative data from an earlier period, and the authors did not evaluate potential cohort differences, it is difficult to comment on whether the increase in participant digital literacy observed in the current research reflects a change in digital skill provision in FE prior to university. Having said that, it is clear when looking at the JISC survey data that FE students frequently describe experiences of technology that mirrors or exceeds the experiences of their HE counterparts. For example, FE students were more likely to use quizzes in class, work online with others, make a record of their learning (e.g., using a portfolio), get feedback on their work or use augmented reality than HE students (JISC 2020).

Pilot JISC surveys were carried out in 2015-16 (JISC 2016) and 2016-17 (JISC 2017); this matches the period where an increase in student digital literacy was observed in this study. In the JISC 2015-16 survey significant differences were observed between FE and HE students accessing of information online (HE 96.0%; FE 94.1%); working online with others (HE 62.8%; FE 46.6%); and producing work in a digital format (HE 79.1%; FE 71.7%): although the statistical test data (such as p values) were not published as part of the reports. More interesting to our observations about changes in digital literacy would be a comparison of FE student experiences in the 2015-16 and 2016-17 surveys. This comparison is confounded by the fact that the wording for these questions in the two surveys is different and therefore are not directly comparable. In the 2015-16 pilot JISC survey, participants were asked whether or not they had undertaken an activity in the previous six weeks with responses being yes, no or don't know: the report on the outcome of this survey (JISC 2016) only stated the figures for those who had undertaken those activities in the last six weeks. Conversely in the 2016-17 survey, students were asked how often they used these activities with answers being weekly or more, monthly, or less or never (JISC 2017) meaning that any comparison would run the risk of an underestimation of the proportion of students using an activity in 2015-16 if they undertook an activity but simply had not used it within the previous 6 weeks.

Investigating the digital literacy of students entering the university in different STEM disciplines showed no significant difference between the cohorts in 2015-16 suggesting that students entering the university had similar experiences in terms of access to the skills investigated. The picture in 2016-17 differs in as much as students entering the university to study computer science had significantly higher digital literacy skills than other disciplines (except for chemistry) despite a mean increase in digital literacy score in most courses. This suggests that the changes seen in student digital literacy are across STEM subjects and not specifically related to the study of bioscience.

An important feature of this survey was the evaluation of longitudinal data to investigate to what extent student digital skills change over the time on their course. As the digital literacy scoring system used a binary approach to scoring (i.e., it measures only whether a skill is used or not rather than changes in frequency of use) the digital literacy score alone may not provide sufficiently nuanced data to address this point. Given the low number of participants that completed both a new and returning student survey, the data presented for skill development at university is limited to case studies. Importantly, all case studies showed an increase in digital literacy between their new and returning values suggesting that since starting university, they have started using new skills although how much these scores changed varied in each case study (changes ranged from 4 to 12). Closer evaluation of these cases as shown in Table 22, shows that the scoring for this case study is not as simplistic as existing skills remaining and additional skills being added but are actually the result of participants stopping using some skills in their personal and social life and starting to use others (either in their personal and social life or on their course). A good example of this can be seen in case study 1 where the participant stopped using live/catch up TV (an enquiry level information literacy skill) and started maintaining a blog or website (a creative level media literacy skill).

Although the pattern of skills used prior to university and the skills used by final year students were for the most part specific to each case study, there was some commonality. All case studies reported not having used cloud storage prior to starting university but using it during their course. In addition, in two out of the three case studies, participants reported using video calls, putting information in to proformas and downloading podcasts as skills developed over the time of their course. These skills fell into the enquiry and upskilling levels within the NTU digital framework whereas developing creative level skills such as maintaining a blog or website was only seen in one case study. A more detailed evaluation of the frequency with which students used digital skills showed that some skills which were used throughout were used more frequently in students' final year of their course than prior to their course. This lends weight to the argument that whilst digital literacy scoring can be used to evaluate student digital skills, using it alongside frequency analysis provides a more accurate reflection of longitudinal changes in student use of technology.

When considering those skills that were used both before and during the course, there was an increase in frequency of the use of a virtual learning environment, interaction with peers and academics online, creating graphs and insertion of media into files in all case studies suggesting that these are skills that are important across a student's course. These skills crossed different categories in the digital framework (learning technologies; communication and collaboration; computer literacy) and include some of the key skills expected by employers (this will be discussed more fully in chapter 4).

These observations are easily explained when the structure and assessment of students on biosciences courses at NTU are considered. Within all full-time bioscience undergraduate courses there is the expectation that students will collaborate on group pieces of work such as presentations and that there will be multiple opportunities for students to do this over the duration of the course. Both presentations and lab reports lend themselves to the insertion of media into documents and students will frequently incorporate graphs of their data as figures into these. The benchmark statements for biosciences (QAA 2019) direct the incorporation of these skills into bioscience courses through statements such as:

- 4.5 “identify individual and collective goals and responsibilities and perform in a manner appropriate to these roles”.
- 5.7 “prepare, process, interpret and present data, using appropriate qualitative and quantitative techniques, statistical courses, spreadsheets and courses for presenting data visually”.

Although the statements are generalised to allow different disciplines within bioscience to tailor the statements to their area, there is the expectation that universities would use the digital tools currently available to achieve this.

3.2 Modified SLEI

Once the normality testing had been completed (see section 2.5.4), this could be used to decide on which statistical test was most appropriate for analysing the data to address the following research questions:

- Is there a difference in the experience or preferences of different cohorts of bioscience students in Superlab or attitude to technology?
- Is there a difference in bioscience and chemistry/ forensic science student lab experience or attitude to technology?

In addition to the data characteristics, consideration was given to the published methods for analysing data from the original tools.

3.2.1 Is there a difference in the experience or preferences of bioscience students over different years of the survey?

3.2.1.1 Data analysis

The distribution of the bioscience data for each scale for each year can be seen in

Table 13. This table shows that most scale data on the *actual* scale is parametric with the exception of rule clarity (all years except 2017-18) and technology use (2016-17) data. Whilst the majority of data sets for preferred scales are also parametric there are a greater number that are not compared to the *actual* scale. These are rule clarity (all years except 2017-18); social cohesion technology use and integration (2015-16). Given the mixed outcome of the normality testing and to ensure that a consistent approach was taken for both actual and preferred scales, a non-parametric test such as the Kruskal-Wallis test is the most appropriate (the non-parametric equivalent of a one-way ANOVA) and therefore require a series of tests to be carried out (one for each scale).

This differs from the methodology applied by Fraser in numerous studies using the SLEI (Aldridge & Fraser 2008; Fraser & McRobbie 1995; Lightburn & Fraser 2007) suggests that the most appropriate test to use when comparing classroom environments would be a multivariate analysis of variance (MANOVA). Although it is not explicitly stated in these studies, it is assumed that their data distribution was parametric and therefore met the conditions required for a MANOVA analysis (unlike that presented in the current study).

A Kruskal-Wallis test with post-hoc two-stage step-up procedure of Benjamini, Kreiger and Yekuteili was carried out for each scale using Graphpad Prism (Graphpad holdings LLC, California, USA). The outcome of the Kruskal-Wallis tests can be seen in Table 31. As a number of tests were carried out, the Kruskal-Wallis p-values were subjected to Benjamini-Hochberg correction to confirm the threshold for significance (to reduce the likelihood of a type 1 error). For the purposes of this calculation the false discovery rate (Q) was chosen to be 20%.

Of the tests carried out, only the technology use scale (both actual and preferred) produced a significant result which required post-hoc analysis.

Table 31: Outcome of the Kruskal-Wallis comparison of Bioscience data for each scale across all years.

Scale	Kruskal-Wallis p-value	Benjamini-Hochberg correction critical value (1/m)Q	Statistically significant/post-test required
Technology use (actual)	<0.0001	P=0.0181	Yes
Technology use (preferred)	<0.0001	P=0.0364	Yes
Social cohesiveness (preferred)	0.2497	P=0.0545	No
Integration (preferred)	0.2665	P=0.0727	No
Integration (actual)	0.4980	P=0.0909	No
Social cohesiveness (actual)	0.7153	P=0.1091	No
Rule clarity (preferred)	0.7600	P=0.1273	No
Openendedness (actual)	0.8050	P=0.1455	No
Attitude to technology	0.8401	P= 0.1636	No
Openendedness (Preferred)	0.0980	P=0.1818	No
Rule clarity (actual)	0.9479	P=0.2000	No

This post-hoc comparison showed that for the actual scale, student responses in 2014-15 differed significantly from other years (2014-15 vs 2015-16 p=0.0023; 2014-15 vs 2016-17 p<0.0001; 2014-15 vs 2017-18 p=0.0115). For the preferred scale, the 2016-17 was significantly different to the other years (2014-15 vs 2016-17 p<0.0001; 2015-16 vs 2016-17 p<0.0001; 2017-18 vs 2016-17 p=0.0005).

3.2.1.2 Discussion and significance of findings

The analyses carried out for the "actual" scales showed that there were no significant differences over the duration of the study with the exception of the technology use scale. The mean item value for the 2014-15 was significantly lower (4.70 ± 3.18) compared to the other years (2015-16 7.34±3.90; 2016-17 8.60±4.30; 2017-18 7.08±3.86). Over the course of the study there were no significant changes to the delivery of the laboratory classes although as noted in chapter 1, the model of tablet used in the laboratory changed. Students who participated in laboratory classes in 2014-15 will have experienced the Samsung Galaxy tablets with android interface whereas in all subsequent years, the students used Lenovo Thinktab 10 tablets with a windows platform. This may explain why the participants in 2014-15 described a different experience of technology use compared to other years. On the preferred scale, the 2016-17 data showed a higher item mean (8.46±4.33) than in other years (2014-15 2.19±4.70; 2015-16 3.74±4.21; 2017-18 3.78±4.492). It is not clear why the preferences in the 2016-17 technology scale are higher than in other years although it is noted that in the digital history survey data, 2016-17 was the year in which digital literacy significantly increased (see Figure 10). However, if this was responsible for the change in the preferred technology use scale, the 2017-18 data would also have been expected to show a higher item mean since digital literacy in bioscience students remained at a higher level (and not significantly different from 2016-17).

3.2.2 Are the experiences of the Superlab the same for Bioscience and Chemistry/ Forensic science students?

3.2.2.1 Data analysis

To be able to make comparisons between disciplines, item means were calculated for each of the *actual* scales once the data had been divided by discipline (data for all years was collated for each scale). The Item means and whether the data was parametric (as indicated by the Shapiro-Wilk test results in Table 32). In this instance, most data sets produced a p-value in the Shapiro-Wilk test that was less than 0.05 indicating that it was not parametric.

Given the data distribution, non-parametric tests were performed. As each test consisted of only two factors, it was not possible to do a Kruskal-Wallis test as in the previous analysis (which requires 3 or more data sets): instead a series of pairwise comparisons were made. Based on the outcome of the Shapiro-Wilk's tests, these pairwise comparisons were made using Mann-Whitney U tests. As there were a number of these tests carried out, the Benjamini-Hochberg correction was used to identify threshold for significance. Mann-Whitney U tests were carried out in Graphpad Prism (Graphpad holdings LLC, California, USA).

Table 32: Summary data of item means, and data distribution for each scale for bioscience and chemistry/forensic science students.

	Discipline	Item mean	SD	Shapiro-Wilk p-value	Parametric (Y/N?)	N
Social cohesion	Bioscience	2.27	.61	0.0279	N	139
	Chemistry/Forensic science	2.12	.67	0.0094	N	177
Openendedness	Bioscience	3.70	.71	0.0155	N	91
	Chemistry/Forensic science	3.50	.62	0.0273	N	136
Integration	Bioscience	2.36	.73	0.1660	Y	91
	Chemistry/Forensic science	2.40	.73	0.0474	N	136
Rule clarity	Bioscience	1.52	.48	<0.0001	N	132
	Chemistry/Forensic science	1.74	.54	<0.0001	N	178
Use of technology	Bioscience	1.36	.81	0.1016	Y	153
	Chemistry/Forensic science	1.29	.76	0.0393	N	186
Attitude	Bioscience	2.78	.85	0.1628	Y	160
	Chemistry/Forensic science	2.99	.82	0.1029	Y	186

The outcome of this analysis is shown in Table 33. Rule clarity, open-endedness and social cohesion p-values were all below the threshold for significance after correction. As can be seen from Table 32, bioscience student mean item scores for open-endedness and social cohesion were higher than those for their chemistry/forensic science counterparts but scored lower for rule clarity.

Table 33: Summary of the calculations for the Benjamini-Hochberg correction. P values that were lower than their threshold value as indicated by the i/m*Q calculation (and therefore statistically significant) are shown in bold and with an asterix

Scale	p-value	rank	i/m*Q
Rule clarity	***0.0002****	1	0.0333
Open--endedness	***0.0147****	2	0.0667
Social cohesion	***0.0615****	3	0.1000
Technology use	*0.3456*	4	0.1333
Attitude to technology	0.3750	5	0.1667
Integration	0.8507	6	0.2000

3.3.2.2 Discussion and significance of findings

The ability of the SLEI to differentiate between different classrooms has been well documented in a range of settings and countries such as: high schools and universities in England, Canada, Australia, USA, Israel and Nigeria (Fraser & Wilkinson 1993; Fraser et al. 1992); a university in Thailand (Santiboon et al. 2012); secondary school biology classes across Tasmania Australia (Fisher et al. 1997; Henderson et al. 2000) and the USA (Lightburn & Fraser 2007). Whilst the literature discusses and compares different classroom environments, there is no indication that these are different cohorts using the same physical space and so the outcome of the current research represents a novel finding since it discriminates between different disciplines using the same physical space. It should be noted, however, that the majority of published studies have used secondary education rather than higher education for their case studies; and in the case of the technology use and attitude scale, these have been used exclusively in a school setting.

An important factor when evaluating the significance of the findings from the modified SLEI is the alternative approach used for the statistical analysis of the data in this thesis compared to those commonly used by researchers using the SLEI tool; which favours the use of a MANOVA analysis (Aldridge, Fraser 2008; Fraser, McRobbie 1995; Lightburn, Fraser 2007) . The literature around the use of this tool does not comment on the normalcy (or otherwise) of the authors' data and so it is not possible to determine whether the published literature makes use of the MANOVA because their data conforms to a parametric distribution. The data presented in this study has a mixed distribution and so the approach taken to hypothesis testing is appropriate for the data sets that are in this study.

Having said that, the data handling approach described by Fraser, makes mention of filling gaps in scale answers with a neutral answer (the number 3), although there is no indication of how frequently this is applied to the data. As a result of the addition of a neutral response, the likely outcome is to bring the data closer to the central tendency and increase the likelihood of data showing a parametric distribution if these additions are numerous. It is not possible for this to be evaluated as information on how many records have been modified is not provided as part of the published literature.

The analysis of the modified-SLEI showed significant differences in three scales: social cohesion, open-endedness, and rule clarity. The item means for social cohesion and open-endedness were higher for bioscience than for the chemistry/forensic science cohort, whereas the rule clarity item mean was higher for chemistry/forensic science. These observations bear similarities to the study by Hofstein et al. (1996) which showed a significantly higher score for open-endedness for secondary school bioscience laboratories than for chemistry; but observed a higher score in chemistry for rule clarity than in bioscience.

Social Cohesion

The item mean for social cohesion was 2.27 ± 0.61 for bioscience and 2.12 ± 0.67 for chemistry/forensic science. Considering the questions that are included in the social cohesion scale, this suggests that bioscience students feel that they are more likely to work with and get to know other students in their class than their chemistry/forensic science counterparts. In part this may be explained by the different approaches or types of experiments that students undertake between disciplines. When bioscience students take a laboratory class in Superlab, they will typically be working as a pair on their experiment, although for some classes they may work together in groups of up to four students: it is rare for students to work individually. Conversely, Chemistry students frequently make use of equipment that increases the likelihood of working independently rather than with their peers: this can include use of fume hoods for undertaking their experiments and moving between laboratories to access analytical equipment (which are located in alternative lab spaces in the same building).

O*pen-endedness*

The item mean for this scale is 3.70 ± 0.71 for bioscience compared to 3.50 ± 0.62 in chemistry/forensics showing a more positive response to this scale amongst bioscience students. As the open-endedness scale is focussed on the extent to which students feel able to independently explore a topic, the higher mean observed for bioscience students suggest that they experience more opportunity to work independently than chemistry and forensic students. Although practical classes in both disciplines make extensive use of protocols to guide practical classes, both have aspects that give students freedom to work independently although it may be the way in which this is managed in different disciplines which changes the student perception. An example of this can be seen in approaches to first year practicals. Chemistry/Forensic science students will experience a circuit of scripted practicals with well-defined objectives and expected outputs, as well as a project where they design and carry out their own experiments. Bioscience students will experience a range of experiments where some aspects may be more flexible throughout but first year students would not typically design their own experiments from first principles. For example, first year bioscience students would undertake a microbiology practical in which they choose areas of the lab and themselves to swab to see what will grow (and can subsequently be identified) on agar plates. This experiment allows the students to investigate what type of organisms can be found in their environment and as part of their microbiota whilst giving them the freedom to make the choice of sample. Similarly, students can bring in a food item from home as a sample to test for genetically modified material. It is perhaps the fact that this choice permeates throughout their practical classes that results in bioscience students scoring open-endedness more positively.

Rule clarity

In comparison to the other scales which showed a difference between disciplines, for rule clarity the item mean was higher for chemistry/forensic science (1.74 ± 0.54) suggesting that these students were more aware of there being different rules for the laboratory compared to bioscience students (item mean of 1.52 ± 0.48). This is perhaps unsurprising when comparing the types of experiments that students undertake, particularly in their first year (first year students make up the majority of participants in this study). Chemistry practicals frequently need to be carried out in fume cupboards due to the hazardous nature of the chemicals used, or potential for unstable or thermodynamic reactions that are being undertaken. In contrast, bioscience students rarely use the fume cupboard and will sometimes even be able to remove safety equipment such as safety glasses to view specimens using binocular light microscopes.

Summary

Taken together, the modifications made to the survey questions (as described in chapter 2 and Appendix 4), deviation in analytical method, and the limited use of the SLEI, TROFLEI or Attitude scales in a higher education environment suggest that caution should be applied when interpreting these results. On this basis, the relevant findings from this study were used to inform the next phase of the project, which is described in chapter 6.

3.2.3 Case studies of changes in student experience and preferences from first year to final year

3.2.3.1 Data analysis

Of all the bioscience participants who undertook the SLEI during their course, only four completed it in both their first year and final year of study. As there were insufficient numbers to evaluate this data using statistical tests, these were evaluated on an individual basis. To do this, scale scores for their first year were subtracted from the scale score in the final year survey to calculate the difference between surveys: as shown in Table 34. For most scales there was a positive difference showing that the score had increased between first and final year. Exceptions to this can be seen in open-endedness (*actual*) for participant 4; rule clarity (*actual*) for participant 2 and three of the participants on the technology use (preferred) scale. The calculated difference for all four participants was negative for the technology use (actual) and attitude to tablets scales.

Table 34: Summary of the changes in scale scores showing changes in the experiences and preferences of 4 bioscience students at the start of their course compared to their final year. Columns are left blank where data is not available due to scales having different question sets.

Scale		Calculated difference between first year and final year scores				Mean diff.	SD	N
		Participant 1	Participant 2	Participant 3	Participant 4			
Social Cohesiveness	Actual	3	2	0	2	1.75	1.29	4
	Preferred	3	1	0	3	1.75	1.5	4
Open-Endedness	Actual				-3	-3		1
	Preferred				2	2		1
Integration	Actual				10	10		1
	Preferred				4	4		1
Rule Clarity	Actual	2	-1	0	0	0.25	1.26	4
	Preferred	2	0	0	2	1	1.15	4
Use of Technology	Actual	-6	-2	-7	-4	-4.75	2.22	4
	Preferred	-6	-4	0	-3	-3.25	2.50	4
Attitude to Tablets		-7	-7	-7	-4	-6.25	1.50	4

3.2.3.2 Summary and significance of findings

The lack of participants who had completed the modified SLEI in both their first and final years means that investigating changes in student laboratory experience over the time on their course can only be done at a descriptive level especially as data for integration and open-endedness scales were not available in all cases. Whilst there were some small changes in some scales for some participants (e.g., social cohesion), the most marked and consistent change was a reduction in the technology use and attitude to technology scores across the life of the course. The scale totals for use of technology (actual) and attitude to technology reduced for all participants as shown in Table 34 with a mean difference of -4.75 for technology use and -6.25 for attitude scale. The preferred technology scale also reduced in three out of the four participants.

The survey does not offer insights to explain why bioscience students' experience and attitude towards technology (tablets) in the laboratory would have reduced over the duration of their course although it could be speculated that student lab experiences in the intervening time have an impact on this since the students will have had experiences in laboratory environments outside Superlab (and for placement students, outside the university) not all of which will have used tablet technology in the same way. It could also reflect a change in the way that students view the laboratory: with use of tablets focussed on accessing the protocol and recording data and researching information around this outside of the lab rather than using it more broadly during the session. In the absence of the ability to generate a larger pool of data to establish how widespread this viewpoint is, a more qualitative approach has been taken to better understand the student experience of technology in their lab learning (see chapter 6).

3.3 DHS/SLEI cross comparison

3.3.1 Survey cross-comparison analysis

The numbers of students who undertook both a digital history and modified SLEI survey in the same academic year is shown in Table 35. As can be seen, the numbers of returning student numbers who completed both surveys is very low so cannot be used for statistical comparison.

Table 35: Summary of the numbers of participants completing both digital history survey and SLEI survey within the same year. Total cohort numbers are shown in brackets.

	Bioscience	Chemistry and Forensic science	Total
14-15 New DHS/SLEI	10 (310)	18 (268)	28
14-15 Returning DHS/SLEI	2 (423)	2 (290)	4
15-16 New DHS/SLEI	20 (319)	11 (201)	31
15-16 Returning DHS/SLEI	2 (185)	1 (139)	3
16-17 New DHS/SLEI	21 (228)	27 (106)	48
16-17 Returning DHS/SLEI	0 (237)	6 (170)	6
17-18 New DHS/SLEI	8 (321)	9 (136)	17
17-18 Returning DHS/SLEI	3 (268)	3 (122)	6

Data for all years of new bioscience students were combined to create a single data set for each scale and a Shapiro-Wilk normality test carried out (see Table 32 for SLEI scale results). The Shapiro-Wilk test for digital literacy score was not significant (p-value 0.1140;

n=44) so is considered to have a parametric distribution. Based on the mixed outcome of the normality testing, Spearman Rho correlation analysis was carried out (as this test makes fewer assumptions about the normalcy of the data) to compare each scale in the modified SLEI against the digital literacy score for each student using Graphpad Prism (Graphpad holdings LLC, California, USA) as it is a more appropriate test to use when working with non-parametric data.

3.4.1.1 Does digital literacy correlate to bioscience student lab experience, preferences, or attitude to technology?

A total of 41 bioscience students undertook both the digital history survey and modified SLEI in the same academic year. The outcome of the Spearman Rho correlation analysis of this data is shown in Table 36. As can be seen from the Rho value of each scale against the digital literacy scale and corresponding p-values, there were no significant correlations since weak correlations would be expected to have a value of 0.3 or -0.3 (depending on whether it was a positive or negative correlation).

Table 36: Correlation analysis of digital literacy against scales in the modified SLEI showing the Shapiro-Wilk normality test outcome and calculated Rho value and probability (p-value).

	Shapiro-Wilks p-value	Is data parametric?	Rho value	p-value
Social Cohesiveness (actual)	0.3528	Yes	0.215	0.183
Social Cohesiveness (preferred)	0.0054	No	0.093	0.566
Open-Endedness (actual)	0.0075	No	0.093	0.624
Open-Endedness (preferred)	0.0203	No	-0.168	0.374
Integration (actual)	0.1033	Yes	0.218	0.248
Integration (preferred)	0.1730	Yes	0.019	0.920
Rule Clarity (actual)	<0.0001	No	0.053	0.746
Rule Clarity (preferred)	<0.0001	No	0.057	0.729
Use of Technology (actual)	0.0593	Yes	-0.001	0.995
Use of Technology (preferred)	0.0362	No	0.184	0.257
Attitude to Tablets	0.0788	Yes	-0.174	0.282

3.3.2 Discussion and significance of findings

The comparison of the Digital literacy score with scales of the modified SLEI showed that there was no correlation between student digital literacy and their laboratory experience (actual or preferred) or their attitude to tablets in the laboratory. Whilst it might be expected that scales such as social cohesiveness which are designed investigate the relationships between students would not correlate to student digital literacy, it is more unexpected that there is no correlation between their digital literacy and attitude or use of technology in the laboratory. This suggests that whilst students have experience and make use of technology in a variety of ways, this does not translate to their enjoyment, experiences, or preferences in the laboratory. When considering how this impacts the way that staff approach their learners' journeys, it suggests that irrespective of their digital skills, students are able to manage their experimental work in a paperless laboratory environment. However, the data from the modified-SLEI highlights the potential importance of the choice of tools as the technology use scores were significantly lower in the year where the tablet technology was based on a limited number of apps (using the Samsung galaxy tablets) and lacked the option to work with the Microsoft office suite of programmes: which were subsequently available with the Lenovo tablets in the following years.

As this data is not able to provide any insight into what (if any) relationship there is between student digital skills and experience, attitude, and preferences for technology use in the laboratory is, this will be explored in more depth in Chapter 6.

3.4 Conclusions

The development of the DHS and modified-SLEI survey tools was designed to address aspects of the first two aims as described in chapter 1 (section 1.12). In brief this was to:

- Investigate the digital literacy of bioscience students (section 3.1) and whether this impacts their laboratory experience (section 3.3)
- Investigate whether student attitude to technology impacts lab experience in Superlab (section 3.2).

The outcome from the DHS survey clearly showed that bioscience students use the internet every day, frequently work across multiple devices and evidence a wide range of digital skills. The digital literacy score generated by analysis of the DHS showed that new bioscience students had similar digital literacy scores to new students in other STEM disciplines in the school of science and technology at NTU although there was an increase in this from 2016-7 onwards which was also observed in other STEM disciplines (except for chemistry/forensic science students). The case studies discussed in this chapter show that student digital literacy increases over the course but the extent to which this occurs can vary between students particularly if their use of skills in their personal and social life changes. To be able to comment on how representative these case studies are of the cohort would require further investigation with larger numbers of participants.

The current research has developed a modified version of the SLEI to explore student lab experience which has been validated for use within NTU. The main outcomes of using this tool are:

- First year undergraduate bioscience students at NTU had a consistent laboratory experience during the four years that data was collected with the exception of technology use.
- The tool differentiated between the experience of the bioscience and chemistry/forensic science students demonstrating that these disciplines make use of the same physical space in different ways in relation to social cohesion, rule

clarity and ability of students to carry out independent exploration (openendedness).

Whilst their observations were at secondary school level, Hofstein et al. (1996) similarly showed a difference in open-endedness and rule clarity scales between biology and chemistry students when using the SLEI. The Hofstein study did not make use of the addition technology use or attitudinal scales and so it is not possible to comment on how these relate to the current study. The current study also describes a difference in social cohesion that was not seen in Hofstein's comparison however this may be in part explained by the difference in context between secondary and higher education.

For the most part, the SLEI has been used to discriminate between different laboratory environments which are presumed to also refer to different physical spaces given that these typically focus on comparison of a range of geographic locations, although this is not explicitly stated. For example, the study by Henderson et al. (2000) compared 28 biology classes across Australia; Lightburn and Fraser (2007) investigated 25 biology classes across USA. Other cross-national studies have surveyed different educational settings, not just secondary education classrooms: Fraser et al. 1992 and Fraser, Wilkinson 1993 surveyed 5447 students across universities and high schools in England, Canada, Australia, USA, Israel and Nigeria.

Student attitude to technology was not significantly different either between bioscience cohorts or between disciplines; and did not correlate to student experiences (according to spearman Rho correlations). Not only this, but where data was available, there was no correlation between student digital literacy and attitude to technology. Interestingly student attitude to tablet technology became less positive over the life of their course, based on case study observations. This data only represented the perspective of 4 participants, so warrants further investigation (this will be investigated in more depth in chapter 6).

Overall, the research described in this chapter suggests that bioscience students' experience of the laboratory (in terms of social cohesion, open-endedness, integration, rule clarity and technology use) is independent of their attitude to technology (tablets) and their personal digital literacy. Aspects of bioscience student laboratory experience will be investigated further in chapter 6.

Chapter 4: Graduate digital skills

This chapter seeks to address aspects of the first project aim (sections 1.12.1) through the creation and use of survey tools (as described in Chapter 2) to investigate graduate employer perspective of expected digital skills and whether NTU graduates have these skills based on the outcome of the DHS (see chapter 3). This survey also assessed the relative importance of digital skills compared to other key skills and competencies such as subject knowledge, problem-solving, time management and teamwork.

4.1 Graduate employer data

In the full release of the employer survey, only ten out of the 42 participants who completed the survey stated that bioscience graduates would fill roles in their institution, although in most cases this was not exclusive, and the organisation also employed graduates from other STEM disciplines. The business areas covered by participants whose organisations employed bioscience graduates were: education and training; health, social care and counselling; IT software and multimedia communications; wholesale and distribution; government and public sector; engineering; advertising, marketing and PR; retail and consumer goods; and legal services. The organisations which did not employ bioscience graduates most often described employing maths and computer science graduates with the most common roles being in human resources, data analytics and programming. As the survey was disseminated by the university's employability team, pilot participants may have received the invitation to participate in the full survey. Since the data was pseudo-anonymised at collection, there is no clear way to establish if that is the case and so the data from the full survey is, for the most part, considered separately from the pilot data.

4.1.1 Employability skills

The most frequent answers provided for the top 10 skills/attributes and the top 5 digital skills they expected bioscience graduate entrants to have is shown in Table 37. As can be seen by the asterixes applied to the skills 8 of the 10 most important skills were shared with the top 10 skills in the pilot study.

Table 37: summary of the top 10 skills and the 5 most important digital skills chosen by final survey participants as being key graduate skills. An asterisk is used to denote skills which also featured on the lists in the pilot study.

Skill	Proportion of respondents selecting this answer
Overall 10 most important skills	
Teamwork*	8/10
Initiative *	8/10
Ability to solve problems*	8/10
Time management*	8/10
Ability to source and critically evaluate information	7/10
Effective oral communication skills*	7/10
Subject specific knowledge*	6/10
Computer literacy*	6/10
Ability to interpret data	6/10
Digital communication skills*	5/10
Overall 5 most important digital skills	
Computer literacy*	10/10
Analyse data using suitable tools*	7/10
Effective use of media*	7/10
Awareness of e-security, data protection and intellectual property rights	7/10
Effective strategies to search for information online and critically evaluate it.	7/10

A breakdown of the number of participants that selected a skill/attribute to be in their top ten skills for their graduate role can be seen in Figure 14. Although the numbers vary according to the skill, only the construct and maintain website had no responses.

A similar profile of the top 10 graduate skills were also observed in the non-bioscience graduate employers with problem-solving, and ability to interpret data featuring as the highest frequency skills, followed by effective oral communication, time management, teamwork, initiative and ability to source and critically evaluate sources of information. However, data analysis , project planning and computer literacy all featured in the top 10 skills for these employers but were absent for bioscience graduate employers as can be seen in Table 37.

Similarly, comparison of the top 5 digital skills showed with the exception of one skill, both groups of employers required the same digital skills. Computer literacy, effective use of media, ability to analyse data using suitable tools, and sourcing and critically evaluating information were in the top 5 digital skills for both employer groups: whereas database construction was prioritised non-bioscience employers over awareness of e-security, data protection and intellectual property (as seen in Table 37).

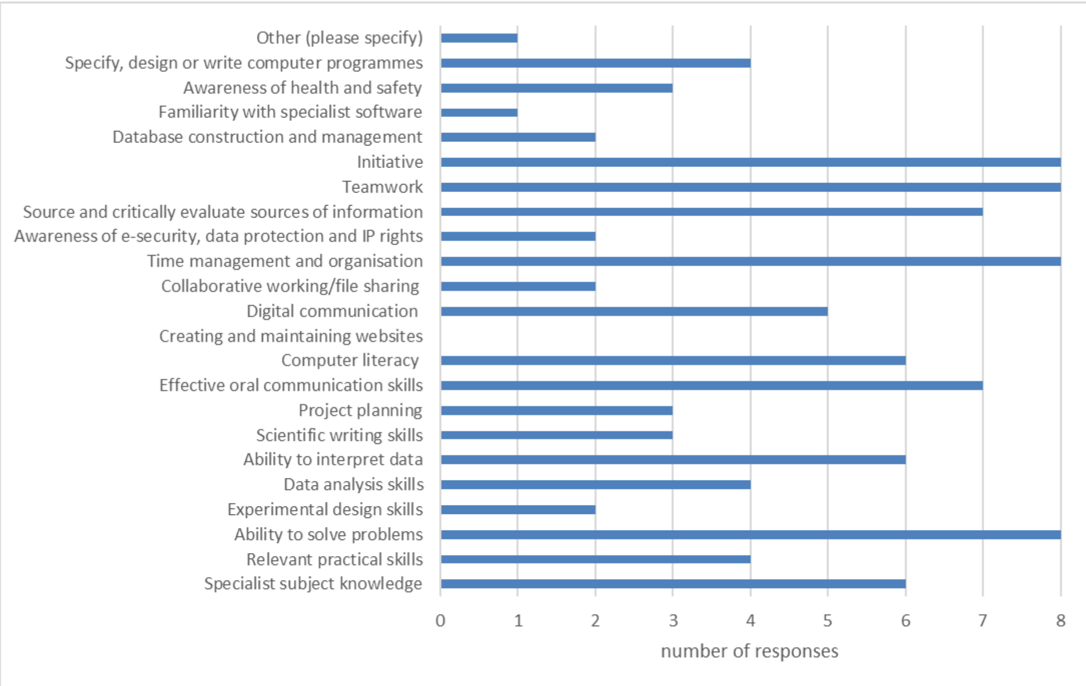


Figure 14: Number of participants selecting different graduate attributes as within the top 10 attributes needed by bioscience graduates for graduate roles.

4.1.2 Digital skills

4.1.2.1 Computer literacy

Enquiry level

As can be seen in Table 38, most participants stated that they expected bioscience graduates to be aware of e-security and data protection: whereas fewer participants expected them to be aware of copyright or intellectual property rights (IPR). Whilst a similar profile of responses can be seen for non-bioscience graduate employers, the expectation that potential graduate employees would be aware of copyright and IPR was higher for non-bioscience graduates than bioscience graduates.

Table 38: Proportion of responses of participants with different graduate recruitment profiles that agreed with potential employees needing to be aware of different digital factors.

Response	E-security	Data protection	Copyright	Intellectual property rights
Bioscience graduate employers (n=10)	80%	90%	50%	50%
Non-bioscience graduate employers (n=23)	87%	87%	74%	74%

Upskilling level

The frequency that graduates were expected to undertake upskilling level computer literacy activities are shown in Table 39. All employers indicated that they expected graduates to understand the security risks of downloading files and apps from the internet. A similar proportion of bioscience graduate employers and non-bioscience graduate employers indicated they expected graduate roles to search online for resources or information, and to select and use appropriate file storage options. Expectations around the use of specialist software was more variable: 83% of non-bioscience graduate employers stated that their role required the use of specialist software on a daily or weekly basis compared to 50% for bioscience graduate employers.

Experienced level

Of the participants answering questions that mapped to the experienced level computer literacy skills, all bioscience graduate employers answering this question (7) stated that they expected graduates in their institution to be able to identify security risks to systems and introduce preventive measures, whereas only 14 out of 23 non-bioscience graduate employers agreed with this statement. The frequency that graduate roles were expected to undertake experienced level computer literacy skills is shown in Table 39. Constructing or managing a database varied in both participant groups. Six of the ten participants stated that bioscience graduates were expected to select appropriate computational devices, interfaces, and protocols on a daily basis whereas for non-bioscience graduates this activity showed greater variability.

Creative level

The frequency that creative level computer literacy skills were used by the ten bioscience graduate employer participants that answered these questions (see Table 39) showed that these skills had a higher frequency of "as required" or "N/A" responses than at previous skill levels. At least half of participants stated that these skills were carried out as required or were not applicable, with eight out of the ten participants stating this as the frequency that graduates would design, construct, or manage networked computer systems in their institution's graduate roles. Four out of the ten participants stated that their graduate roles expected them to be able to incorporate information security when building software systems. Similarly, there was a high proportion of non-bioscience graduate employers for whom these skills were not applicable or were used as required.

Table 39: Summary of the frequency of computer literacy activities of different levels expected in graduate roles for bioscience (n=10 ; except where asterix applies, then n=9) and non-bioscience graduates (n=23). Frequency is abbreviated as follows: D is daily; W is weekly; M is monthly; Q is quarterly; AR is as required; N/A is not applicable.

	Bioscience graduate employers' response (%)						Non-bioscience graduate employers' response (%)					
	D	W	M	Q	AR	N/A	D	W	M	Q	AR	N/A
Upskilling												
Use specialist software	50%	0	20%	10%	10%	10%	61%	22%	0	4%	13%	0
Select and use appropriate file storage options	70%	10%	20%	0	0	0	70%	13%	0	4%	9%	4%
Search online for resources or information*	78%	11%	0	0	11%	0	65%	17%	4%	0	9%	0
Experienced												
Construct or manage a database	10%	10%	30%	10%	20%	20%	30%	9%	22%	13%	17%	9%
Select appropriate computational devices, interfaces, and protocols	60%	20%	10%	0	10%	0	17%	4%	17%	17%	30%	13%
Creative												
Specify, design and write computer programmes	30%	0	10%	10%	20%	30%	26%	9%	13%	0	26%	26%
Construct and maintain webpages	10%	0	20%	0	20%	50%	0	9%	17%	4%	39%	30%
Design, construct or manage networked computer systems	10%	0	0	10%	30%	50%	4%	9%	9%	9%	22%	48%

4.1.2.2 Media literacy

The upskilling level media literacy question relating to the embedding of images or multimedia objects into files received a varied response. Thirty percent of bioscience graduate employers stated that graduates used these on a daily basis; 10% of respondents on each of a weekly and monthly basis; 20% as required, with the remaining participants stating this was not applicable to graduate roles.

The responses from non-graduate employers was similarly varied but with the highest number of responses being that this skill was used on a weekly basis (30%) or not applicable (26%).

4.1.2.3 Information literacy

Enquiry

Creating documents using a word processing package was categorised as an enquiry level information literacy skill. As can be seen in Table 40 this was a daily activity for half of the bioscience graduate roles; which was a similar outcome to that seen for non-bioscience graduate roles.

Upskilling

Eight out of ten (80%) participants stated that they expected graduates to be able to identify legal and ethical security risks in data/information storage, whereas only 61% of non-bioscience graduate employers had this expectation. Six participants (60%) expected those in bioscience graduate roles to support and develop others through use of professional networks: whereas this expectation was lower in non-bioscience graduate roles (43%). As seen in Table 40, when asked how often graduate roles would make use of analysis tools the most common responses were daily or as required (30% each); by comparison in non-bioscience roles 48% of participants make use of these daily, with a further 26% using them weekly.

Experienced

Table 40 shows that, a third of the bioscience graduate roles stated that constructing bibliographies or collating references in a management tool (33%; 3/9) was not applicable which was similar to that described in non-bioscience roles (39%).

Creative

Of the nine participants that answered the creative level information literacy skill question, 56% (5/9) expected bioscience graduates to critically evaluate the validity and reliability of source material on a daily basis: this was similar to observations for non-bioscience graduate roles where 55% of roles used this skill daily.

Table 40: Summary of the frequency of information literacy activities of different levels undertaken by bioscience graduates (n=10 ; except where asterix applies, then n=9) and non-bioscience graduates (n=23; n=22 were § used).

		Create a document or report using a word processing package e.g.MS Word	Use analysis tools (e.g Excel, SPSS) to record and analyse data	construct bibliographies or collate references in a management tool (e.g. Refworks)	Critically evaluate the validity and reliability of source material
Skill level		Enquiry	Upskilling	Experienced	Creative
Bioscience graduate employers (n=10)	Daily	50%	30%	11%*	56%*
	Weekly	20%	10%	11%*	33%*
	Monthly	10%	20%	22%*	11%*
	Quarterly	0	10%	0*	0*
	As required	20%	30%	11%*	0*
	N/A	0	0	33%*	0*
Non-bioscience graduate employers (n=23)	Daily	43%	48%	4%	55%§
	Weekly	13%	26%	13%	26%§
	Monthly	17%	13%	0	4%§
	Quarterly	4%	4%	4%	0§
	As required	22%	4%	35%	14%§
	N/A	0	4%	39%	0§

4.1.2.4 Communication and collaboration

Enquiry

When asked how frequently graduates would be expected to use email to communicate with individuals or groups either within or outside their organisation all respondents (for both bioscience and non-bioscience graduate roles) stated that this was a daily activity

(Table 41). Whereas creating a presentation using a digital tool received a range of responses from both bioscience and non-bioscience graduate employers. Non-bioscience graduate roles were most likely to use this skill on a monthly basis or as required; whereas there was a more even split in the frequency that bioscience graduate roles used presentation skills.

Upskilling

As seen in Table 41, half (56%) of bioscience graduate employer participants stated that they expected graduate roles to use conferencing software on a daily basis with a further 11% expecting it to be used on a weekly basis. For non-bioscience graduates, the cumulative percentage for daily and weekly use of conferencing software was similar: 67% for bioscience graduate roles compared to 65% for non-bioscience graduate employers. However, the proportion for each response was more evenly split between daily and weekly use for the non-bioscience graduate employers than for the bioscience graduate employers.

Use of social media was less commonly required on a daily basis than using conferencing software for both groups of employers but was much more likely to be used “as required” or to not be applicable than the use of conferencing software (bioscience graduate employers 22% for conferencing software, 33% for social media; non-bioscience graduate employers 17% for conferencing software, 56% for social media). The proportion of non-bioscience graduate roles where social media was not applicable was higher than for bioscience graduate employers (36% non-bioscience graduate employers; 11% bioscience graduate employers).

Table 41: Summary of the frequency of communication and collaboration activities of different levels undertaken by bioscience graduates in a variety of business areas.

		Create a presentation using a digital tool such as MS powerpoint, or prezzi	Use email to communicate with individuals or groups both within the organisation and externally	Use online conferencing software (e.g. skype) to hold meetings	Use social media (such as facebook or twitter), or professional networks (e.g. LinkedIn, researchgate)	Work collaboratively or share information using digital tools such as googledocs, dropbox or onedrive	Using Virtual Private Networks (VPNs) to securely connect to work network from remote locations e.g. home
Skill level		Enquiry	Enquiry	Upskilling	Upskilling	Experienced	Experienced
Bioscience graduate employers (n=9)	Daily	22%	100%	56%	33%	33%	22%
	Weekly	22%	0	11%	11%	44%	56%
	Monthly	22%	0	11%	22%	0	0
	Quarterly	33%	0	0	0	0	0
	As required	0	0	22%	22%	22%	22%
	N/A	0	0	0	11%	0	0
Non-bioscience graduate employers (n=23)	Daily	9%	100%	26%	13%	26%	26%
	Weekly	22%	0	39%	26%	30%	26%
	Monthly	30%	0	9%	0	9%	4%
	Quarterly	13%	0	9%	4%	0	0
	As required	26%	0	17%	26%	30%	43%
	N/A	0	0	0	30%	4%	0

Experienced

Of the bioscience graduate employers that answered questions for this skill level, only two out 9 responses (22%) stated that they did not expect graduates entering their organisation to be able to select online collaborative tools that take account of copyright and data protection, compared to 30% in non-bioscience graduate employers with a further 17% stating that this was not applicable to their role. For both questions that asked about the frequency of use of experienced level skills in collaboration and communication, the most frequent responses for bioscience graduate employers were weekly for both the option to work collaboratively or share information online (40%) and use of a VPN for remote working (50%). This differed from non-bioscience graduate employers where working collaboratively or sharing information online were most commonly undertaken weekly or as required (30% in each case) and use of a VPN was as required (43%).

4.1.2.5 Learning to learn

Upskilling

Of the 10 bioscience graduate employers that answered the question of how often graduates in their organisation would be expected to manage their own time or organise meetings using shared calendars or other digital tools, most (80%) indicated it was a daily task: this was similar to that reported for non-bioscience graduate roles (83%).

Experienced

Responses to the experienced level question about the frequency of using relevant tools to plan projects either individually or as a group, received a more varied response than the upskilling level questions. For both employer groups the most common response was that it was a weekly task (40% for bioscience graduate employers; and 26% for non-bioscience employers).

4.1.2.6 Learning technologies

Experienced

The most common response to how often bioscience graduate employer groups would use digital tools to design assessments was "as required" (44%); for non-bioscience graduate employers the most common responses were weekly or that it was not applicable).

4.1.2.7 Digital identity and employability

Enquiry

Both groups of graduate employers indicated that they expected all graduates to use passwords for security; and most to be able to distinguish between social and professional networks (100% for bioscience graduate employers; 91% for non-bioscience graduate employers).

Experienced

All bioscience graduate employers, but only half (57%) of non-bioscience graduate employers, expected graduates to be able to manage the security of multiple accounts/digital identities online. For non-bioscience graduate employers, a greater proportion (65%) expected graduates entering their organisation to be able to manage several digital identities (compared to managing multiple accounts): this was similar to that for bioscience graduate employers (70%).

When asked how frequently those in graduate roles used digital tools for professional development, the most used response for bioscience graduate employers was that they were used on a weekly basis (44%), followed by as required (22%): the order of these were reversed in non-bioscience graduate employers although the higher value differed markedly (As required 27%; weekly 22%).

Creative

Bioscience graduates entering participant organisations were more likely to be expected to be able to enhance their privacy settings online (80%) than non-bioscience graduate organisations 61%).

4.1.3 Outcomes and significance of findings

The numbers of participants who completed the full employer survey was significantly less than the numbers of participants that were expected to complete the survey (which would ideally have been more than 100) to have representative data that would have enabled discussion of the skill requirements for a range of roles. With only a maximum total of 44 participants taking part and with some questions being answered by 32-33 respondents, a more substantive iteration of the survey would need to be carried out to be able to comment on how representative this data is and to gain insight into a greater range of potential graduate roles.

Employability skills

When examining the responses of participants to what the 10 most important graduate skills are, the most frequently selected skills are all explicitly mentioned in the biosciences benchmark statements or are implied: such as critical evaluation of information (QAA 2019). An example of the latter is computer literacy which is referred to in the benchmark statements as students needing to be able to “use the internet and other electronic sources critically as a means of communication and a source of information”. These observations are in keeping with information previously collated by the RSB from bioscience learned societies which highlighted teamwork, initiative, problem-solving, communication skills and, computer and technical literacy as top 10 employer sought skills (Blackford et al. 2012).

For bioscience graduate employer only 2 of the most frequently selected top 10 skills related to digital skills: computer literacy and digital communication. However, these were only selected by half of the participants. Whilst these categories are generalised at this stage in the survey, the types of skills encompassed by the enquiry and upskilling levels of the computer literacy and communication and collaboration areas of the NTU digital framework (NTU 2014) would be in keeping with the UK government's expectations of digital skills for life and work (Department of Education 2019). Examples of life skills would include using email to communicate with others and use word processing software; whereas work skills would include using a range of tools to share documents with colleagues and using video conferencing for communication. Looking at the student perceived benefits of technology in their learning as described in the DHS (section 3.1.2), there are clear parallels with employer survey findings since students highlighted that technology had benefits in terms of communication, collaborative working, and development of professional skills.

Many of the 10 most important skills, and 5 most important digital skills described by bioscience graduate employers were also described by non-bioscience graduate employers, suggesting a commonality across graduate employment. However, there were also some differences: non-bioscience graduate employers listed data analysis and project planning among their top 10 skills instead of digital communication skills and subject knowledge. They also prioritised database construction over awareness of e-security, data protection and IP for digital skills.

Data provided by a range of STEM employers, centred on the manufacturing sector, highlighted a similar range of key employability skills such as being a team player, communication (written and verbal), problem-solving, proactive (which would equate to initiative in this study) and ability to source and synthesise information (McGunagle, Zizka 2020).

Digital skills

Computer literacy

Despite there being differences in prioritisation of enquiry level skills such as awareness of e-security and data protection against other employability skills, these were still widely described as a requirement by all graduate employers. For the computer literacy skills, the higher the level of the skill as described by the NTU digital framework, the less frequent these skills were typically used. Many of the enquiry level skills (such as knowing about e-security, using email and social media, and word processing documents) fit within the government's description of digital skills for life (Department of Education 2019) so it is perhaps not surprising that these are common throughout different job roles. However, there were some areas where bioscience and non-bioscience graduates varied in the frequency that skills were used though. An example of this can be seen for the use of specialist software (upskilling level) with bioscience student much less likely to do this on a daily or weekly basis than non-bioscience graduates.

Media Literacy

Whilst only one question (at an upskilling level) specifically targeting media literacy was included in the survey, the outcome showed more variation in the responses than was observed in the computer literacy upskilling questions both for bioscience and non-bioscience employers. Bioscience graduates were more likely to utilise these media literacy skills than non-bioscience graduates: with the most frequent answer supplied for bioscience graduate roles being on a daily basis, whereas for non-bioscience graduates this was most likely to be on a weekly basis (30%). In both groups of employers 30% of participants selected that media literacy skills were not applicable, suggesting that as with high-level computer literacy skills, the importance of media literacy skills may be more dependent on job role rather than being universally applicable.

Information literacy

For both the bioscience and non-bioscience employers, information literacy skills show frequent use of skills across the different levels: from enquiring to creative skills. In fact, in both employer groups the create level skill (critical evaluation of the validity and reliability of source material) was the skill which showed the highest percentage of participants stating that it was used on a daily basis (56% for bioscience employers; 55% for non-bioscience employers).

The skills covered in this area of the framework are supported by the bioscience benchmark statements (QAA 2019) which include the need for students to be able to evaluate different sources of material to be able to make reasoned arguments.

Communication and collaboration

The skills examined in this category were broadly applicable across both groups of employers although non-bioscience graduates were more likely to use these skills as required than bioscience graduates. An example of this can be seen in the use of conferencing software where the most common response was daily (56%) compared to 26% of non-bioscience graduate employers using this on a daily basis. Since this survey took place prior to the pandemic, it seems likely that this dimension of the framework might have changed significantly since this time. During the COVID-19 pandemic, conferencing software such as MS Teams and Zoom were routinely used during lockdown periods across all business areas to enable learning, collaboration, and organisation to continue when doing so via face-to-face meetings was not an option. With the upskilling of staff and routine use of digital communication methods necessitated by these circumstances, businesses have moved forward in using these skills to develop strategies for staff to use a hybrid working model (Gratton 2021). This means that these communication skills remain will likely remain in more frequent use than prior to the pandemic.

Learning to learn

The skills represented in this section relate to time management/organisation (upskilling) and project planning (experienced). Time management was a skill that was identified in the original top ten skills for both bioscience and non-bioscience employers; project planning featured in the non-bioscience employer top ten skills. Most bioscience and non-bioscience graduate employer roles expected graduates to manage their time on a daily basis (80% for bioscience employers; 83% for non-bioscience employers). Whilst graduates organising their time was a frequently used skill, the responses for project planning was more varied for both employer groups suggesting that it is a more role specific skill.

Digital identity and employability

The questions in the employer survey relating to the enquiry level digital identity and employability domain, showed a common expectation that all graduates would use passwords for security and in most cases would be able to distinguish between social and professional networks. However, there were substantial differences between bioscience and non-bioscience graduate employers in terms of being able to enhance privacy settings online (creative level) with this being more commonly expected of bioscience employers (80%) compared to 61% for non-bioscience employers. It is perhaps not surprising that this is required by a high proportion of employers as e-security and data protection were important across both employer groups.

4.2 Comparison of bioscience employers' expectation of digital skills vs. bioscience student digital skills

4.2.1 Data comparison

As shown in Table 42, for the skills that were represented in both the DHS and employer survey, a high proportion of responses from bioscience employers showed that those activities were expected in graduate roles. The exception to this was maintaining a blog/website (DHS) which overlapped with "construct and maintain webpages" in the employer survey. This activity was required in only half of the graduate roles and was poorly represented amongst the students' experiences: the highest percentage of usage being 15.31% in the 2017-18 cohort. At least 50% of students had used the other activities shown in Table 42 in the previous year: in many instances the proportion of students using these skills was much higher. Amongst these activities, co-creating resources or working with a peer online scored the lowest percentage across the cohorts. However, there is a limited overlap between the two survey tools and so there are a limited number of comparisons that can be made.

Table 42: Summary of data from DHS (student experience columns) and employers' survey (labelled employer expectations) questions that target the same activities. Data is shown as the percentage of respondents, with number of participants shown in brackets. Student experience data is shown for each year of the DHS survey (with new and returning students shown separately if data was available)

	Employer expectation	Student experience				
		2017-18 (new)	2016-17 (new)	2015-16 (new)	2015-16 (returning)	2014-15 (new)
Co-create resources or work with a peer online.	100% (9)	67.03% (91)	56.82% (88)	57.89% (95)	75.00% (4)	62.93% (116)
Use formulae to manipulate data a spreadsheet	100% (10)	89.13% (92)	67.42% (89)	76.04% (96)	100.00% (4)	80.00% (120)
Create graphs using a spreadsheet		89.25% (93)	87.64% (89)	82.29% (96)	100.00% (4)	90.68% (118)
Insert images, tables and graphs into word processed files or presentations	88.89% (9)	100.00% (93)	98.88% (89)	97.92% (96)	100.00% (4)	98.32% (119)
Use cloud storage	100% (10)	74.19% (93)	84.27% (89)	65.62% (96)	75.00% (4)	81.67% (120)
Interact with staff or students online	100% (9)	93.55% (93)	87.64% (89)	94.79% (96)	100.00% (4)	89.08% (119)
Use social networking sites	88.89% (9)	99.01% (101)	100.00% (89)	89.69% (97)	100.00% (4)	96.69% (121)
Use video calls	100% (9)	96.00% (100)	93.26% (89)	74.23% (97)	0.00% (4)	82.64% (121)
Maintain my own blog or website.	50% (10)	15.31% (98)	14.77% (88)	12.37% (97)	0.00% (4)	14.05% (121)

4.2.2 Outcomes and significance of findings

The focus of this part of the discussion is to address how well bioscience courses prepare students for the world of work. When comparing the student responses against this employer expectation, it can be seen that a high proportion of students meet those skill requirements (many with over 80% of respondents using the skill). The skill which scored the lowest percentage of respondents across all years was co-creating resources with peers online (values ranged between 56-75% across the surveys). These findings are in keeping with the outcomes from JISC surveys which indicated a similar proportion of students working with others online (62.8%; JISC 2016) and seven out of ten were producing work in a digital format. Similarly, in 2019 24% of students stated that they never worked with other students online (inferring that 76% have; JISC 2019); and in the 2020 survey 56% of learners worked with others online.

Interestingly, the student experience is predominantly composed of data from new students and since the survey asks them to describe their experiences in the previous year, it suggests that many of the students are already using these skills before they come to university. As part of the NTU course design, students collaborate and use online tools to co-create resources in both second and final year of their course, so it perhaps not surprising that the proportion of students using this skill is higher in the returning student survey. Half of the employer survey respondents expected graduates to use skills like maintaining a blog or website suggesting it is a lot more role specific than skills such as "use of analytical tools such as spreadsheets" or "cloud storage", which are used by most employers. The use of this skill amongst the student respondents was typically between 10-15% (except for the 2015-16 returning student responses) suggesting that students would be poorly prepared for these roles. This highlights the point made in the government paper which suggests that employers will be experience digital skills gaps at a technical level and which they will need to provide training to overcome (Department for Culture 2016).

4.3 Conclusion

Comparison of bioscience employer expectation and bioscience student experience suggests that a high proportion of students possess the digital skills that employers require in graduate roles although many students already possess these skills when starting their course. Having said that, not all students had familiarity with these skills (e.g., the highest score for using cloud storage was 84%) so reinforcement of these skills as part of university courses would help to develop confidence in their use and to ensure that all students have these core skills. This may help in levelling the playing field for less priviledged students in terms of digital inequality, at least to a certain degree. Overall, the survey reinforced that basic computer literacy skills, organisation/time management and some communication skills were common to all bioscience job roles with other skills (especially those at experienced or creative level) being relevant or used frequently in specific job roles.

When considering how this compares to non-bioscience employers, it is clear that there are core skills which are widely used by all graduates whereas others are more specialised to roles filled by graduates from particular disciplines. For example, all employers valued problem solving, communication skills and expected graduates to use digital tools to manage their time (time management also being a skill prioritised by employers). Whereas, data analysis and project planning were important skills for non-bioscience employers with database construction prioritised as a key digital skill, but these were not prioitised by bioscience graduate employers. Although published in 2015, a review of graduate attributes across tertiary education in different countries (with Australia contributing twice as many papers to the review as the UK, or any other country) demonstrated a similar outcome with communication, teamwork, problem-solving and technical skills accounting for the most frequently represented (Osmani et al. 2015). Despite this, the data presented in this study and described in the literature, is consistent with the World Economic forum's Future Jobs report which predicts that problem-solving and critical thinking will be key skills in 2025 as the pandemic and increasing impact of automation changes the employment landscape (Whiting 2020).

Chapter 5: Pre- and post-laboratory scaffolding to support student learning.

The content of this chapter has contributed to two published papers (S. J. Rayment et al. 2022a; Rayment et al. 2023) as shown in Appendix 8 and Appendix 9. The content of this chapter summarises and updates the context for of these findings to account for more recent published literature.

5.1 Context

As highlighted in chapter 1, laboratory education can be undertaken for a number of reasons which target the different facets of Novak's meaningful learning (Novak, 1980) including building bridges between theory and practice (cognitive), building practical skills (psychomotor) and for motivation (affective). However, limits in working memory can result in reduction in learning gains due to cognitive overload: in other words the need to process too many items through the working memory simultaneously (see figure 1, chapter 1 for illustration of working memory learning model). As highlighted by Reid (2008) and Agustian and Seery (2017), the perception filter has an important part to play in how we approach preparing students for success in the laboratory. Familiarising students with technical language, equipment, and processes that they will experience in the laboratory can allow the perception filter to reduce the load on the working memory, resulting in students being able to prioritise information and enhance learning gains. As discussed in section 1.2, this pre-laboratory approach has been used effectively in bioscience courses as shown in the study by Gregory and Di Trapani (2012), and Cranford et al. (2014).

5.2 Experimental design

This study is split into two parts. The first part involved a survey of bioscience and chemistry module leaders across UK higher education institutions: a total of 30 higher education institutions participated in this survey which was carried out in academic year 2016-2017. The survey was designed to establish current pre- and post-laboratory practice across bioscience and chemistry courses (at a module level) in UK. The second part describes a case study for the development and use of technical videos to support student learning in the laboratory within the NTU biosciences department.

Both parts of this study studies were approved separately by the NTU School of Science and Technology Non-invasive ethics committee (16/17-64). Study 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.

5.3 Pre-and post-laboratory scaffolding in UK higher education institutions

5.3.1 Methodology

The survey which was used to collect data for the pre- and post-laboratory scaffolding of student learning is provided in Appendix 10. This survey was created in collaboration with Jennifer Evans.

The survey itself had three key areas of investigation:

- If and how pre-laboratory sessions were used e.g. whether they were compulsory to attend
- What pre-laboratory activities were used in the module,
- What post-laboratory activities were used in the module.

Use of pre-laboratory sessions (e.g. lectures and seminars) was recorded separately from pre-laboratory activities as the former represents an interaction between the student and a member of the academic team, whereas an activity is most likely to be an interaction between the student and resources or other material.

As part of the descriptive information collected, participants were asked to confirm the level of the module (NQF levels were used). Although the survey was designed to be used throughout the UK, there are different terminologies used to describe module levels depending on location. In England, Wales and Northern Ireland undergraduate and Postgraduate (Masters) levels are described as NQF levels 4-7; in Scotland the equivalent levels are SCQF 8-10. When setting up the survey, levels 4-7 were used as descriptors: given that there was no overlap with the Scottish level equivalents, it was assumed that there would be no confusion when listing the levels for Scottish universities.

Data presented in the results section is shown as the percentage of responses (rounded to the nearest whole percentage point).

Invitations to participate were distributed using two different methods. The first was paper survey distribution; the second method was electronic using either personalised emails or academic mailing lists. The 30 UK HE institutions participating in the study, provided data for 88 modules (45 chemistry; 43 bioscience). The breakdown of level of study for bioscience and chemistry modules included in this study are shown in table 1 of appendix 8.

To identify potential activities that could be used to support laboratory classes, pertinent literature was reviewed. The list of activities that were given to participants as choices for pre- and post-laboratory activities to select from are shown in Table 43 with the addition of an “other” category with associated space for free text entry for any activities not covered by these categories. Not all activities had a key reference but were included due to prior experience of the survey’s authors.

Table 43: Activities listed for pre- or post-laboratory activities (ticks are used to show where these activities were listed) and examples of where these have been seen in the literature

Activity	Included as Pre-laboratory activity	Included as Post-laboratory activity	Example reference
Read protocol/script	✓	X	
Take online quiz	✓	✓	(Cann, 2016)
Watch a video	✓	✓	(Rodgers et al., 2020)
Further reading e.g. journal article, textbook	✓	✓	
Complete relevant calculations	✓	✓	
Complete a safety exercise	✓	X	(Coleman & Smith, 2019)
Hot pen writing	✓	✓	
Write an essay	✓	✓	
Draw a schematic diagram	✓	✓	
Virtual simulation	✓	X	(Dyrberg et al., 2017)
Experimental design/development	✓	X	
Prepare and deliver an oral presentation.	X	✓	

5.3.2 Survey findings

Pre-laboratory sessions and activities

Although the analysis is shown in full in appendix 8, the key findings for the pre-laboratory aspects of the survey were:

- Pre-laboratory lectures and seminars were similarly frequently used (used in 65% of bioscience modules and 60% of chemistry modules) but were more likely to be on the same day as the lab in bioscience modules (54% for bioscience; 22% in chemistry modules).

- Session attendance was more likely to be compulsory in chemistry modules than bioscience modules (67% of chemistry modules; 42% of bioscience modules).
- Both subject had a high proportion of modules where students were expected to undertake a preparatory exercise or activity (bioscience 65%; chemistry 73%). These were more likely to be compulsory or required for entry to the lab for chemistry modules than bioscience modules (72% chemistry; 24% bioscience).
- Comparison of the numbers of activities used in each module showed that chemistry modules used a greater number of activities in their modules compared to bioscience modules (3-5 activities in chemistry modules; 1 in bioscience modules) although in both disciplines the most common activity was for both disciplines. The full distribution of the data for pre-laboratory activities can be seen in figure 3 of appendix 8.
- In bioscience modules, the types of activities varied at different stages of the learner journey. All NQF level 4 and two thirds of level 6 students were asked to read the protocol but only level 4 students were asked to perform calculations, take an MCQ or do a safety activity. Whereas only level 6 students were asked to undertake experimental design or other activities that were integrated with their theory content.

Post-laboratory sessions and activities

The full description of the outcome of the survey questions which focused on the post-laboratory activities is shown in appendix 9, but the key points could be summarised as:

- A high proportion of the modules surveyed stated that they used post-laboratory activities (78% for bioscience modules and 81% of chemistry modules).

- As shown in figure 3 of appendix 9, the most common activities in both disciplines were generating reports and performing calculations.
- All chemistry and most (%) of bioscience modules expected students to undertake data handling activities after lab classes.

5.3.3 Discussion of survey outcomes

Whilst this is discussed in more detail in Appendix 8 (Rayment et al., 2022a), the key findings of this study are summarised below.

Pre-lab activities in biosciences

- The profile of pre-laboratory support described by survey participants demonstrated a marked difference between the chemistry and bioscience modules. In bioscience, students were more likely to have a pre-laboratory lecture/seminar which was on the day of the laboratory class and non-compulsory pre-laboratory activities than for chemistry modules.
- Whilst this study represents the first systematic review of pre-laboratory support for bioscience, this is not the case for chemistry modules. The previous work of Carnduff and Reid (2003) reviewed pre-laboratory activities in 47 chemistry departments in the UK and Ireland and found that 40% of these had pre-laboratory provision: this is markedly lower than in the current study in which reported 73% of chemistry modules provided pre-laboratory activities and 60% had pre-laboratory lectures or seminars.
- An interesting point of note was the proportion of bioscience modules in which a high level of completion (81-100%) of optional activities were reported. Of these, approximately half were at NQF level 6-7 suggesting that either the activities were more engaging or students were more motivated to engage with them – perhaps

because they were more integrated into their laboratory work and therefore perceived to have a higher value, as described by Agustian and Seery (2017).

- The NQF level 6 modules also showed a difference from lower-level modules in terms of the types of activities undertaken: from more experimental design activities and workshops at level 6 to more technical aspects of the lab at level 4 (e.g. reading the protocol and performing calculations). This is in keeping with the model described by the framework described by Seery et al. (2019) which described NQF level 4 equivalent lab classes as focussing on developing experimental skills. This aligned well with the video case study which aimed to familiarise students with core practical skills.

Post-laboratory support

- The post-laboratory data provided by UK HE module leaders highlighted that similarly to the pre-laboratory findings, chemistry modules were more likely to have compulsory activities than their bioscience counterparts (81% for chemistry; 67.6% in bioscience).
- The most common activity used in both disciplines was to write a report although both disciplines used a range of activities, many of which seemed likely to be assessment-linked (e.g., vivas and peer assessment).
- Literature discussing post-laboratory support highlights that students value these activities for supporting conceptual understanding as, irrespective of whether the laboratory itself expository or problem-solving/ inquiry-based, meaningful learning occurred when they were given opportunities to consolidate their learning with prior experience through time for reflection, or addition activities such as report writing and presentations (Anwar et al., 2017; Domin, 2007; Tobin 1990).

- Given that 10-20% of modules do not scaffold opportunities to engage students in higher order thinking about their laboratory classes, these modules would appear to reduce the potential effectiveness of laboratory learning since integration of both pre- and post-laboratory activities have been argued to be required for maximal benefit from laboratory learning (Lewis, 2014; Reid, Shah, 2007; Carnduff, Reid, 2003).

5.4 Development of technical videos to support bioscience laboratory classes

5.4.1 Methodology

When the Rosalind Franklin building was first opened, students and staff completed lab evaluation surveys as a mechanism for getting feedback on Superlab as a new laboratory environment. As part of this survey, both staff and students were asked what techniques students found difficult within the laboratory. Responses from these surveys were used as the basis for the video topics (unpublished work). Having identified a number of areas that both staff and students perceived to be challenging, and recognising the potential benefits of video resources for pre-laboratory scaffolding as described by numerous published studies (e.g. Croker et al., 2010; Gregory & di Trapani, 2012; Rodgers et al., 2020), 11 videos were created to support these techniques. The videos included in this case study focussed on: making a bacterial smear; heat fixing bacterial slides; gram staining, microscopy of bacterial samples; binocular light microscope anatomy; aligning the light source of a light microscope (Koehler illumination); focussing a light microscope; using a spectrophotometer; making dilutions; mixing solutions; and making serial dilutions. The videos were created within the Superlab environment to ensure that any barriers that might have been created by using different makes or models of equipment were minimised. For example, different models of light microscope may position their diaphragm in different locations (either at the light source or with the condenser).

The first group of videos were made available to cohort 1 (n=319) and the feedback (self-reflection, student survey responses and staff feedback) were incorporated into the second group of videos which were made available to cohort 2 (n=228) and cohort 3 (n=323) alongside the first group of videos. Student cohorts consisted of undergraduate biology and forensic biology students at NTU who were in the first year of their course.

Creating video resources

Prior to creation of video content, consideration was given to identifying likely challenging aspects of the techniques to be covered. This was based on the researcher's prior experience of the issues arising in first year student practicals using these techniques or equipment. This information was used as the focus for the storyboarding of the videos. Storyboarding of the proposed video ensured that a methodical approach was taken to ensure a good flow of information and appropriate detail given in the challenging areas of the topic. An example of this process can be found in appendix 8.

Using the storyboard, videos were created by recording video footage in and then editing and narrating this using a combination of Adobe Premier Pro and Audition (Adobe Systems Incorporated, San Jose, CA). It was necessary to record the narration post recording due to the high level of background noise in the laboratory. An example of the software interface for video editing is shown in Figure 15. Once this was complete, the videos were exported and published to the researcher's YouTube channel (Google LLC, San Bruno, CA) as unlisted videos. The perceived benefit of using Youtube was that many students would already be familiar with it; and that smartphones could play the videos (which could not be guaranteed if the university's VLE was used to host the video). These two features were important as it was perceived to allow students to personalise their learning by supporting a more mobile learning environment (as described in the study by Squire & Dikkers, 2012). Subtitles were added to the video to enhance the accessibility of the recordings.

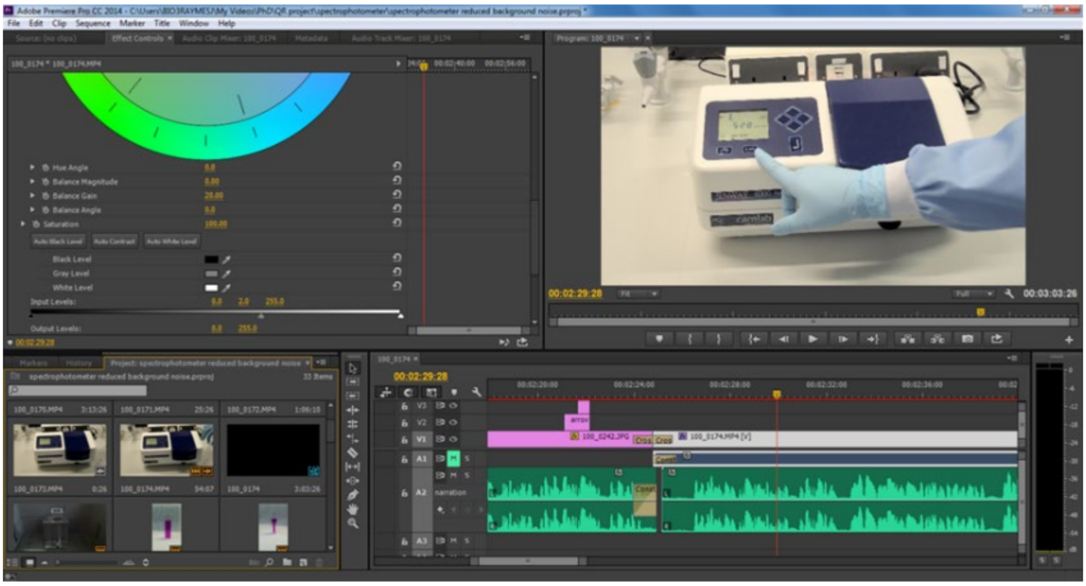


Figure 15: Adobe Premier Pro interface (Adobe Systems Incorporated, San Jose, CA) showing the editing of the spectrophotometry video footage.

Analytics (number of views) for each video were recorded using YouTube channel data. This data was used to calculate the number of views per 10 students for each video to standardise this data to allow comparison across different cohorts since the size of each cohort varied. In addition to the three cohorts described in the study, the Youtube analytics were collected for the first of the academic years impacted by the pandemic (2020/21) where students experienced reduced lab access due to pandemic restrictions to establish whether there has been a change in usage as a result.

The first group of videos that were created were core microbiology techniques which academic staff had identified as challenging for students. These videos were embedded into the laboratory protocol so that students were able to access them at the relevant time. Students were able to access their videos before, during and after their laboratory class. The videos focussed on:

- Making a bacterial smear
- Heat fixing slides
- Gram staining

- Using a microscope to visualise bacteria

The post-laboratory survey (as described below) was given to the first cohort of students as part of the critical reflective cycle used to evaluate the videos. This cycle followed the pattern described by (Gibbs, 1988) and is summarised in Figure 16. In addition to feedback from students, feedback was sought from academic and technical staff through personal communication to take into the analysis phase.

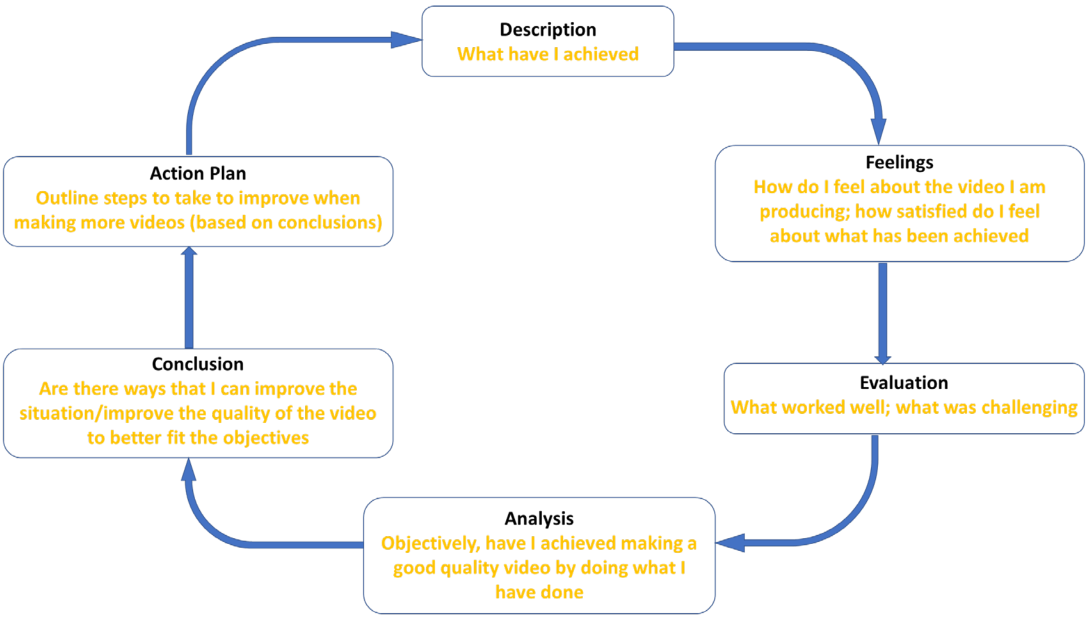


Figure 16: Schematic representation of the reflective cycle used during the making of technical lab videos. The aspect of the cycle as described by Gibbs is shown in black; the orange text represents the way in which this process was applied during this study

The action plan created was used when generating the second group of videos which addressed core bioscience techniques. These were:

- Spectrophotometry
- Dilutions and solution mixing
- Microscopy (anatomy, alignment and focussing)

The second group of videos, which were added to the videos available to the second and third cohort were made available within module rooms rather than specific protocols as they were applicable across multiple experiments. In the evaluation survey students and staff also identified pipetting as a skill that students found challenging. Although videos were made to support various aspects of this technique (e.g. accurate pipetting and reading pipette volumes) these were excluded from the analysis to avoid mis-representing data as participants in the first cohort selected this option (before the video had been made) suggesting that academic staff were using videos from other sources that could have been inappropriately attributed to the researcher's suite of videos.

Video evaluation (survey)

Student expectations of use of technology to support labs and their experience of the laboratory videos were evaluated using a pre-laboratory and post-laboratory survey. Students completed the pre-laboratory survey prior to starting their classes to provide information on the resources that they expected to have available to them. The post-laboratory survey was designed to report on what technology students experienced in their laboratories but also three aspects related to the technical videos as listed below.

- Quality of the video resources: evaluated through likert-like scale questions.
- Impact on student understanding using concept inventory style questions (American Chemical society, n.d.; Hestenes et al., 1992). Examples of these questions can be seen in Appendix 8, figure 2.
- Video usage: investigated using a combination of open and closed questions. The closed questions used a likert-like scale (5 point) to assess the extent to which participants agreed or disagreed with a series of statements. Both positively and negatively worded statements were included to minimise the risk of acquiescence response bias (Lavrakas, 2008). The open questions were designed to provide more detail about the way that students would use the videos outside the laboratory (before or after). Responses were evaluated using thematic analysis as described by Saldaña (2015).

Video evaluation (Focus group)

Evaluation of survey phase data highlighted specific aspects that warranted further investigation. In addition to direct survey responses, the data also suggested that there may be barriers to uptake as there was a poor rate of uptake of videos amongst participants. A focus group was chosen as the method for this investigation as it allowed for the stimulation of discussion about the resources (an example of which was shown during the focus group) between participants that wouldn't have been possible with other methods.

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 the requirement of the students to have experienced the full laboratory programme before engaging in the focus groups, and yet also for the researcher not to be in an active assessment cycle with the students. At the time of the focus group, only 2 of the recruited participants attended. The researcher did not lead the focus group but was instead only present during the session to facilitate playing a clip from one of the videos and to record the order in which participants spoke.

5.4.2 Video case study findings

Although the analysis is shown in full in appendix 8, the key findings for the video survey and focus group are described below.

Quality of the videos

The students in scored the video sound and video qualities positively. As well as agreeing that the videos were of an appropriate length, were relevant to them and that they had an acceptable level of background noise (as can be seen in figure 4 of appendix 8).

Impact on student understanding

Unfortunately, too few students completed the pre- and post-video survey to be able to directly comment on the concept inventory style questions.

Video usage

Many of the key outcomes showing the impact of video usage are shown in figure 6 of appendix 8 but can be summarised as:

- The videos had a positive impact on student confidence in working independently (50% or greater agreed or strongly agreed)
- Students agreed that the videos were useful to their learning. The open questions in the survey highlighted that students found them useful before the laboratory class for familiarisation, boosting confidence and increasing efficiency when in the lab; whereas revision and self-assessment and consolidation of learning were highlighted as uses of the videos after the laboratory.
- Approximately two thirds of survey participants agreed or strongly agreed that "using the videos in the lab helped me focus on the task I was set".

Video analytics

Figure 17 (which is a reproduction of figure 5 of Appendix 8; Rayment et al., 2022a), shows the change in views on YouTube per 10 students within the first-year cohort. This approach was taken to presenting the data due to the fluctuation in student numbers in different academic years. The graph shows a clear increase in all the videos created in this case study during the 2020-21 academic year.

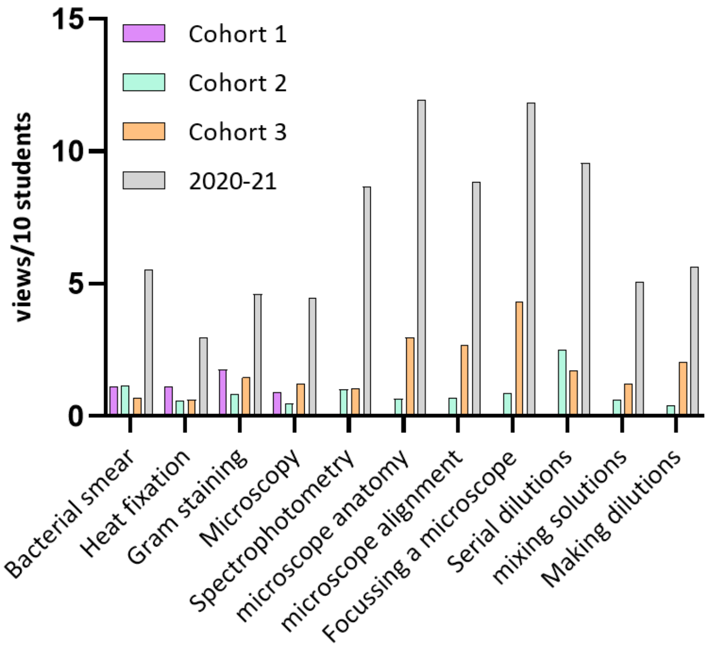


Figure 17: Graphical representation of the YouTube analytics for case study (reproduced with author permission from Rayment et al., 2022a). Student cohorts 1-3 were first year undergraduate bioscience and forensic biology students in the three consecutive years. Cohort 1 was 319 students; Cohort 2 consisted of 228 students; Cohort 3 had 323 students. 2020-2021 data represents the first-year bioscience undergraduate students in the first of the pandemic affected cohorts (471 students).

5.4.3 Discussion of video case study outcomes

Whilst this is discussed in more detail in Appendix 8 (Rayment et al., 2022a), the key findings of the video case study are summarised below.

- Student survey and focus group responses demonstrated that the key benefit of accessing the technical videos produced in this case study ahead of their laboratory classes, was familiarisation with the material. In the focus group, there was discussion that this could help to reduce student anxiety about the laboratory class.
- Survey responses suggested the potential for the videos to reduce cognitive load and working memory given the positive responses to statements such "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". These statements align with the

work of Reid (2008) and Sweller (2010) who suggest that ability to focus on a task is lost when the working memory limit is exceeded (i.e. we enter cognitive overload).

- Students who utilised the videos frequently made use of more than one video. However, video uptake was relatively low in the first two cohorts. The focus group suggested that this was because students were not aware of where to find the resources.
- Access to technical videos gave students more confidence to work independently and to work more efficiently in the laboratory. These observations are in keeping with other studies where students who undertook virtual laboratory activities prior to the laboratory described feeling more confident. (Coleman & Smith, 2019; Dyrberg et al., 2017).
- The YouTube analytics showed a substantial increase in use of the technical videos during the first pandemic cohort compared to previous years. As noted in Rayment et al. (2022a) the use of some of these videos was extended during the pandemic to support students in other contexts. Prior to the pandemic the videos were used by level 4 students either in their term 1 modules, or in the level 4 microbiology module. Whereas, during the pandemic the videos were also used to support level 5 students who were undertaking a microbiology technical lab report assessment. The videos provided a route for the level 5 students to understand the techniques that had been used to generate data for them to use in the assessment. As the microbiology videos would have been used by both the level 4 and 5 at a similar time, it is therefore difficult to separate the relative contribution to the video analytics.

5.5 Concluding comments

The studies presented in this chapter have demonstrated the extent to which bioscience and chemistry modules make use of pre- and post-laboratory support to enhance their laboratory provision. Whilst the “snapshot” of UK HE module provision of pre- and post-laboratory support has increased in Chemistry since the last review in 2003 (Carnduff and Reid, 2003), this study is the first systematic review of bioscience provision. The addition of a technical video case study has enabled the demonstration of the benefits of availability of these resources in terms of familiarisation with equipment and processes ahead of the lab and the consequent benefit in reduction in anxiety and increased confidence and focus when in the laboratory. These observations align with literature that has demonstrated increased learning gains in the laboratory when students are familiarised with aspects of the laboratory prior to the class itself (Gregory & di Trapani, 2012; O’Brien & Cameron, 2012; Rollnick et al., 2001).

Although this study preceded the COVID-19 pandemic, it is important to consider how these observations may fit into the new paradigm this has created. As highlighted in section 1.9, academics’ strategic response to lab education being impeded by reduced or total loss of laboratory activities on campus has resulted in creation or use of a range of virtual tools, including video resources. Whilst videos, such as the technical videos described in this chapters’ case study, would familiarise students with the relevant technical skills, students do not necessarily consider these as a direct replacement for hands-on experience as shown in (McKenna, 2023). However, having access to these resources can enable students to be more prepared for their return to on-campus labs (Heng et al., 2022). Certainly, the use of the videos created in this study increased substantially during the pandemic (as seen in Figure 17), with their use also being applied in more diverse contexts. Such resources are only one of many approaches that have developed during the pandemic; with increasing use of VR and AR, even amongst academics who had previously been resistant to taking these approaches (Tsakeni, 2022; Nischal, Zulema Cabail, & Poon, 2022; Choate et al., 2021). These types of resources, which often support development of experimental design, problem-solving and data analysis skills can give a high level of satisfaction, whether or not the situation requires distance learning (Bassindale et al., 2021). A case study for the integration of these different resources for laboratory learning during the pandemic can be seen in the paper by Wilkinson et al. (2021).

An important development in supporting academics and technical staff during the pandemic was the creation of networks such as The DryLabs network (#DryLabsRealScience). Set up by Dr Nigel Francis (Swansea University), Dr David Smith (Sheffield Hallam University) and Prof. Ian Turner (University of Derby), this network was designed to share practice and innovation in dry lab and capstone project alternatives (Francis, 2020). It has enabled academics worldwide to support both each other, and student learning when distance and virtual learning solutions were essential. Such an approach has similarly been seen in chemistry where online learning networks have supported academics and academics have similarly made use of virtual resources to support student learning (Jones, Shepler and Evans, 2021).

The lessons that the pandemic have shown us, can equally be applied outside of this and provide students with an enriched post-pandemic curriculum compared to previous experiences. These include a wide range of virtual laboratories (Cheesman et al., 2014) such as those created by Labster® (Copenhagen, Denmark) and Learning science (Bristol, UK) (Coleman & Smith, 2019; Dyrberg et al., 2017); pre-laboratory quizzes (Cann 2016; Gregory and Di Trapani 2012); and instructional videos (Croker et al. 2010; Gregory, di Trapani 2012; Rodgers et al. 2020). One benefit of this is that the poor uptake of the videos described in this chapter could improve when integrated into a more substantial package of resources. This was certainly observed when a package of technical videos and virtual resources from Learning science (Bristol, UK) were used to support a “Bioskills at home” initiative that allowed NTU bioscience students to develop practical skills such as pipetting during the pandemic (Rayment et al., 2022).

These observations may be particularly pertinent in terms of tackling student lab anxiety as described in this chapter and in chapter 6. However, as noted in section 1.9, the students whose education has been disrupted by the pandemic may be particularly at risk of having reduced confidence in the laboratory and in terms of lab skill competency (Francis, McClure and Willmott, 2021). For these cohorts especially, the availability of pre-laboratory resources may be particularly valuable to increase familiarity with lab equipment and processes and therefore reduce lab anxiety.

Another benefit to providing students with a more sophisticated laboratory learning experience is the potential for it to improve student engagement: this is particularly relevant when considering that students studying during the pandemic described a lack of motivation (Bashir et al. 2021; Chaplin, Kohalmi and Simon 2024; Pennino et al., 2022). As highlighted in section 1, this may be especially valuable since students reported having a renewed appreciation for laboratory education after returning to campus (de los Santos et al., 2023) and were broadly positive about a blended learning approach (Tahir et al., 2022). However, the role of the educator may be key to this process as previous research suggests that the personalising the student experience by greater dialogue between the educator and student can shift student attitudes to e-resources to become more positive (Mayer, 2017). And, students described a lack of support from their instructors as a barrier to learning (Chaplin, Kohalmi and Simon, 2024).

The outcome of this chapter fits well within post-pandemic laboratory education findings with technical videos having a place in the resources used to support student learning. However, to what extent there has been a shift in the proportion of bioscience modules in

UK HE institutions are offering pre- and/or post-laboratory support is currently less clear and would warrant further investigation.

Chapter 6: What is the role of technology in student lab learning?

The research conducted in this chapter aims to build on the research findings described in chapter 3, to investigate how students use technology in learning associated with practical classes and explore their attitude to this technology. The main findings of this study have been published (see appendix 9). However, the study will be described in more detail here.

6.1 Study rationale

The design process for this study and rationale for the decisions made in how to investigate student use and experience of technology for the lab learning is shown in Figure 18. At the beginning of the process, the individual has been placed as central to the understanding of the purpose of the study, as it is how they construct their understanding of the lab that is being investigated. In this context, technology is viewed as a tool which students may use to develop their understanding. In this respect, the principles in this part of the thesis align with those of connectivism which ascribe that technology can be used as part of the network of resources available to individuals to develop their understanding of a topic for themselves (Siemens 2005; Siemens 2017).

Thereafter, recognition that learning related to laboratory material may take place either in the laboratory (i.e., during the class and therefore directly observable) or, outside of the laboratory (i.e., before or after the session and therefore not directly observable) shaped the methodology choices. As the use of technology outside of the laboratory cannot be directly observed, a semi-structured interview approach was designed with the aim of establishing:

- What students define as technology?
- How students develop their understanding of laboratory material outside the laboratory and the role that technology has in this?

- How their perception of their use of technology in the laboratory correlates to the data from the think-aloud recordings?

The first point was important to make, as how the students define technology may be critical to understanding how they perceive it to impact their learning as well as identifying whether students have the same understanding of what technology is.

This represents a novel approach to the investigation of the student cognitive and metacognitive processes in their laboratory-based learning and the role technology has in this.

To investigate the cognitive and metacognitive processes that students use to develop their understanding of the laboratory and the role that technology plays in this, a concurrent think-aloud protocol was proposed. A think-aloud protocol is a valid methodology for the aims of the study as it is more likely to shed light on “why” and “how” they use technology than other methodologies. Although many studies use think-aloud studies under controlled conditions, fewer do so in a real-world setting. Having said this, student nurses’ approach to using technology in clinical decision-making (Todhunter 2015) and how chemistry students solve open-ended problems, have both successfully used a think-aloud approach in a clinical or laboratory setting (Overton, Potter and Leng 2013).

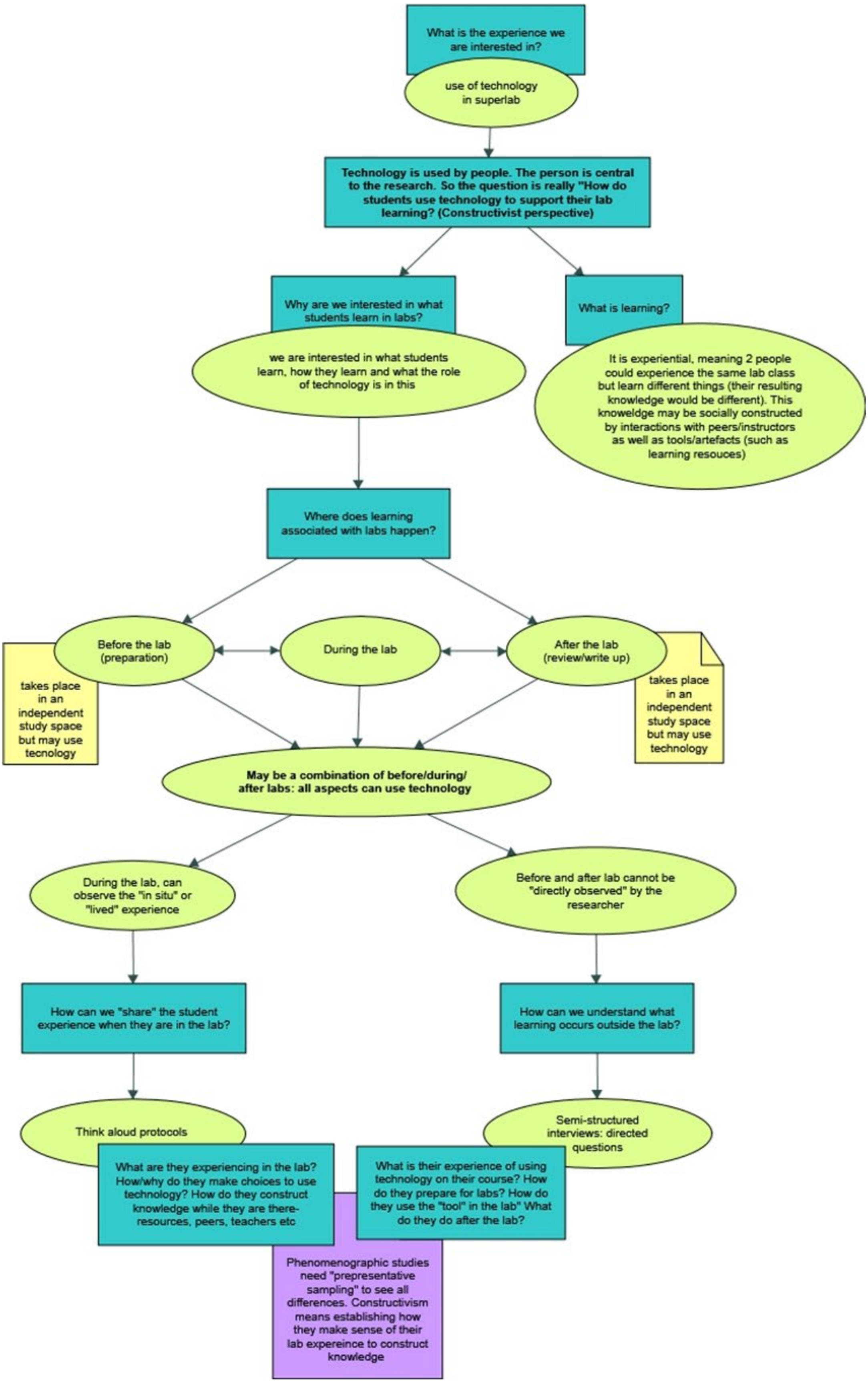


Figure 18: Rationale for development of the research strategy proposed to investigate how students use technology in lab learning. Questions are shown in blue, answers/statements are in green, limitations in yellow and purple points relating to the philosophical approach.

This method had advantages over the use of observation as:

- Due to the number of participants in each group (5-6 participants spread around a room of one hundred students) the logistics of being able to mark the activities of participants at defined intervals would be difficult to achieve.
- The use of technology e.g., referring to the tablet to check a piece of information or using a piece of equipment may occur over a short period of time so if observation had been chosen as a method, there was a likelihood of underestimating the frequency of use.
- Observation protocol may have been able to address “how” students were using technology but would not have given insight into why they were making these choices.

Challenges in applying think-aloud in a laboratory setting.

Previous retrospective think-aloud style studies that video recorded participants in the laboratory (using worn and static cameras, and lapel microphones) highlighted that the tripod recordings were limited by whether the participant remained in frame and therefore were at risk of potentially losing opportunities for discussion in the retrospective interview (Galloway, Bretz 2016). One solution to this was the use of a wearable camera (such as a GoPro) which gave an indication of what is going on in the laboratory from a participant viewpoint, however this was not feasible in the Superlab because students use their personal login details to access resources on the tablets and so this would have breached data security. Since making a video recording to collect data for a retrospective think-aloud method would have also had the potential for data loss or “misremembering” as previously described and the use of personal cameras was not an available option, it was proposed for participants to make personal audio recordings whilst in the laboratory. This imposed limitations on the data collected and analysed: for example, gesture coding could not be included in the proposed analysis strategy. However, on balance this was more advantageous than the other options as there would be no loss of data and, allowed for a concurrent approach to be used which had the benefit of eliminating the likelihood of misremembering. Additionally, since the purpose of the study was related to understanding how students were using technology and why they were making the choices they make, the loss of ability to code their physical actions (i.e. what they are doing) was of secondary importance.

6.2 Method rationale and development

6.2.1 Study design and ethics

This study was divided in to two parts. The first was a pilot phase that utilised a single participant to test the design of the experiment. The pilot participant undertook one session in the lab where they used the think-aloud protocol as well as the semi-structured interview (as shown in Figure 19). Once the process and data produced in the pilot had been reflected on, lessons learned from the study were applied to the design of the main study. For this, 10 participants were recruited. Each participant undertook two lab sessions where they used a think-aloud protocol as well as the semi-structured interview.

This study was independently scrutinised and approved by the SST non-invasive ethics committee (17-18/42). Where amendments were made following initial approvals, the study was returned to the ethics committee for approval of amendments. Use of the research tool did not commence until ethical approval was in place. Participants in this research were provided with an incentive commensurate with the time and inconvenience of participating in the research.

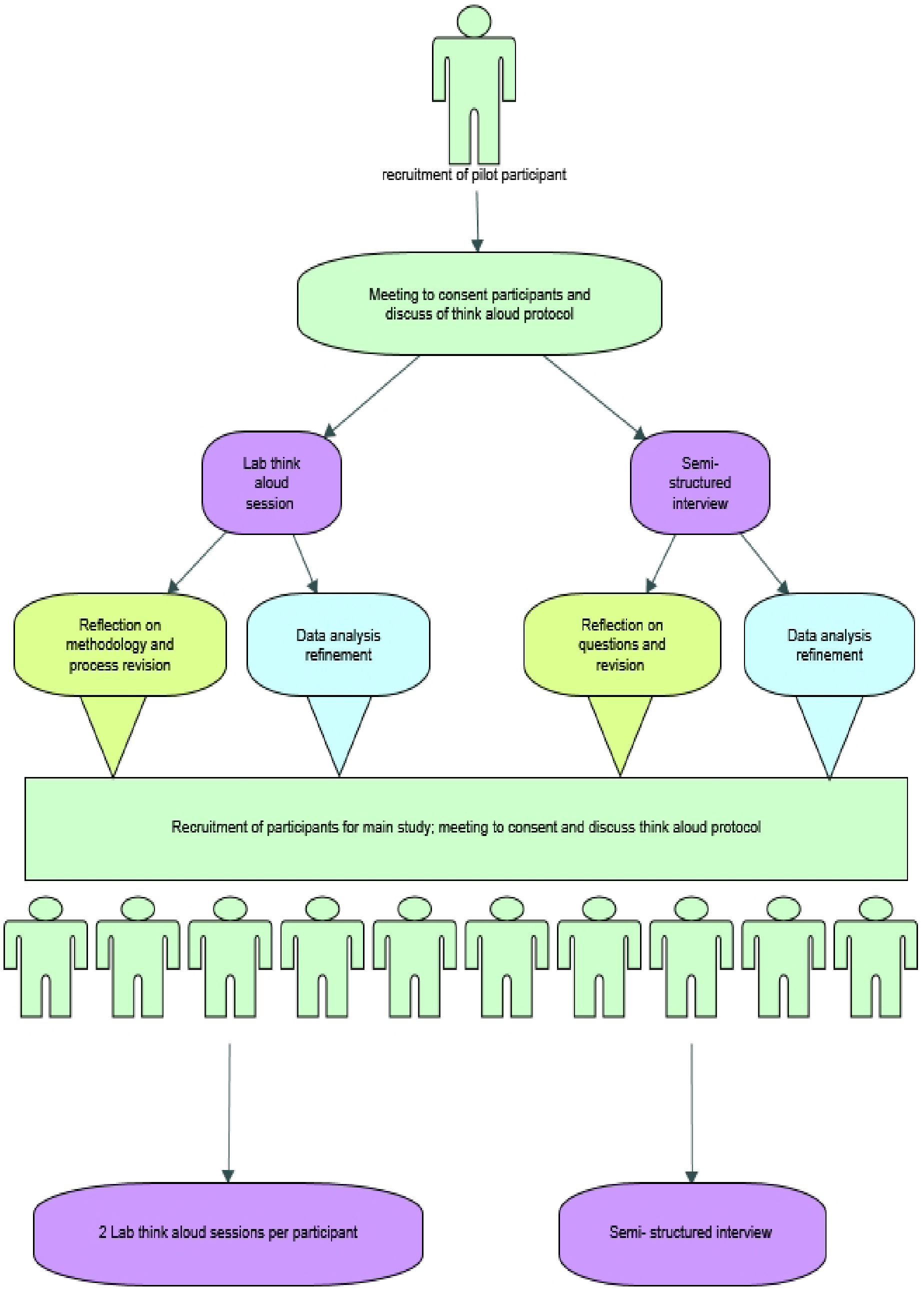


Figure 19: diagrammatic representation of the experimental process. Purple boxes are used to highlight methodology; green boxes for participant action outside of the research method; yellow is used for method refinement and blue used for data analysis.

6.2.2 Pilot study

For the pilot study, the participant was recruited through the BIOL22321 (Microbial structure, identification, and distribution) module: this module is taken by second year microbiology and forensic science undergraduate students. Students attending this module were asked to complete an expression of interest form and one of these was selected at random to participate. At the time when the participant was consented to take part in the study, the think-aloud process was explained to them, and they were given an opportunity to practice verbalising their thoughts. This opportunity was provided as a previous study suggested that giving participants an opportunity to practice reduced the cognitive load when using the methodology for the experiment (Cennamo, 1995). The participant was informed that they should verbalise any thoughts that came into their head with the exception of username and passwords used to log in to devices/software when in the laboratory.

Think-aloud Protocol in the laboratory.

To be able to record the data generated by the participant verbalising their thoughts while in the laboratory, they were given a dictaphone to use as a recording device (Sony ICD-PX370; Sony Group, Tokyo, Japan) attached to a lapel microphone (Sony ECMCS3 Microphone; Sony Group, Tokyo, Japan) that could be attached safely to the laboratory coat. Both pieces of equipment met the safety requirements for the laboratory with no porous surfaces, meaning that they could be effectively decontaminated between uses. For the pilot study, the participant was asked to record their thoughts in a section of their laboratory class in which they were choosing and performing an API test strip (Biomerieux, Marcy-l'Étoile, France) for bacterial identification. This experiment built on the previous class in which students had performed a series of tests such as gram staining on “unknown” bacteria growing on an agar plate to identify them. The laboratory class where the think-aloud recording took place was to positively identify the organism. The participant was given a laminated sheet of paper on which the words “Keep talking” were written. This reminder was propped up on their workstation so that it was plainly visible to them: the participant was given the option of whether they wanted the reminder or not since the data was being collected during a routine laboratory class and participants may feel more self-conscious amongst their peers with the reminder present.

Verbatim transcripts of the participant voice were made by the researcher. As the transcript was being made, analytic memos were incorporated to aid in the sense-making of the transcript and to ensure that relevant non-verbal information was not lost from the record of the session. These memos included when the participant paused in their talking, when their vocal intonation was suggestive of them reading, when they were singing rather than talking and when the recording included clear sounds of equipment being used (such as adjusting the volume on an autopipette).

Semi-structured interview

The questions used in the interview can be found in Appendix 10 and had several key themes that were related to the topics of interest identified in Figure 18.

As with the laboratory sessions, the semi-structured interview was recorded using the Sony ICD-PX370 dictaphone (Sony Group, Tokyo, Japan). Preliminary interview transcription was performed using Dragon (Nuance communications Inc, Massachusetts, United States): this transcript was then corrected by the researcher to be a verbatim record of the interview.

6.2.3 Rationale for think-aloud data analysis

Whilst researchers may use a think-aloud approach to collecting data, the method of analysis can vary substantially and are dependent on the aims of the study and the cognitive process being studied. Ericsson and Simon (1993) described the use of protocol analysis with think-aloud data. This approach begins with transcription of the verbalised data followed by segmenting it into phrases or short section which encapsulate a thought or idea. These are then aggregated into episodes that can be coded using codes that the researchers have pre-determined as appropriate to the task or model that is being explored. As a final step in protocol analysis, the researcher investigates the pattern of the codes in their data and how this relates to their research question.

Whilst some studies may contain elements of the protocol analysis, many use alternative or additional coding methodologies to contextualise their data: many of which are coding strategies where the codes are generated based on the data rather than prior to data collection. An example of this can be seen in the study of critical care professionals' decision making which used a combination of level 1 and 2 protocol analysis together with ad hoc coding (Lundgrén-Laine, Salanterä 2010). The table below (Table 44) summarises examples of different approaches used in think-aloud studies.

Table 44: Examples of think-aloud studies and the analysis methods used.

Study	Analysis	Authors
Decision-making in nurse practitioners	Cognitive/ reasoning process coding (4 for diagnostic decision-making and 5 for therapeutic decision making)	(Offredy, Meerabeau 2005)
Decision-making in critical care professionals	Protocol analysis and ad hoc coding	(Lundgrén-Laine, Salanterä 2010)
Problem-solving in undergraduate physics	Multi-dimensional coding which incorporated gesture analysis and speech pauses	(Hutchison et al. 2015)
Problem-solving in chemistry students, academics and professionals	Thematic analysis for using grounded theory approach	(Randles, Overton 2015)
Metacognitive and collaborative talk used to solve maths problems	Coded to discriminate between metacognition, social talk and collaboration	(Smith, Mancy 2018)
Socially-shared metacognition in pharmacy graduates	Socially shared metacognitive coding scheme; analytic memos; strategy identification	(Lobczowski et al. 2021)

6.2.4 Analysis of Pilot study data

Think-aloud data analysis

Since the laboratory is a shared space where students work in pairs (and sometimes larger groups), analysis of the think-aloud data in the current study was based on the socially shared metacognition coding scheme described by Lobczowski et al. (2021). The first three stages of this (along with participant examples) are shown in Table 45 which is a reproduction of table 1 included in appendix 9 (Rayment et al., 2023). During the coding described by Loboczowski et al. (2021), analytic memos were made which enabled the researchers to identify strategies that participants used: these memos were then applied as inductive coding for the fourth stage of coding. The present study used Loboczowski's first three stages of coding but made use of analytic memos differently (i.e., during transcription). Since the think-aloud sessions were recorded in the laboratory where students were performing experiments, process coding rather than indictive coding was used as the fourth coding type as this would better capture the actions that the participants were taking. Some examples of the process coding are:

- the code "*identifying mistake*" where the participant said:

  "I think I was mixing the wrong one. That one? Take that out, check if it's a hundred microliters first".

- "*acquiring resources*" was the code applied to a participant transcript in the following passage of their transcript:

  "Right, there you go. We need loads of these tips. Can we borrow some of those blue ones please?"

- The code "*using equipment*" was applied to the segment of the participant transcript below as they were verbalising using different equipment and resources to complete their experiment:

"I've put the pipette back on the tray, I'm getting the glass spreader and getting the alcohol. And I'm getting the plates ready. So we're going to start with the 10 to the minus 3".

Table 45: description of the first three levels of the socially shared metacognition coding scheme described by Loboczowski et al. (2021), how they were applied to the pilot study, and with examples or quotes (as shown in appendix 9; Rayment 2023).

Code	Definition	Example/quotes
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?"

Semi structured Interview analysis

Two first cycle methods were used to code the semi-structured interview transcript. These were structural and descriptive coding as described by Saldaña (2015). For the next cycle of coding, the descriptive codes were mapped against the structural codes to identify key themes in the data for each structural code. The structural codes applied to the questions identified in Figure 18. As listed in appendix 9 (Rayment et al., 2023), these were:

- What is technology? (Code: technology)
- How do students prepare for labs? (Code: lab preparation)
- How do students use technology? (Code: tech use)
- How are students using technology in labs? (Code: technology in labs)
- How do students feel about technology? (Code: attitude)
- What do students do after labs? (Code: post lab)
- How do labs fit into the development of identity as a scientist? (Code: lab scientist)

6.3 Pilot study outcomes

The purpose of the analysis of the pilot study was to reflect on the data analysis and whether it was suitable as an approach for the main study given the research objectives. In this section, the findings from the data analysis are also described to provide insight into how the main study analysis was further developed.

6.3.1 Think-aloud lab session.

The cross-tabulation of the process coding (that applied to technology) with the mode of learning, cognitive regulation processes and targets of regulation are shown in Table 46. Process coding generated 19 codes, however only 3 of these related to technology. These were: *preparing equipment, using equipment; using tablets*. Examples of other codes included: *discussing non-experimental topics, stating observations, reflecting on self*.

Table 46: Summary of how the process coding of the pilot think-aloud recording relates to the metacognitive coding scheme.

	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	1	2	1	0	0	2	0	0	1	2
using equipment	2	0	0	0	0	1	1	0	1	2
using tablet	15	2	0	0	1	17	1	0	11	6

The most frequent technology-related process code for the pilot participant was "*using tablet*". This referred to when the participant was reading material using the tablet or querying what they needed to do. In the latter case, this querying could be in either *SRL* or *SSRL* depending on whether the participant was working independently or discussing their activities with other students on their lab bench. The use of tablets was observed when the participant was monitoring or controlling activities and the target of the learning was most frequently observed to be related to their task understanding.

6.3.2 Semi-structured Interview

As previously stated, the key facets to be investigated during the interviews were:

- How the students defined technology (as this had a bearing on their subsequent answers).
- How students develop their understanding of laboratory material outside the laboratory and the role that technology has in this.

Following the coding strategy described in section 6.2.4, the interview data was coded by structural coding and descriptive coding. Table 47 shows the alignment of descriptive codes with each structural code applied to the pilot study data.

Table 47: NVivo crosstabulation matrix analysis to show how descriptive codes were categorised under the structural codes for the pilot study

Technology	**Tech use**	**Attitude**	**Lab preparation**	**Technology in labs**	**Post lab**	**Lab scientist**
Technology uses electricity	constant connection to tech	comfortable with technology	re-write protocol for understanding	screen projectors	write a report	practicals and lab write ups develop job skills
computers for learning	games	excel is stressful	read protocol	headset	late lab discourage post-lab activity	labs give feeling of doing real science
technology in medicine	music	slow at typing	ongoing learning	tablets in lab	report writing links content and labs	
technology in shop	communication	comfortable with technology	laptop for researching	lab equipment	understanding comes after labs	
lab equipment	streaming TV	comfortable with new technology	take second year labs more seriously	comfortable with technology	practicals make science real	
technology makes life easier	researching information for assessment	cost of equipment causes anxiety	read protocol	understanding lab content	labs help content understanding	
	producing work	unfamiliar equipment causes anxiety		peer support	portfolio	
	researching information for understanding	comfortable with technology		lecturer support	re-write notes	
	lecture notetaking	technology makes information immediately accessible		stress adds to confusion in the lab	lab report helps understanding	
	identifying spelling mistakes			labs can be stressful	re-write protocol for understanding	
	no typing notes at college			prefer working alone	re-write notes	
	new software			managing stress		
				prefer paper		
				writing aids understanding		
				technology makes information immediately accessible		

Defining technology

For this participant the definition of technology was specifically focussed on the need for electrical input, that it makes life easier and information more accessible. Using this definition, mechanical devices were not included meaning that common lab equipment (such as pipettes) were excluded from the definition. This definition was consistently applied throughout the interview as can be seen by the examples and uses of technology given (under the technology, Tech use and technology in labs structural codes in Table 47) which all have electronic aspects to them. This included the earpiece and receiver (coded as "*headset*") which students use in the Superlab to be able to hear the academic instruction.

The pilot study participant indicated that they were comfortable with their personal technologies and that the amount of time spent on various devices meant that they felt constantly connected to them as can be exemplified by the following quote:

> *"It's usually my phone and my laptop. Neither of them is ever switched off. I'm like glued to the screen at this point."*

Further, they also indicated a high degree of confidence in using new technology when this was in their personal life as highlighted 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."*

However, the perceived cost of other equipment that they might encounter as part of their course created anxiety that was not present when using technology in their personal life, as shown in the following quotes

> *"But if I've been given a piece of technology, I can roll with it. Unless it was like "this is a £350,000 piece of equipment". You try your best, but I don't want to touch that at all."*

> *"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."*

Developing theoretical understanding

Based on the codes in Table 47, several themes developed. The first of these was that they perceived the time that they spent in the laboratory to be primarily focussed on skill acquisition rather than content understanding and so the main role of technology in this environment was in performing the experiment and finding information e.g., being able to read the protocol or do research using the laboratory tablets to find out information. In this respect, the role of technology in the laboratory was viewed as being relating to their future career, as highlighted by this quotation:

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

Whilst the participant did undertake activities prior to entering the laboratory, they expressed that their understanding of theoretical concepts only developed after the laboratory class when they were undertaking a post-laboratory activity. They spoke about the idea that for them there was a combination of factors as the practical element stimulated their interest whereas the write up provided them with the context to be able to develop their understanding of the topic further. This is exemplified by the quotes below.

> *"Writing up a report means you go further in depth with what you're doing and then things click".*

> *"… 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".*

"But I like the practical because it gives me a real-life view of what is happening and why... But if you can actually see it and see something, and touch something, then you're involved in it. When you're involved in it, stuff clicks a lot better."

6.4 Summary and changes based on experience of pilot study

6.4.1 Changes to Think-aloud methodology

As described in the outcomes above, the pilot think-aloud session highlighted that the most common use of technology in the laboratory class itself was using tablet technology to monitor/control task understanding whilst working independently (in SRL) suggesting that it is acting primarily as a source of information. Reflection on the use and analysis of the think-aloud highlighted changes that could be made to improve the methodology for the main study.

These were:

- **Participant preparation**: As the pilot participant chose not to practice the think-aloud methods prior to the laboratory class, in the revised participant preparation the researcher provided a brief example of "thinking-aloud" based off a common word or phrase before asking the participant if they would like to practice. The aim of this was to reduce potential barriers that may inhibit the participants practicing (for example if they felt self-conscious). It was expected that by providing a researcher example, even if participants did not want to practice, they would have a clearer understanding of what they were expected to do.
- **Data analysis**: The process coding generated numerous codes that were extraneous to the aims of the study and the nature of some codes generated were ambiguous in terms of whether technology was involved resulting in the researcher returning to the original transcript for confirmation. To correct this for the main study, the process codes were changed to ensure that those which used technology (and which

would therefore be included in the subsequent evaluation of the data) could be easily identified.

6.4.2 Changes to the Semi-structured interview

The aim of the semi-structured interview was to establish the participant's definition of technology; how technology features in student's understanding of laboratory material outside the laboratory; and whether their perception of their use of technology in the laboratory correlates to the data from the think-aloud recordings.

The questions included in the interviews allowed the participant to articulate their own definition of technology and to provide an understanding of how the participant uses technology in pre- and post-laboratory to develop their understanding of a given topic. For this participant, technology was used to support both pre-and post-laboratory activities. Whilst pre-laboratory activities focussed on gaining an understanding of what the participant was going to be doing in the laboratory, it was the use of contextualised post-laboratory activities such as writing laboratory report or portfolios (and the research associated with these) that were key to their change in understanding. Comments made by the participant during the interview highlighted that they perceived the role of technology in the laboratory to be for performing experiments and accessing/researching information to allow them to complete their experiment successfully. This is in keeping with the observation in the think-aloud session which suggested that technology was primarily equipment used to perform the experiment or tablet technology used for task understanding.

Taken together this suggests that the semi-structured questions developed, and analytical strategy used appropriate for the aims described for this method.

During the interview, one of the questions was observed to be sufficiently similar to another question in the protocol that the responses were duplicated and so only one version was retained (the removed question is shown in Appendix 10).

6.5 Main study

6.5.1 Methodology

This proceeded as described in the pilot study (section 6.2) with the modifications as described in section 6.4. All data (pilot and main study) were collected prior to the COVID-19 pandemic.

Selection of laboratory classes and recruitment of participants

Since it is difficult to assess whether the use of the think-aloud process has an impact (positive or negative) on participant learning, the main study used laboratory sessions that were not directly assessed (e.g., through the writing of formal reports). Two second year laboratory sessions were selected for use with the think-aloud protocol. The reasoning for this was:

- As this study took place in the first term of the academic year, it would not have been appropriate to recruit first year students as they would still have been familiarising themselves with the laboratory as well as being in a new peer group. It was hypothesised that recruiting participants from this group would be less likely to yield reliable data than experienced students due to the potential for them to be experiencing higher cognitive overload and anxiety if they were asked to undertake addition activities whilst there.
- Either second or final year modules would have provided a pool of experienced participants however the choice of module was restricted as many of the final year laboratories contribute to assessments or take place in other laboratories spaces within the department and so were not suitable for this study. Whilst there are

assessed practical classes in the second year, there were an appropriate number of modules remaining with non-assessed lab classes in Superlab that could be used.

The first session involved students working in groups of 4 to perform SDS-PAGE analysis on a gel which they loaded with different amounts of a liver sample. The part of the protocol selected for the study was where students prepared and loaded samples onto the gel. The second session took place in a microbiology module where students attempted to isolate bacteria from washing up sponges that they had brought from home. Students taking this module used a stomacher to manipulate the sponge to release contents into a buffer which was then used to make serial dilutions that were plated on a variety of media (agar plates).

The sessions selected were from modules that biomedical science students are enrolled on (other courses may be enrolled on one or other of the modules but only biomedical science students take both). The potential participant pool was approximately 250. As described in section 4.3.1, participants for the main study were recruited by submission of expression of interest cards that were completed during a lecture. The expression of interest requested information of the potential participant's age group (21 or under; 21-35; 36 or over); gender (options given were male, female, other/prefer not to say); whether they had any recognised disabilities that impacts their laboratory experience; and whether English was their first language. The last of these was used to identify whether any of the participants were likely to have additional challenges with the think-aloud protocol due to the necessity to translate their thoughts from their native language before speaking them aloud. The study received sufficient expressions of interest that a participant selection process could be applied to recruitment of participants: the pilot participant was not eligible for this phase of recruitment. As far as possible the selection of participants was designed to provide representation of all the variables used in the expression of interest form: to ensure that, as far as possible, participants selected were representative of the cohort. In characteristics such as gender, this was easily achieved; in other areas such as age, there were limited responses and so this is reflected in the numbers of participants recruited in these areas.

Of the participants recruited to the study:

- 5 were male; 5 were female (no participants selected the other/prefer not to say option)
- All except one were aged 21 or under; the remaining participant identified as being aged 36 or above.
- 3 out of the 10 participants stated that they had a recognised disability that impacted their laboratory experience.
- One participant stated that English was not their first language.

The main study provided the participant with an incentive in recognition of the time and inconvenience of participating.

6.5.2: Main study outcomes and significance

6.5.2.1 Think-aloud protocol.

Refinement of the process coding following the pilot study identified 4 codes that directly related to the involvement of technology in the main study. As shown in Table 48 and Table 49 , these were: *preparing equipment*, *querying protocol*, *using tablet* and *using equipment*. Each of the following codes was followed by the word "technology" during the analysis for clarity purposes and to make them easier to identify for cross-tabulation: this has been removed from the final tables shown below for ease of reading.

During the think-aloud lab sessions, two of the food microbiology recordings were lost due to technical failure. In one case there was no recording made and for the other, the recording consisted of static. As a result, 8 participant food microbiology laboratory recordings were available for analysis compared to 10 for the SDS-PAGE lab.

Table 48 shows that unlike the pilot study, the participant use of technology in the main study was most frequently seen in socially shared regulation of learning rather than self-regulated learning for activities involving technology and that these were most likely to be within the monitoring or controlling of their learning processes. Comparison of individual participant data coding showed a variation in the balance and number of *SRL* and *SSRL* coding occurrences. Of the 8 participants that there were two recordings for, three had equal or greater numbers of codes for *SRL* than *SSRL* in both labs; two exhibited greater numbers of *SRL* in one and greater numbers of *SSRL* in the other lab; and three had greater or equal numbers of *SSRL* in both laboratory classes. The three participants who showed a balance towards *SRL* rather than *SSRL* either expressed social or other anxiety about being in the lab or showed concern over the technical skills of their lab partners during their interview. This was similar to the pilot participant who expressed a preference for working independently.

Table 48: summary of how the cognitive coding of all main study think-aloud sessions maps to the coding of activities that use technology

	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

Whilst the observation that *monitoring/controlling* was the most common regulatory process for all process codes involving technology, the most frequent target of regulation differed according to the process code. For the *preparing equipment* and *using equipment* codes, the target of regulation was most likely to be *task performance*: the target of regulation for *querying of the protocol* or *using tablet* was most frequently observed to be *task understanding*. These observations were the same as for the pilot study although the numbers of recorded observations for *preparing equipment* and *using equipment* in the pilot were low.

The number of process codes for *using equipment* and *using tablet* was a lot higher than for the *preparing equipment* and *querying protocol* codes. For example, when comparing the modes of learning, there were 250 incidences of *using equipment*, whereas the total for querying protocol was 47.

To be able to evaluate whether the processes that students used during their laboratory classes differed according to the experiment being undertaken, the mean number of recorded incidents of the technology-based process codes <u>per participant</u> in each of the modes of learning, cognitive regulation processes and targets of regulation were calculated (see Table 49). The mean rather than total was used for this analysis as there were not an equal number of recordings for both sessions due to the technical issues described above, resulting in two lost data sets in the food microbiology experiment. The mean was generated based on the data in Table 48 so variation between participants was not calculated. In Table 49, despite many of the values (those highlighted in bold text) have a value of 1 or more (meaning that the number of times this process code was present for a particular cognitive code was equal to or greater than the number of participants in the data set), only 3 of the cross-tabulated codes were present for all participants (in italicised red text). These codes also had the highest values: approximately double or more of any other cross-tabulated code. These were all found in the using equipment process code for the SDS-PAGE experiment and were: SSRL; monitoring and controlling; and task performance. In the food microbiology experiment, these codes similarly showed the highest cross-tabulation of codes although these were not found in all participant transcripts.

Table 49: cross-tabulation of how cognitive coding of think-aloud sessions map to the coding of activities by process coding. Data is expressed as mean number of observations per participant (to 2 d.p) for the SDS-PAGE and microbiology sessions as there were a different number of available recordings for the two different laboratories. Text in bold has a value of 1.00 or more; italicised text in red are represented in all data sets.

		preparing equipment		querying protocol		Using tablet		Using equipment	
		SDS-PAGE	Sponge	SDS-PAGE	Sponge	SDS-PAGE	Sponge	SDS-PAGE	Sponge
Mode of learning	SRL	0.20	0.25	0.20	**1.38**	**3.00**	**1.25**	**3.80**	**1.25**
	SSRL	0.40	0.50	0.80	**2.88**	**3.20**	**2.75**	***10.70***	**4.88**
	CoRL	0.10	0.00	0.10	0.25	0.50	0.13	**2.30**	0.25
	CoRL- other	0.00	0.00	0.00	0.00	0.00	0.00	0.60	0.13
Cognitive regulation processes	planning	0.00	0.13	0.10	0.75	0.40	0.63	0.30	0.13
	monitoring or controlling	0.60	0.63	0.70	**3.13**	**5.60**	**3.00**	***14.30***	**5.50**
	reflection	0.10	0.00	0.10	0.00	0.40	0.13	**2.40**	0.50
Target of regulation	content understanding	0.00	0.00	0.00	0.00	**1.30**	0.13	0.600	0.13
	task understanding	0.00	0.13	0.60	**3.25**	**2.10**	**3.25**	**3.50**	0.88
	task performance	0.50	0.63	0.30	**1.63**	**2.70**	**1.00**	***11.70***	**5.50**

Comparison of the distribution of the codes demonstrated that whilst the values may differ, the distribution of values was the same in both experiments except for when students were using the tablet. As can be seen in Table 49, when using tablets, the target of regulation differed in the two experiments, with *task performance* being highest in the SDS-PAGE experiment and *task understanding* being the highest in the food microbiology experiment.

This is reflective of the process that participants used to undertake their laboratory work: a schematic representation of this process is seen in Figure 20. Where the target of regulation was task performance, participants were most likely to use the tablets strictly as a source of information to be acted on. In comparison, where task understanding was the target of regulation, although the tablet was used as a source of information, this information was further discussed or considered by the participant to reach an understand of what was being asked of the participant. In some cases, this may involve using the tablet to use the internet to look up addition material as shown in the quote below.

"I wonder why it's varying amounts. Might google that on the tablet."

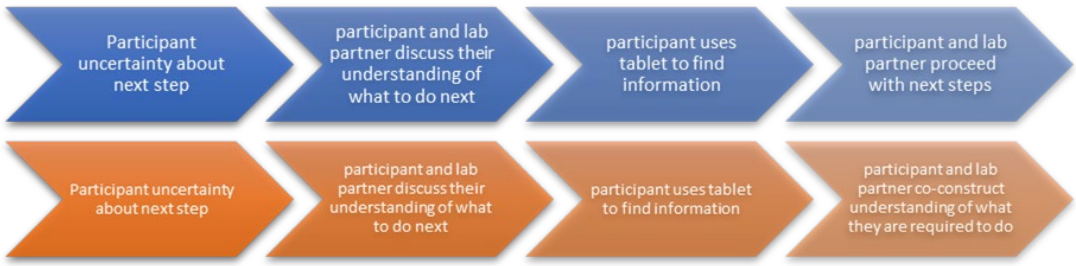


Figure 20: Process that participants go through to complete laboratory tasks. The scheme shown in blue is indicative of the target of regulation being task performance; the process shown in orange relates to task understanding.

6.5.2.2 Semi-structured interviews

As for the pilot study (Table 47), a cross-tabulation of structural codes and descriptive codes was created for the main study. As this part of the study generated 279 descriptive codes, this table is included in this thesis in appendix 12. An additional second cycle coding method was incorporated into the analysis so that these descriptive codes were clustered into categories as shown in Table 50: this was to ensure that emerging patterns in the data were more easily identifiable.

Table 50: coding categories created from laboratory interview analysis descriptive codes

Category	Codes within category
Technology is…	technology is electrical equipment with a specific function, technology is complex, technology accesses the internet, technology are machines, technology is man-made, technology doesn't have to be electrical, technology helps information sharing, technology is electrical, technology is a tool created for a specific purpose, perception of technology depends on role technology uses electricity
Lab equipment	strip tests, water bath, chemicals, plate reader, pipettes not technology, pipette, bunsen burner, electrophoresis, microscopy, pens, paper, centrifuges, organ bath, tablets in lab, lab equipment, spectrophotometer, headsets, measuring weight
Personal technology	TV, headphones, lights, bluetooth speaker, glasses, apps or software, christmas lights, bag, games, music, dictaphone
Learning technology	ebooks, online journal articles, computers for learning, projector screen/screen projector, learning resources, online quiz,
some technology personal and learning	tablet, laptop, mobile phone, computers, mobiles do everything, computer does everything
many uses for technology	transport, kitchen appliances, bathroom appliances, hobbies, furniture is technology, home security, technology in research, artificial intelligence, research home automation

technology has many applications	streaming, watching videos, taking photographs, web browsing, simulation, relaxation
More technology used at university	more facilities available at university, no typing notes at college, demonstrate equipment, operated by lab staff, fewer practicals at college, work online, need technology for degree, excel used more, more lab time and increased complexity, more frequent use than at college, timetable, Technology strongly influences university life, check emails, smartcard, new software, increased frequency of use
technology can help with learning	technology helps you learn new things, recorded lectures, expect new technology, university app, life long learning, laptop for researching, technology not needed for learning
Technology used in lectures	technology changes taught material, make notes, use phone in lectures, lecture note taking
Modules use technology in labs differently	different application of same equipment, different technology in different labs, some technology module specific
lab technology consistent	technology integral to a lab, health and safety technologies, some technology shared across modules, read protocol in lab, paperless lab
Technology in assessment	laptop for researching, use software appropriate for assessment, researching information for assessment, online submissions
technology can cause anxiety	Excel is stressful, reluctant to use new technology, anxiety based on technology capabilities, mixed confidence
lab equipment can cause anxiety	reliance on unfamiliar learning technology causes anxiety, no impact on lab interest, fear of breaking new technology, anxiety that mistakes will affect learning, cost of equipment causes anxiety, unfamilar equipment causes anxiety, faulty equipment, complexity of technology causes anxiety
labs can cause anxiety	sense of pride, being compared to others, anxiety about going into lab, added pressure, difficult to ask for help, intimidating, anxiety if lab assessed, singing reduces anxiety
labs are a positive experience	hands on experience, new techniques, labs are enjoyable, advising peers increases confidence
labs are frustrating	repetitive, dislike waiting, lab introduction too long, lab entry, frustrating to not use data, acquire equipment, varied skill and knowledge levels is frustrating, make labs less repetitive, change practicals
guidance improves confidence	written instructions, need instructions, tablet training, support with new technology, lab equipment becomes familiar through repeated use, ask for help
lack of support	no guidance, frustrations impact learning
confident with technology	enjoy new technology, more confident, comfortable with technology, comfortable with new technology
puts theory into practice	practicals make science real, labs give feeling of doing real science, learn by doing, technology in labs applies theoretical concepts, labs help content understanding, labs are beneficial for learning, technology in labs applies theoretical concepts, learn by making mistakes
technology keeps us connected	news and media, social media, multiple devices simultaneously, technology is convenient, communication
reflection helps connect theory and practice	portfolio helps learning, reflection, portfolio
career preparation	portfolio for future career, practicals and lab write ups develop job skills, doing science makes you a scientist, not a scientist until in a job, scientists have professional standards, lab technology prepares for future career, technology increases confidence

technology is everywhere	technology applies across learning and personal life, technology is prevalent, constant connection to technology, technology in shop, technology for fitness, banking, online shopping, technology in medicine
library resources and support	online training, library one to one support, library services, books, technology helps information sharing
technology enables us to gather information	lab technologies gather or analyse data, researching information for understanding, use phone to find information, exporting data
second year vs first year	first year to catch up, second year has a higher workload, no difference, less prepared, take second year labs more seriously, second year labs applied, career based, less prepared, do more activities than in first year, no change, important to get right
Accessibility	technology makes information immediately accessible, technology helps us, improve accessibility, Support software, support with new technology, no drawbacks
Distraction	technology can be a distraction, social media distracts from work, loss of social skills, more focussed in lectures
personalised learning	self-motivation, work more independently, flexible working, calendar
labs change theory understanding	understanding changes during the lab, researching information in the lab
labs don't change theory understanding	focussed on doing the experiment, no knowledge gain in labs, link to theory less clear in labs than lectures
labs are social spaces	peer support, social expectations increases anxiety, social inhibition, competitive
learning consolidated after lab	lab reports help understanding, understanding comes after the lab, review lecture that links to practical, writing links lab with theory, theory concept understanding changes post-lab, report writing links content and labs, change in understanding is a thought process, writing aids understanding, calculations
preparation improves lab experience	pre-lab prep reduces mistakes, mistakes ruin experiments, bring items from home for testing
pre-lab activities	read protocol, read through seminar, No pre-lab prep, no pre-lab prep for ERD labs, pre-lab calculations, directed research
Post-lab activities	post-lab seminar, re-write notes, use data outside lab, write a report, review seminar material, no activities post-lab, review lecture that links to practical, revision, more post-lab consolidation needed, re-write notes
technology can have drawbacks	phone radiation, eyestrain from overuse, technological problems, identity theft
technology develops understanding	technology involved in change in understanding, technology impacts concept understanding, change in how we learn, technology can increase focus
technology makes things easier	technology makes life easier, easier to read typed notes, technology saves time

Cross-referencing the categories generated for this study against the structural coding, enabled the generation of a map to identify what was happening in preparation for labs, during labs and after labs from the participants' perspective (Figure 21). This map was focussed on the learning aspects of technology and so did not incorporate the categories relating to personal use of technology or definition of technology.

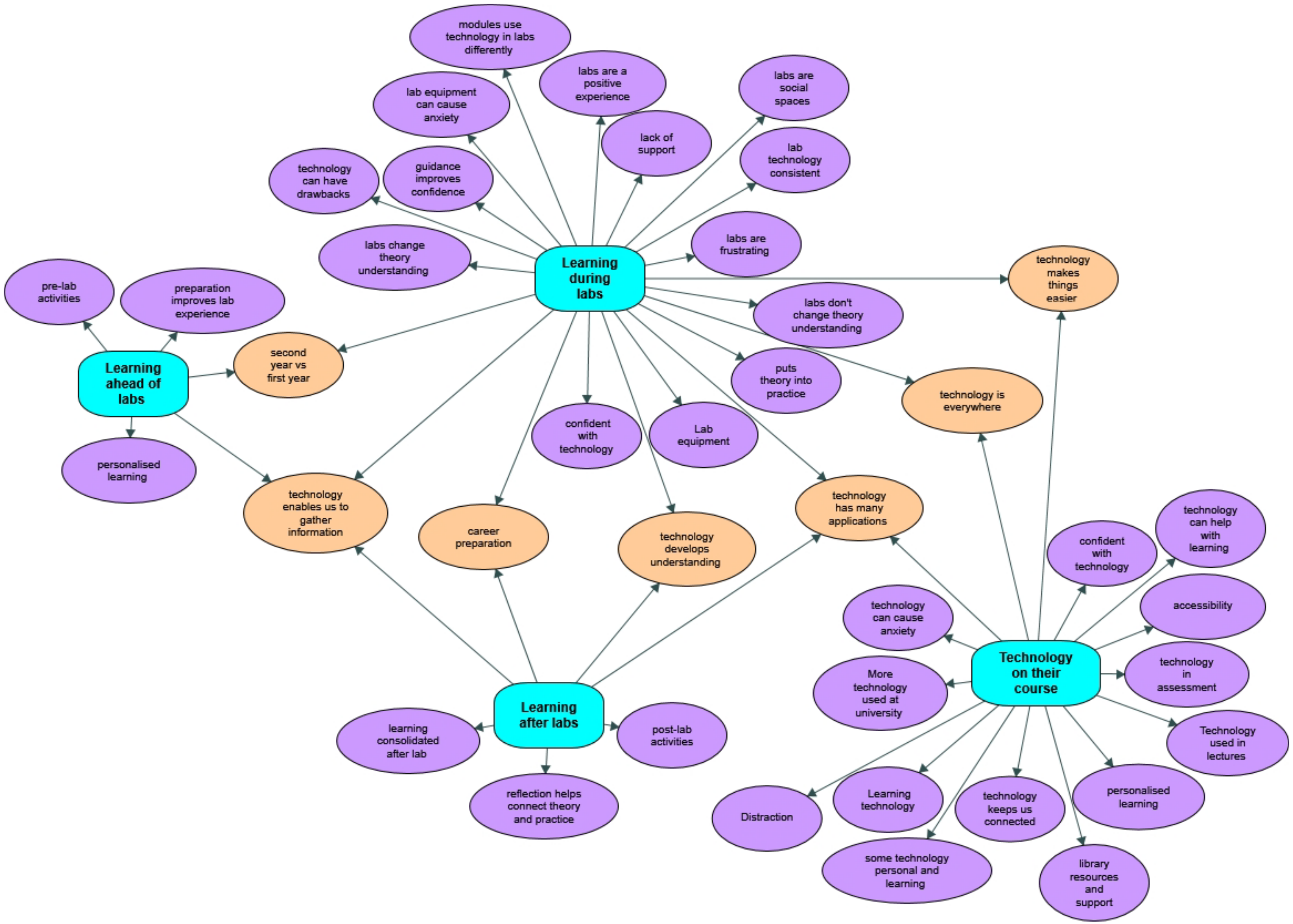


Figure 21: Map of coding categories based on areas of learning. Boxes in blue are the key theme; purple is used for categories that relate to a single theme; orange is used for categories that are common to more than one of them

As a result of the differences in the way that participants described technology, the range of examples they described as technologies varied and in one instance generated codes that conflicted with one another. There were some commonalities however, with mobile phones and laptops being agreed on as technology by all participants: headsets, centrifuges and spectrophotometers were all frequently described as laboratory equipment that students encountered as part of their lab learning. Those whose definition of technology were centred around technology being defined as a tool that helps us or has a specific function included further examples such as paper and pens as technology. In terms of laboratory equipment, these participants included pipettes (which are best described as mechanical) as technology whereas for participants who defined technology as having an electrical component these were not viewed as being technology: hence why conflicting codes can be seen in the Lab equipment category in Table 50. Participants who retained a definition of technology that required it to use electricity (and therefore did not view resources such as pipettes that are routinely used in the laboratory as technology), could arguably have completed laboratories such as the food microbiology experiment without using any technology: had they been able to access the protocol on paper rather than using a tablet and had not required the headset to hear communication from the academic. In this instance, technology as described above, is acting only as a source of information (either written or verbal). This is consistent with the use of tablets seen in the think-aloud transcripts of the laboratory sessions (see Table 49) which showed, both in the pilot and main studies, that the tablets were mainly used in the monitoring of the task understanding or performance. In the main study which of these was most associated with the use of the tablets varied according to the experiment, suggesting that the nature of the individual task may influence the target of regulation. So, in the case of the SDS-PAGE experiment, students are using unfamiliar equipment and processes and so use the tablet to help them follow the steps in the process (task performance); whereas in the sponge experiment, they are using familiar equipment but are using the tablet to help them understand what is required of them: possibly because this practical class involved a number of smaller experiments which had some similarities (plating out serial dilutions made from different source material) but also were in some ways unique (the source material and it's preparation, and the media used for plating differed for each experiment). This is consistent with the findings in Table 49 which shows that under the *querying protocol* code, the food microbiology experiment had higher values than the SDS-PAGE experiment throughout. That said, caution should be applied when interpreting this type of data as it only accounts for the number of coding events and not the length of time that participants spend in a given mode of learning.

A common theme in the data (as shown in Table 50) is the prevalence and impact of technology with coding categories including *technology is everywhere, technology makes things easier*, *many uses of technology*, *technology has many applications* and *technology keeps us connected*. Taken together this suggests that participants perceived technology to have a significant impact in many aspects of their life. In some cases, participants went as far as to state that they felt a constant connection with technology and that these are technologies that they are comfortable with.

Whilst mobile phones and laptops were the most common type of personal technology described by participants as being part of their daily life, these were also described as being multi-functional pieces of technology that also served to support their learning in a number of ways; including allowing them to access course material, emails and timetables (this will be discussed more in the section on technology on their course).

As well as being comfortable with their personal technologies, participants indicated in their interviews that trying new technology was not a concern for them particularly those used in their personal and social life: either because they felt that the technology was sufficiently similar to other technology e.g., swapping to a new phone or computer, or because if they damaged their own equipment, this was their own responsibility. These finding are in keeping with the 2020 Jisc student digital experience insights survey which suggested that 76% of respondents were comfortable with trying new technology (JISC 2020). When discussed in more depth, some participants in this study were less comfortable with trying new technology in a lab learning situation than in their personal life, citing anxiety around its unfamiliarity, the importance of the experiment in their assessments and concern over the associated cost of the equipment if it was damaged. Even those participants who were not anxious, discussed a desire for clear instruction (personal or written) to assist them with new lab equipment: this was not mentioned when describing how they approached new technology in their personal life and the type of comment by the pilot participant (shown again below) was frequently expressed by participants in the main study.

> *"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."*

Technology in learning

Developing theoretical understanding

The categories generated in the interviews have been broken down into the topic areas (blue boxes) in Figure 21 to be able to understand how students use technology in learning, and how students develop their theoretical understanding of a topic. An image showing the most frequent codes applied to the interview data is shown in Figure 22. This includes all codes that were found 3 or more times (98 out of the 297 codes); with the highest frequency being mobile phones which was coded 35 times across the ten interviews. In this instance the word cloud is a visual representation of a large set of frequency data and so is a useful tool to assist in the identification of key topics or themes.

Technology on their course

One of the most common topics that were discussed in depth by participants was the way in which their use of technology had changed since starting university. For many participants the use of a VLE

was a new aspect to their learning (this can be clearly seen in Figure 22). For the purposes of coding, participants describing use of the VLE or the university's app (which allows students to access the VLE, amongst other things) were coded together as "University App" as it can depend on which device is being used to how students access the VLE. When participants discussed their experiences at college, most participants commented that they had not had prior access to a VLE although one participant commented that they had had access to a VLE page but had not made use of it. As well as accessing learning material via the VLE, some participants also discussed the need for technology in their assessments, either for researching material or for submission of assessments which are commonly done online. Participants described that at college or sixth form it was common for them to be able to access the information they needed via their course books whereas at university this was insufficient and that the use of ebooks and researching information using the internet were needed to supplement this.

As a part of this, participants described the use of library facilities to search for or access their resources or making use of library support sessions to help with their understanding of using specific software needed on their course as shown in the quote below.

"I use Excel for graphs and things but I never really felt comfortable using Excel... So I just used the library for a piece of coursework and it was a one-to-one session"

Although the quoted participant did not discuss their prior experience of using Excel during their interview it would have been interesting to explore the extent to which their use of

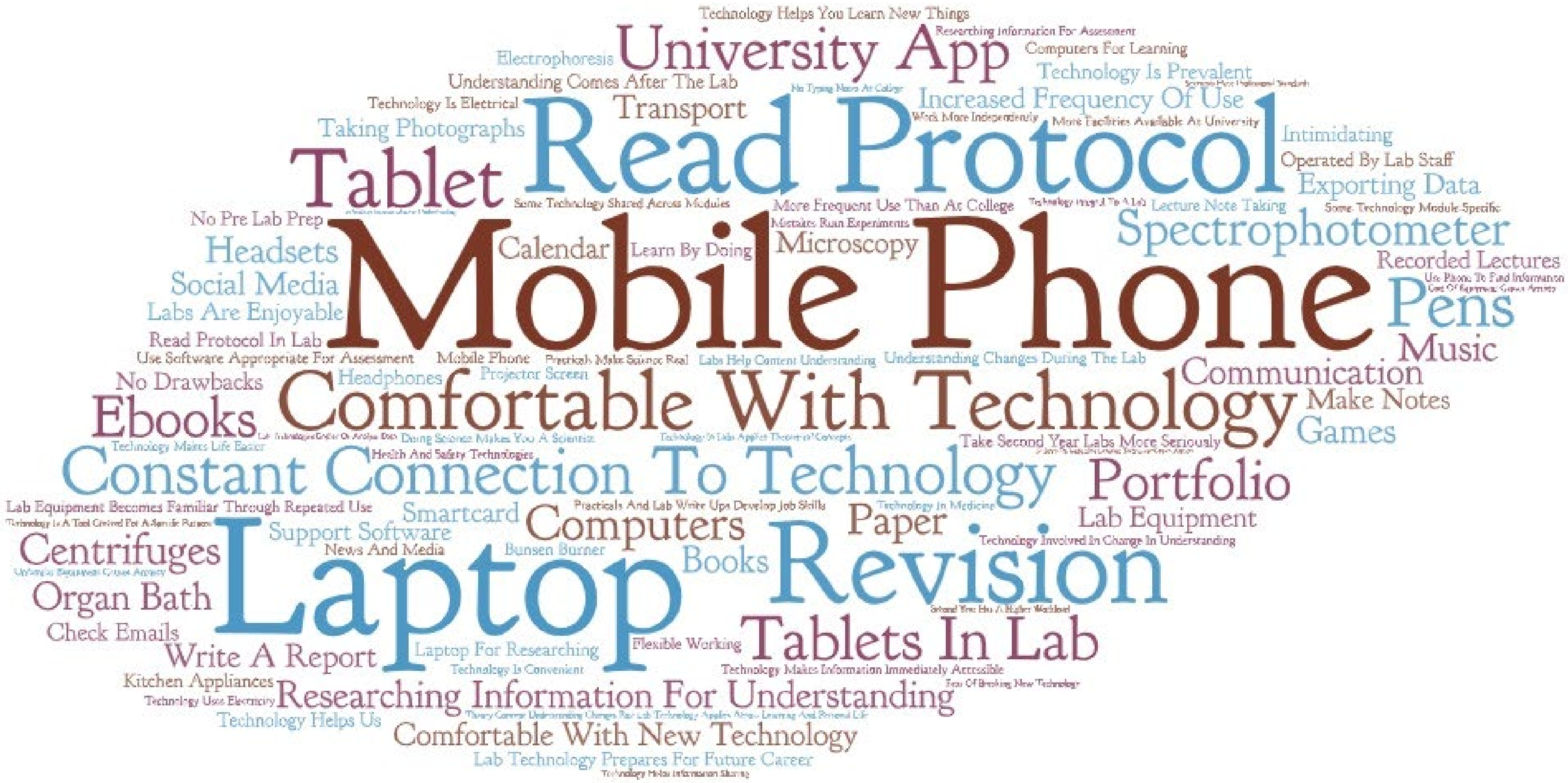


Figure 22: Word cloud showing the most frequent descriptive codes applied to the semi-structured interview data

specific support was motivated by familiarity (or lack thereof) or the fact that they were needed to use its output as part of an assessment.

Whilst it was common for participants to comment on their awareness of resources being at their disposal prior to university, the frequency with which they were using them had changed significantly at university (for example, changing from notetaking on paper at college to using their laptops for note taking at university) as well as having access to additional resources that they had not previously had access to in some cases (e.g., a VLE). The exception to this was the participant in the aged 36+ category who commented that they had initially struggled with using technology on their course (but not in their personal life) because it was contrary to the way that they had learned at school, as can be seen by the quotation below:

> "I struggled in first year with everything being electronic and being on the internet, and being not pen and paper-based. I'm old-school. So I sort of shied away from it a fair bit. But this year I'm using it a lot more and I am finding it does make things a bit easier."

Despite the issues noted above, participants viewed the use of technology in their education positively as it allowed them to personalise their learning, increased accessibility of information and made things easier. This is in keeping with the findings in the JISC student digital insights survey 2020 which showed that 83% of students were motivated to use technology to support their learning (JISC 2020b). Participants all expressed that they were comfortable with their personal technologies and the technologies they used in their personal learning.

In addition to the codes/categories which were found exclusively in this topic, three codes were shared with learning in the lab. These were: *Technology is everywhere*; *technology makes things easier; technology has many applications* (this also found in learning after labs). Within the course context it highlighted that: students experienced technology in different areas of their course and within different contexts of daily life; that activities after the laboratory supported their learning in different ways; within the laboratory, the discussion was more focussed towards the fact that the technology within the laboratory has a wide range of uses. Participants cited a range of examples of laboratory equipment with varied uses - from techniques such as electrophoresis used to separate specific types of molecules based on size, and microscopy used to visualise bacteria that would not be visible to the naked eye.

Learning ahead of labs

There were 5 categories of codes which developed during discussions with participants on how they prepared for laboratory classes: three of these were only observed in the section on learning ahead of the lab. These were: personalised learning, pre-laboratory activities and pre-lab activities improve lab experience. The category of personalised learning focussed on students' self-motivation and the flexibility to organise their time to best suit their learning. Of the ten participants, seven of them undertook activities before going to the laboratory, which (as shown in Table 50; Figure 22) predominantly focussed on reading the protocol so that they were familiar with the experiment they would be performing: which is something their lecturers also asked them to do. These activities were described by the participants as being voluntary rather than required (i.e., they did not contribute to a module assessment or need to be completed before students could enter the laboratory). These findings are in keeping with published data (as shown in Rayment et al. 2022a), which showed that reading the protocol was the most common pre-laboratory activity that bioscience students were asked to carry out for their modules across UK Higher education institutions.

Those who discussed why they undertook pre-laboratory activities stated that it helped them to work more efficiently, reduce the likelihood of making mistakes when in the laboratory and increased their confidence. These observations are in keeping with those in the published literature which have demonstrated that pre-laboratory activities can increase student preparedness (Rodgers et al. 2020; Gryczka et al. 2016; Sarmouk et al. 2020; Rayment et al. 2022a), organisation/time management (Rollnick et al. 2001; Gryczka et al. 2016), and confidence (Dyrberg et al. 2017; Cheesman et al. 2014; Whittle, Bickerdike 2015; Rayment et al. 2022a): with some further demonstrating enhanced learning gains which was hypothesised to be due to reduced cognitive load (Gregory, di Trapani 2012; Sarmouk et al. 2020). In addition, some studies have highlighted that pre-laboratory preparation can impact on the interactions in the laboratory, elevating the cognitive focus from procedural questions to higher order (conceptual) questions that linked to the underlying theory (Whittle, Bickerdike 2015; Winberg, Berg 2007).

This discussion lead students to compare their experiences in first year (where fewer of the students prepared before going into the laboratory) against their activities in the current (second) year of study, highlighting that they were taking labs more seriously as they were more complex and counted towards their degree: although in some cases this was balanced against a perceived higher workload resulting in the students feeling less prepared (categorised as first year vs second year) as shown in the quotes below:

"… now the labs actually count. Like most of them I've had this year have counted towards a piece of coursework, so you've got to do them right and understand what you're doing."

"I probably do it more on my way to uni than I did last year. I was a bit more prepared last year."

The final category that applied to learning before labs was "technology enables us to gather information". This category was shared with both learning during labs and after labs; and relates to the fact that technology features in the participants ability to research material before, during or after the laboratory to aid their understanding - as demonstrated in the quotes below.

Researching before the lab: *"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".*

Researching during the lab (ERD relates to a category 1 laboratory in a different building to Superlab where students use pen and paper in place of tablets): *"whenever we have the lab in ERD, you don't have the tablets. You have the paper copy of the protocol. But I always Google as I'm in there about things I'm not sure about. Whereas you can't do that when you're in ERD. So, I think it's a benefit having it."*

Researching after the lab: *"if there's still unknown information you want to look up, you can always go onto the webspace or journal articles … assessments as well based on these labs"*

Although the findings from the interviews are suggestive that pre-laboratory activities have benefits in terms of potentially reducing participant cognitive load in the laboratory, they do not give any indication that these activities impact their topic understanding as broadly speaking participants described their purpose in undertaking these as familiarising themselves with the equipment and procedures they would be using and discussions about content understanding were seen relatively infrequently in the think-aloud laboratory sessions.

Learning during labs

In addition to changes in their approach and use of technology in their learning, several of the participants discussed changes in their approach to laboratory work since coming to university. Where previously they may have watched a video or teacher demonstration, they were now performing experiments for themselves. Whilst not all participants put their current studies into this context, all participants discussed that they felt that the laboratory was an important part of their education as it allowed them to develop the skills that they needed in their future career and that it prepared them for the world of work. In some cases, this also inferred a sense of "being a scientist" as they described scientists as "doing science".

The categories that were generated for student experiences in the laboratory were at times conflicting. Some participants described labs as a positive experience, and something that they enjoyed. Whereas for others there were expressions of the anxiety and frustrations that lab work raised. Some of these were transient (such as the lab being an intimidating space for new students but something they have become used to). Social anxiety, and anxiety created by using unfamiliar and/or expensive technology were the most common reasons cited for these negative perspectives of lab classes. One participant in particular expressed frequent negative opinion towards different aspects of labs due to previous negative experiences and making numerous recommendations on how these could be improved: these suggestions included avoiding repetition, providing more guidance and to stop using a lab introduction at the start of the session as this can use up significant time that the students would prefer to be actually undertaking the experiment: frustration at the length of the lab introduction was also mentioned by one of the other participants. In this case it was suggested that students recognised that their time in the laboratory was limited and that the introduction either repeated material that they had covered in their seminars or was materials that students should have prepared ahead of time (e.g., information relating to the protocol).

Six out of the 10 participants expressed the opinion that their theoretical understanding of topics is changed during their lab class and that technology is involved in this process due to it's use in the experimental process as shown in this quote from one of the participants:

> *"being able to do, to touch and to work with the technology even if I'm not good at, just goes "ah right, inside there this is happening and I know that's happening because I've done the theory". But I'm also working with the technology, I'm doing it. It really does reinforce it, yeah."*

The remaining students (who didn't feel their understanding changed during the lab) described that the process of lab work was, for them, an opportunity to practice skills and the focus on completing the experiment efficiently as described by one of the participants:

> *"I don't like to mess about in the lab. I just like to get it done."*

Seven participants discussed that labs were important in building their career skills as can be seen below.

"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"

The category of career preparation is seen in both the learning during labs and learning after labs topics as some participants also discussed the use of portfolios for their professional development.

Examining the findings in the main think-aloud study (see Table 49) where technology was predominately used in the monitoring or controlling of task understanding/performance and there was very little coding for content understanding, it is clear to see how they would come to view practical classes as designed to develop their skill base. This is in keeping with findings from chemistry laboratories where students who were interviewed following a lab class described their learning to be psychomotor (i.e. skills based) as opposed to being cognitive (knowledge based) (Galloway, Bretz 2016). Similarly, evaluation of student perceptions of instrumentation in laboratory classes highlighted that they considered that it's use during laboratory classes improved technical skills but not other aspects such as problem-solving or familiarity with equipment (which was linked with pre-laboratory activities or explicitly structuring inquiry processes; Warner et al. 2016).

Teaching students' laboratory skills was one of the objectives of bioscience laboratory classes according to Adams et al. (2008) along with a range of others such as learning the scientific method, health and safety and contextualising taught concepts. Whilst participants discussed the fact that labs were beneficial to their understanding of the theory from their lectures during their interview, and half of the participants indicated that they felt there was a change in understanding during the laboratory class itself, the data from the think-aloud study gives limited evidence in support of this given the low incidence of content understanding as the target of regulation. Content understanding was coded within sections where the participants were using tablets and equipment but not when they were preparing equipment or querying the protocol although these varied between experiments with the SDS-PAGE experiment showing higher incidents of coding for content understanding than the sponge experiment. One possible explanation for this is that during the SDS-PAGE experiment, there were periods where the students were "waiting": either because they were incubating their samples (the protocol required students to denature their protein samples at 100°C for 5 minutes) or because they were waiting for the second group with whom they shared the gel loading to be at the same stage as them. As a result, these gave them the opportunity to discuss their understanding of the experiment and its' context in the theory. By comparison, the food microbiology experiment had no incubations except for the 30 seconds that the sponge was placed in the stomacher for, during which students frequently prepared for what to do when this was complete. Alternatively, the change in understanding may occur during tasks which do not involve the use of technology. Further analysis of the full range of process coding would enable further insight into this but falls outside the aim of this study which is focussed on how students use technology in their learning.

The former explanation is in keeping with the observations of Philip and Taber (2016) who discussed that practical activities were in the domain of the "observable" as opposed to the domain of the "idea" which results in a disconnect from the underlying theory. In their study, scaffolding school practical lessons to assess whether students engaged with the domain of "ideas" resulted in more discussion of the concepts involved. An example of the scaffolding they used including using a pre-laboratory lesson to allow students to construct their own method for carrying out an experiment to isolate DNA from kiwi fruit based on a range of available techniques that were labelled according to what they each achieved e.g., to break cell walls open mechanically. This meant that by the time students went to the perform their experiment they already had a clear link between what they were doing (observable) and why they were doing it (domain of ideas). Students on bioscience courses at NTU could benefit from having additional scaffolding or opportunities for reflection to enable them to make connections between the content/ theory and the activities that they undertake in the laboratory.

The observations in this study are also perhaps at least partially explained by the work of by Pieschl et al. (2013) who suggested that when students undertake a complex task, metacognition can be reduced because of the tasks' high cognitive load (intrinsic). The implication of this is that the focus during a class is about cognitive and metacognitive process that would facilitate successfully achieving a given task as opposed to retrieving and making connections with information about the relevant theory stored in their long-term memory. Examples of this could include using previous technical knowledge to prioritise important information and monitoring/ controlling of known processes such as pipetting and making serial dilutions. As previously discussed in chapter 1 (section 1.2), laboratories are complex environments that can have a high cognitive load for learners in a number of ways (Agustian, Seery 2017): either because of the innate complexity of the material (intrinsic load), the challenges of identifying important information (extraneous load) or processing new information for long term storage (germane load). Taken together with Pieschl's observations, this presents a picture of the learning environment which, given the style of the laboratories studied (where students are primarily given a protocol to carry out), lends itself toward skill development rather than integration of the practical with their content understanding at that point but that with additional scaffolding or opportunities for reflection, students could gain a deeper understanding of their topic alongside development of skills.

Similar to the work of Philips and Taber (2016), the work by Hofstein in a secondary education setting suggest that to facilitate the connection between ideas and practice requires scaffolding. In the case of Hofstein, students faced with practical sessions that use a problem-solving approach rather than following a protocol (as in this study) viewed their experience as being more integrated with the underlying theory based on the outcome of using Fraser's SLEI tool (Hofstein et al. 2001b). In addition, whilst the secondary education biology education in their country (Israel) had a greater emphasis on inquiry-based labs, resulting in a higher score on the openendedness scale, chemistry had a higher score for integration, meaning that students were able to identify the link between the theory and practice more easily for chemistry classes than bioscience classes

(Hofstein et al. 1996). In the study presented in chapter 2, level 4 bioscience students at NTU similarly showed a higher openendedness score than their chemistry counterparts but there was no significant difference for the integration scale suggesting that unlike Hofstein's study, there was no differentiation in terms of recognising how the bioscience and chemistry students viewed their practical classes linked to the theory. The data in this chapter deals solely with the perspective of bioscience students and so does not provide further commentary of how integrated bioscience students consider their labs and theory to be however the lack of coding for content understanding from the think-aloud recordings suggests that bioscience students do not see a strong link between theory and practicals whilst they are in the laboratory. However, there is evidence that students develop their understanding of the integration of the lab with it's underlying theory through post-laboratory activities.

Learning after labs

As highlighted in the earlier interview analysis and seen in Figure 21, the topic of learning after labs shares coding categories with all of the other topics: the *technology has many applications* category is connected to technology on their course and learning during labs topics; *technology develops understanding* and *career preparation* also feature in the learning during labs topic; and *technology enables us to gather information* is found in the learning before, during and after labs topics. In the context of learning after the labs, the *technology enables us to gather information* coding category related primarily to students' ability to access data they had collected during the laboratory (experimental data or photographs) for their follow up work such as portfolio or formal report writing (a written report which provides context/relevant background information on the experiment, results and their interpretation) which includes data analysis or their researching of further material to help with their understanding and preparing their assessment (see Table 50 and Appendix 12). The significance of students' ability to use technology to research information for their understanding can be seen by the prominence of this code in Figure 22.

Eight out of the 10 participants stated during their interview that for them, the activities that they undertook after the laboratory were involved in their change of understanding of a topic: four of these stated that their understanding changed both during and after the laboratory. Participants describing changes in understanding after the laboratory most described this change as being related to assessments (formal reports) where they were required to analyse and explain their data in the context of the underlying theory. Three different examples of how participants described the change in their theoretical understanding are shown below. The first relates to writing up a report after the lab, the second is a more general description of how their understanding changed and the third describes a similar process in relation to creating a portfolio piece. In each case, it is the process of reviewing the material after completing the practical which shapes the change in understanding.

> *"I would usually reflect back on the protocol and that would trigger instances where I would physically remember doing those steps. So, when I'm doing a write up I'd reflect on that, reflect back on the seminars and the theory behind what we're doing."*

> *"…because you start like, from the lectures you get, that you get given. So you go through the lectures like, ok cool. But after the lab, once you complete the practical, you go "oh this makes sense. This piece of theory applies to this device" and stuff like that.*

> *"Or if I'm probably going to do a portfolio piece or something on one of the labs. So some of the understanding will come from that. Because as I'm going back over it, "oh so that's what that meant in that lecture" …"*

For all bar one participant, this change in understanding was described as involving technology as this is the way that students accessed the information or described it as being related to using the lab equipment. For this participant, whilst they acknowledged that technology provided them with a source of information, they described the actual change in understanding as being a thought process (as below).

"I just think back, and I understand why we did it kind of thing"

This is in keeping with published literature by authors such as Domin (2007) whose study with first year chemistry undergraduates suggested that in expository laboratories (following a protocol) student conceptual understanding developed as a result of post-laboratory activities such as problem-solving tasks, writing up the laboratory class or having time to reflect on their experience. In a similar way, biochemistry students across multiple universities in Indonesia perceived that feedback on lab reports or being given an opportunity to present their lab results after a lab class would provide more effective lab learning (Anwar et al. 2017). In the case of Domin's study they did, however, highlight that undertaking problem-solving style labs impacted the student's perception of when understanding changes to being focussed within the session itself. Further to this, Domin suggested that irrespective of the type of laboratory, students required an opportunity to reflect on their experience to turn rote learning into meaningful learning. For the participants in this study, both the use of the portfolio (which incorporates reflective practice) and post-laboratory activities such as report writing during which students use technology to research and contextualise their findings fit this model of reflection on their experience to facilitate meaningful learning.

The role of technology in laboratory learning

As described above, all bar one of the participants indicated that technology had a role in their change in understanding of topics covered in their laboratory learning: with this participant stating that there was a change in understanding which came after – not during – the laboratory but that this did not involve technology. However, comparing the processes they described for this with those from other participants who stated that technology did have a role in the change in their understanding after the laboratory, these appeared similar. Both that participant and the participants that stated that technology did have a role, described using technology to research information but the difference seemed to be in how participants described the change taking place. In most instances, because of the role of technology in information gathering, participants perceived technology to be involved in changing their understanding because without the information (and for some participants, access to analytical tools such as Excel) their understanding would not have changed. By comparison the participant who perceived that technology did not have a role in changing their theoretical understanding stated it was because they considered it to be an internal thought process: so the method by which the information was gathered was separate from changes in their understanding.

The process described by the majority of students who considered that their understanding changed after the laboratory reflected a similar perspective to those participants who described their understanding changing during the laboratory. Within the laboratory, the physical process of performing the experiment, enabled students to link what they were doing with their background knowledge because some facet of the work reminded them, or helped them to contextualise, the theory they had already learnt.

When considering the learning process surrounding the laboratory, there are multiple stages which can be influenced by technology as can be seen in Figure 23. Broadly, this suggests that the role of technology in laboratory learning could be summarised as falling into the following categories:

- **Skill development:** this focusses on the use of laboratory equipment or software (e.g. Excel) to analyse lab data. For participants this skill development was positively viewed as being beneficial towards their career goals.
- **Information gathering, storage, and synthesis:** this aspect of the use of technology permeates both their personal and learning journey by making use of external resources (often online resources or applications). Within laboratory learning, information gathering can be found at all stages (although in different contexts) with the analysis and synthesise being most likely to occur in task understanding or performance.
- **Data analytical tools:** this is found in the post-laboratory phase where data gathered in the laboratory are analysed so that they can be developed for further use e.g., in assessment.

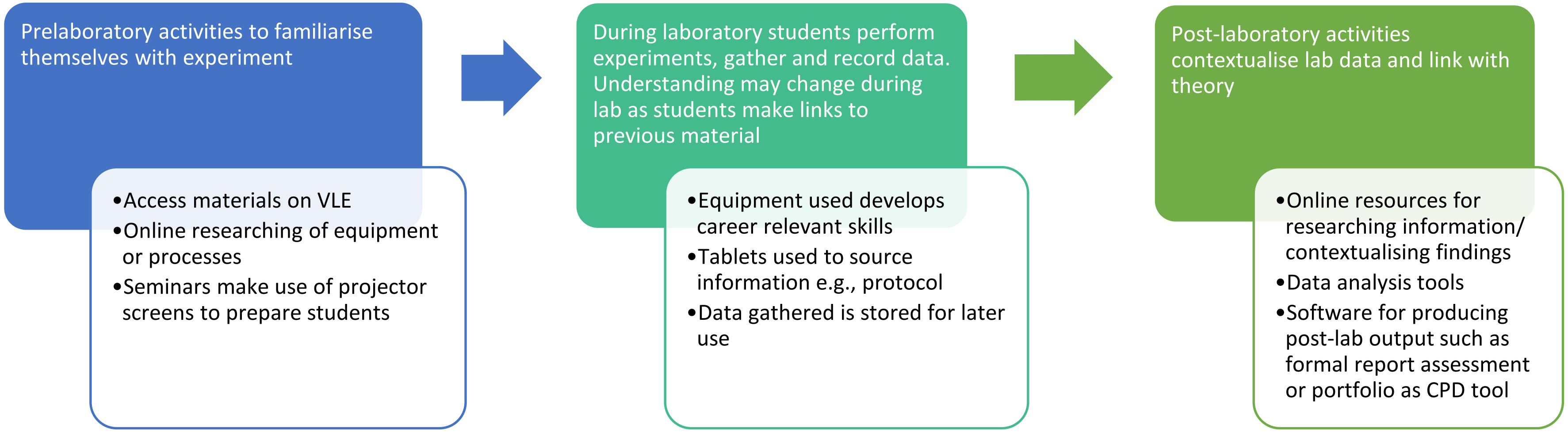


Figure 23: Reproduction of the summary of the learning process surrounding the laboratory shown in appendix 9 (Rayment et al., 2023). The coloured boxes give an overview of the participants description of the different phases of learning. The associated text boxes describe the participant's use of technology in that learning phase.

6.6 Conclusion

6.6.1 Technology use

Data gathered from participants in this study suggest that technology is pervasive in their personal lives and in their education with devices such as mobile phones and laptops being multi-functional. When focussing on the participants lab learning, the interviews (supported by the think-aloud sessions) demonstrate that technology impacts all stages of their lab learning: from preparation for the laboratory, carrying out the laboratory class and in activities afterwards that help to consolidate their learning.

Section 6.1 described the rationale for this study as being to identify how students use technology to support their lab learning and to explore their attitude to technology.

<u>Technology in lab learning</u>

As described above, the tasks that participants used technology for can be broadly split into three categories: *Information gathering, storage, and synthesis*; *skill development*; and *data analysis*.

<u>Information gathering</u>: this was applicable across all aspects of lab learning. For example, before the laboratory students used technological devices to familiarise themselves with the equipment and processes they would be using in the laboratory to increase the likelihood of successful completion of the experiment; in the laboratory they used the material projected onto the screen by academics and tablets to access information such as protocols and for recording/exporting data; and after the laboratory for research on the experimental topic to help them interpret and contextualise their findings.

<u>Skill development</u>: Whist this was predominantly focussed on laboratory skill development, participants also described having to learn how to use specialist software such as Excel for data analysis and use of other tools such as the VLE for accessing

information. In many cases, participants looked for guidance and support (from peers or staff) in developing these skills for their learning and seemed less inclined to "learn by making mistakes" than in their personal and social life because of the perceived importance of being successful (e.g., if experimental data contributed to an assessment) or because of anxiety over the cost of the equipment involved.

<u>Data analysis</u>: data interpretation required not only the use of specialist software to analysis but also the use of technology-based resources to interpret. As described in this chapter these events frequently occurred after the laboratory when participants were asked to produce assessed work such as lab reports.

6.6.2 Attitude to technology

Analysis of the interviews with participants showed that students had a broadly positive attitude to all technology and were able to see that it had a role to play not only in their personal life and their learning but also in a range of other areas including transport and medicine: which have a significant impact on modern society. Students' description of having grown up surrounded by technology and its pervasiveness, may do much to account for their comfort both with their own technologies and with new ones. The only common concern that students had around the use of technology were where they felt added pressure to "succeed": either because of an assessment or because of the fear that failing would damage expensive equipment.

6.6.3 Potential impact on staff practice

Pre-laboratory scaffolding: reducing student anxiety

Given that students who carried out pre-laboratory activities described these as being to familiarise themselves with equipment and processes that they would encounter in the laboratory, it would seem logical that resources and scaffolding should be provided to maximise the potential for student learning especially since Rayment et al. (2022a) demonstrated that only 65% of bioscience modules in UK HE institutions, used pre-laboratory sessions or activities to prepare students. Given the participants anxiety over using these laboratory technologies, student experience and learning in the laboratory may be improved if more modules provided pre-laboratory activities/sessions with particular attention being paid to increasing familiarity with expensive laboratory equipment prior to the class: as opposed to just reading the protocol, which was the most common activity described by Rayment et al. (2022a). Lab anxiety is not exclusively a phenomenon seen only in the current study. Studies with Turkish chemistry students have similarly shown laboratory anxiety although in these instances, the anxiety was most focussed on health and safety (69% of students who participated in the study were concerned that making a mistake could result in injury to themselves or others) and anxiety around breaking expensive equipment (Sesen and Mutlu, 2014). Similar observations have been made in the UK where a mixed methods approach highlighted student anxiety about breaking equipment and making mistakes (George-Williams et al., 2022).

During laboratory scaffolding: enhance content understanding

One of the interesting points shown by the think-aloud data was that different experiments appeared to have different targets for metacognitive regulation, and it was hypothesised that participants could potentially be using gaps in their experiments to reflect on what they were doing. Whilst the think-aloud data shown in this chapter does not show a high frequency of change in content understanding during the lab, the interviews showed that at least half of the participants felt that their understanding of a topic did change during the laboratory itself. To enhance student understanding of the theory further, laboratory protocols could include scaffolding activities or reflective prompts to encourage students to think about the underlying theory going on in their experiment or what they would hypothesise the outcome to be and why.

Post-laboratory scaffolding: enhancing metacognition

Similarly, as described in Chapter 3, 21.6% of bioscience modules did not use any post-laboratory activities to support student learning (65.6% had required activities; 10.8% had optional activities). Given the finding of this study, where 8 out of the 10 main study participants as well as the pilot participant all expressed that post-laboratory activities impacted on their understanding of the laboratory's underlying theory, this would appear to be a missed opportunity to scaffold consolidation of lab learning and to facilitate students' being able to connect the theory with their laboratory observation. In particular, activities which require students to contextualise their data (either in the literature or to explain it within the context of their module content) would be beneficial to enable students to make meaningful connections between the laboratory and their content understanding, thereby facilitating formation of long-term memories as described by Novak (1980).

6.6.4 Reflection on methodological approaches

The combination of the think-aloud and interview methodology provided data that enabled the aims set out for the study to be addressed. For the most part, the discussion in the interviews around use of technology in the laboratory were in agreement with observations that were made from the think-aloud data. Further analysis of the coded data would be required to address the question of participant's change in content understanding during the laboratory more fully, since the explicitly technology-based process-coded data used did not widely support this within the metacognitive coding framework: instead, the use of technology appearing to be centred on task understanding or performance. One possibility is that these changes put additional pressure on the working memory and so are occurring in the times when participants stopped talking to facilitate processing. To investigate whether that is the case, making static recordings (e.g., tripod-mounted video cameras) alongside the audio recording would give the researcher a visual prompt to be able to discuss with the participants what was happening during the times when they stopped talking. Whilst in itself the video recordings would be an incomplete record due to students moving around the laboratory (as highlighted in section 6.1) it could be used effectively to gain more insight into whether participant understanding of the underlying theory changed during these times if used as part of an interview discussion: in a similar way to that described by Galloway and Bretz (2016).

Chapter 7: Conclusions

7.1 Reflecting on thesis research aims.

In Chapter 1, the overarching aims for this project were described and a map (Figure 5) created to show how each of the studies was connected to these. In drawing together final thoughts on the project, it is appropriate to reflect on what the research findings say about each of the aims.

Aim 1: Establish student digital literacy and whether this affects their lab experience.

Chapters 2 and 3 described the design and use of two survey-based tools that were designed to address this aim. The outcome of the DHS and modified-SLEI showed that students accessed the internet every day with most using their smartphone everyday (an observation that was borne out in the semi-structured interviews in chapter 6). Whilst significant differences in digital literacy scores were seen between first year student cohorts, an individual's digital literacy did not correlate with any of the characteristics of the modified-SLEI (which was designed to explore their laboratory experience) suggesting that these factors are not related. However, students do have different lab experiences in the same laboratory space based on their course: the analysis of the modified-SLEI suggested that bioscience students scored more highly than chemistry students in open-endedness and social cohesion but lower for rule clarity. Overall, this creates a picture of bioscience students having more opportunity for exploring topics and more peer interaction but with less obviously defined differences between the rules in the lab and other teaching spaces than for chemistry students.

Comparison of student digital skills (data from the DHS) against the employer survey data demonstrated that a high proportion of students on bioscience course acquired or already had the skills that employers required of their graduates. A caveat to this is that the data from the DHS 2015-16 returning students was considered less reliable than for other cohorts due to there only being 4 participants (compared to the 88-121 for all other data sets).

Whilst it did not create a quantitative measure of digital literacy, the study described in chapter 6 highlighted that students felt confident with their personal technologies, often feeling able to move between technologies without instruction because of their familiar nature. Conversely, the unfamiliar nature, complexity, and perceived cost of some of the technologies encountered in the laboratory was described as a cause of anxiety for some, and participants frequently described taking measures such as familiarising themselves with the processes or equipment in the lab ahead of time or having a preference for written instructions for their use, which was not dependent on how they described their comfort and familiarity with their personal technologies.

Aim 2: Student's attitude to technology and its effect on their experience and learning.

The open questions in the DHS highlighted that student participants across different cohorts had a broadly similar, and positive, view of technology in education: this focussed on the benefits in flexibility to study, developing professional skills, as a source of information as well as a perception of "levelling the playing field". The most common issue identified with technology was its potential to serve as a distraction particularly in terms of the availability of social media.

Similarly, the interview discussions with participants in chapter 6 demonstrated a broadly positive attitude towards technology with participants recognising that both in their personal/social lives and their learning journey, technology was integral. Their personal use was frequently described as for communication (through social media, gaming, emails), media (news, streaming content, or music) or as a source of information. As demonstrated by two of the participants, so integrated has the use of technology become as a rapid source of information, that when they had difficulty in defining technology, their solution was to want to "google it". In addition to their personal use, participants recognised benefits of technology in medicine and transport as well as in a range of day-to-day activities. Other than one participant's concern over data security and potential for reduced development of verbal communication skills, the only concerns about technology came from its use in their learning. The participants were positive about the use of technology from the point of view of having benefits to their learning and preparedness for the world of work (where they expected to use similar technologies), but some expressed anxiety or frustration: especially in respect of being able to adequately use the equipment or software. As highlighted under the first aim, this was at times directed towards the pressure they perceived from the impact that things going wrong could have on their experiment and related assessment. Whilst the participants expressed these concerns, these did not appear to address the observations in the modified-SLEI which saw a reduction in the attitude to tablet score in the longitudinal case studies and it remains unclear what the reason for this is.

Except for one participant for whom frustration and social anxiety appeared to outweigh the potential benefits of practical classes, students expressed enjoyment of or saw benefits to laboratory classes: particularly in giving the necessary skills for their chosen career and "making science real". In both the think-aloud sessions and interviews, there was clear support for the participants' focus on development of skills during laboratory which often (but not always) according to the participants' definition involved technology. Given the objectives of the laboratory classes used in this study (each followed a set protocol) this is perhaps not unexpected. Having said that, participants described that laboratory classes had the potential to change or become integrated into their theoretical understanding of a topic during or after the laboratory class.

Aim 3: Establish staff practice in the provision of pre-post lab activities.

This latter point is of particular importance therefore when considering how modules and courses scaffold learning around the laboratory. The survey that was undertaken of UK HE institutions as part of this thesis (chapter 5) collected data from 30 institutions across the UK and provided data on 88 modules (45 chemistry modules and 43 bioscience modules). This study highlighted that two-thirds of bioscience modules engaged learners before the laboratory; with a similar proportion using post-laboratory activities to analyse or interpret data (often as part of an assessment). The number of pre-lab activities varied between disciplines with bioscience students typically only asked to read the protocol. This is in keeping with the commentary from the semi-structured interviews: although students who undertook pre-laboratory preparation typically described undertaking additional activities such as watching videos or looking for further information online to support their preparation when aspects of the laboratory or equipment involved were unclear to them.

7.2 Commentary on research findings

Taking the outcome for the various studies in this thesis together presents a picture of the undergraduate bioscience students at NTU as *confident with digital technologies in their personal and social life*. Whilst many technologies that form the core of their learning journey at the university (such as laptops and mobile phones) are multifunctional and also feature strongly in their personal life, unfamiliar technologies such as complex and *expensive laboratory equipment can be a source of anxiety* for some students. This may present learning challenges given the complex nature of the laboratory; as outlined by Agustian & Seery (2017). Given this, more extensive pre-laboratory activities would be a valuable route to reducing these potential barriers to learning gains. The case study example provided in this thesis (chapter 5) shows that the pre-laboratory provision of technical videos can have benefits in terms of building student confidence and familiarity ahead of the laboratory: similar to the experiences described in the semi-structured interviews. Whilst the case study was not able to ascertain whether this impacted on student learning per se, the literature would support this being a possibility (see Rayment et al., 2022a for detailed discussion) and would *strengthen the argument for wider adoption of scaffolding for lab learning ahead of the laboratory* itself.

With the semi-structured interviews in chapter 6 highlighting *the importance of post-laboratory activities in consolidating learning* and moving the laboratory from a seemingly psychomotor dominated experience to one that develops students' understanding of the underlying theory, it is important to reflect on current practice. At the time that the study was undertaken, two thirds of bioscience modules used compulsory post-laboratory activities in their modules with a further 10% having optional activities. This is not to say that every laboratory in the module had supporting post-laboratory activities, but those that did often had activities that were assessment-linked e.g., generating reports, oral presentations, posters or portfolios; and in almost all cases involved data handling of some form.

With that in mind it brings us back to why undergraduate laboratories are undertaken in bioscience education. These reasons are numerous and do include development of practical skills (which came out as a strong feature in how technology was used in the laboratory: chapter 6) but also areas relating to students' theoretical understanding and affective considerations (Adams 2009). The former being to contextualise a theoretical concept and develop an understanding of the scientific method; the latter being more focussed on building student confidence, engagement, and reflective skills. Some evidence of these can be seen in the data described in this thesis. Student participants in chapter 6 were clearly engaged with their laboratory studies, which for some facilitated a change in their theoretical understanding during or after the class. Changes during the class were more likely to be described as something “clicking into place” whereas changes after the class involved a process of research and analysis. Evidence of building reflective skills were also described to some degree by participants through their description of portfolio work. Students on bioscience courses at NTU undertake portfolios designed to demonstrate their skills and include a reflection on their success and areas for improvement. Not all participants described this as an activity they undertook post-laboratory and those that did, did not indicate that this was a process that followed every lab: suggesting that reflective practice does not become an integrated part of their lab practice. It was, however, interesting to note that in the video case study, access to the technical videos after a lab class served not only as a potential information source for revision but also to allow them to reflect on their performance: suggesting that these resources have multiple benefits for students.

Overall, this study suggests that, from a student perspective, *provision of practical education (especially scaffolding pre- and post-laboratory) can have a significant impact on their understanding of a given topic*: but since one third of bioscience modules do not have pre-laboratory or post-laboratory activities, there are clearly ways to develop practice further if one of the stated aims of having laboratory classes is to contextualise theoretical understanding. The study demonstrates that current learners engage well with technology in their learning, seeing it as giving them the skills needed to be prepared for future work.

As mentioned elsewhere in the thesis, it is pertinent to remember that the observations made in this project are based on data collected prior to the pandemic and so it is important to consider the impact that this has had on undergraduate bioscience practical education.

The circumstances that students found themselves in during the lockdown periods and social distancing had a significant and negative impact on student wellbeing and mental health which in turn had a significant impact on student learning (Nurunnabi, Almusharraf, and Aldeghaither, 2020). Many students reported feeling a disconnect with their learning and others on their course due to issues in managing their own time, a feeling of lack of support, and distractions (Bashir et al. 2021; Chaplin, Kohalmi and Simon 2024; Pennino et al., 2022). Given the observations in this project around the potential for social anxiety in collaborative spaces such as the lab, and anxiety around using unfamiliar equipment (chapter 6) this observation provides an even stronger argument for pre-laboratory scaffolding and support for students to be able to make the most of the laboratory as a learning environment.

As described in section 1.9, this disruption in student education either during their education at university or, more recently, prior to university means that additional thought is required when considering resources and approaches to supporting these learners whose educational journey has been impacted in this way. Since the studies in chapters 5 and 6 have demonstrated that pre- and post-laboratory activities can have a significant impact on student confidence in the laboratory (particularly through pre-laboratory activities) and an improved integration of their theory and practical knowledge, more scaffolding around laboratory classes would potentially have even greater benefits for these cohorts than has previously been observed. Based on this, the findings of this thesis would appear to be as impactful, or even more so, than when the data was collected.

As highlighted in the review of literature in chapter 1, strategic avenues taken in response to the pandemic included creating or utilising videos, simulations, dry labs and lab demonstrations in place of laboratory classes. Although prior to the pandemic, the video case study described in chapter 5 (and appendix 8) demonstrated the potential ways that technical videos could support laboratory learning, both ahead of the laboratory (to increase student confidence and reduce anxiety over using unfamiliar equipment or processes) as well as post-laboratory (for reflection and revision). Since the videos were hosted on YouTube, the viewing analytics could be compared from the time that they were first introduced to viewing during the pandemic. These figures show a dramatic increase in the use of these videos, which is in keeping with the published literature from academics such as Heng et al. (2022), Wilkinson, Nibbs and Francis (2021) and Smith and Francis (2022) which demonstrated the benefits and trends in using video-based resources in supporting learning during the pandemic. The video case study in chapter 5 (Rayment *et al.*, 2022a) also highlighted that the increased use of these resources during the pandemic reflected their broader incorporation to support a range of different activities at different levels of study: including pre-laboratory support for NQF level 4 students and as part of a suite of resources used to support a lab activity at NQF level 5. All indications from the literature would suggest that these resources can continue to support practical education whether or not the laboratory classes are returned to their original design. An example of this, albeit on a different scale, is the use of virtual simulations and remote experimentation as massive open online courses (MOOCs) during the pandemic, which resulted in greater levels of inquiry-led and self-directed student learning, as well as building confidence in the laboratory skills (Radhamani et al. 2021).

The data from chapter 6 demonstrated that biomedical science students valued the opportunity to develop hands-on practical skills as they associated this with professional skills that they would make use of as part of their future career. Similar observations were made in Ulster where students recognised the value of the wet laboratory alternatives as equally of value for skills such as critical thinking but described that these were not a substitute for hands-on practice in terms of skill development - especially in terms of capstone projects (McKenna, 2023). This may, in part at least, reflect the difference in expectations that students have for their project compared to their supervisor. Lewis et al. (2017) described how students viewed the project as an opportunity to gain greater understanding of a particular topic whereas staff viewed it as a way to build competency in skills looked for by graduate employers which, as discussed in chapter 4, were more likely to be transferrable skills rather than knowledge based. The diversification of project types available to students as a result of the pandemic, has the potential to allow students to personalise the type of project chosen to better suit their future career plans. For a third of students, this would likely result in non-traditional capstone projects (Lewis 2020). Within NTU, the use of bioinformatics, education-based and meta-analysis style projects were all accessible to bioscience undergraduate students prior to the pandemic, however these have remained greater in number than before the pandemic and with many practical projects retaining elements of bioinformatics even if the main focus is on laboratory experimentation. With the pandemic providing the potential for more sophisticated approaches to laboratory education and the integration of multiple avenues of research than previously (as shown at NTU), there are distinct benefits in terms of building student digital skills (such as use of bioinformatics) and entrepreneurship: both of which are desirable for graduate employers (Rolfe, Adukwu 2023).

However, universities need to consider the resources that are put into supporting students with these types of activities as assumption that the students have access to appropriate digital resources in their home environment has the potential to disproportionately affect the most disadvantaged students who may be experiencing digital poverty (Bashir et al., 2021). This was evident, even prior to the pandemic since one out of the 10 participants described in the interview in Chapter 6 that outside of the university they were reliant on their phone as their primary learning technology for university work. However, since the pandemic, this has become a growing concern given the current cost of living crisis (Ragnedda et al. 2022).

As mentioned earlier, with students return to campus, the incorporation of resources and approaches created during the pandemic to complement face-to-face labs or where appropriate used in their place, presents an opportunity to prioritise development of new activities and avenues of inquiry for students as well as create a more sophisticated blend of virtual and hands-on practical education. With this in mind, it is pertinent to reflect on the student experience described in chapters 2, 3 and 6 to consider whether the predominantly protocol driven approach to laboratory education described for these cohorts are the best of use of their limited laboratory time. Further discussion on this is included in the future direction section of this chapter (section 7.4).

7.3 Constructivism vs connectivism

In chapter 1 (section 1.10) it was described that the outcome of this thesis may support a better understanding of whether current practices in laboratory education at NTU (with the expectation that this may also be true in other bioscience degree courses) would be best described as a social constructivist or connectivist framework for learning.

Taking the data from the think-aloud sessions and the interviews, together with supporting evidence from the digital history survey (section 3.1.2), there is strong justification for revising the framework within which students learn on their bioscience course at NTU to sit within connectivism rather than constructivism.

The think-aloud sessions show direct evidence of how students utilise a range of resources to support and develop their understanding, which is supported by student responses to the DHS question centred on whether technology has a positive or negative impact on their learning (see table 27 and figure 9). The evidence from the think-aloud sessions can be broken down into two categories:

1. <u>Peers as a resource</u>:

Throughout the laboratory sessions students work in collaboration with a laboratory partner and these have a significant impact on their learning. As shown in Appendix 9 (Rayment et al. 2023) where the number of instances of SSRL is higher in each case than SRL as a mode of learning, socially shared construction of knowledge is a key aspect of the laboratory. This was supported by the interviews which identified labs as social spaces.

2. <u>Devices as a resource</u>:

Within the connectivist framework, devices are also included in the network of sources of support for learning and this has been demonstrated both within the laboratory (where participants used technology to access information such as protocols, perform their experiments and to promote their understanding of their task) as well as during the interviews (where participants described the use of technology to familiarise themselves with the lab ahead of time as well as analyse and research their topic after the laboratory to increase their understanding and contextualise their findings). Similarly in the DHS, participants described technology as a source of information that extends their understanding of a topic and improved their focus on the task they were undertaking.

In some cases, the use of technology and peers to aid in learning is simultaneous or shared. For example, in the laboratory think-aloud sessions students discuss and interpret what they are doing using the tablet as a shared source of information. Whereas, in the DHS, students described technology as beneficial in supporting collaboration and communication with others as part of their learner journey.

Having said that, not all participants agreed that technology impacted their understanding of a topic covered by their laboratory class. To make sense of this, requires consideration of the definition of connectivism. According to the connectivist theory, learning occurs when individuals make use of an integrated network of connections: these can include social networks (such as peers or teachers), as well as appliances such as computer networks (Siemens 2005; Siemens 2017). The key here is that these are integrated with one another and impact on one another but that the learner is at the centre of this. In this way, technology would form one of the resources or avenues for students use to support their learning, whilst not being the exclusive source. The data generated by this thesis would support this interpretation.

7.3.1 Reflection on methodological approaches

The combination of the think-aloud and interview methodology provided data that enabled the aims set out for this study to be addressed. For the most part, the discussion in the interviews around use of technology in the laboratory were in agreement with observations that were made from the think-aloud data. Further analysis of the coded data would be required to address the question of participant's change in content understanding during the laboratory more fully, since the explicitly technology-based process-coded data used did not widely support this within the metacognitive coding framework: instead, the use of technology appearing to be centred on task understanding or performance. One possibility is that these changes put additional pressure on the working memory and so are occurring in the times when participants stopped talking to facilitate processing. To investigate whether that is the case, making static recordings (e.g., tripod-mounted video cameras) alongside the audio recording would give the researcher a visual prompt to be able to discuss with the participants what was happening during the times when they stopped talking. Whilst in itself the video recordings would be an incomplete record due to students moving around the laboratory (as highlighted in section 6.1) it could be used effectively to gain more insight into whether participant understanding of the underlying theory changed during these times if used as part of an interview discussion: in a similar way to that described by Galloway and Bretz (2016).

7.4 Future direction

A perhaps natural extension of the study described in chapter 6 is to consider not only how students are using technology in their laboratory associated learning but also what they are learning and how integrated this is with their existing knowledge. To this end, a pilot study has been designed using a mind-mapping approach (a technique commonly used to investigate student understanding of a topic; Heinze-Fry & Novak, 1990; Novak, 1990, 2010; Novak & Cañas, 2006) to examine how students' understanding of a topic change over the course of their undergraduate final year project. This study will use a pre- and post-project mind-mapping exercise based around SDS-PAGE; which is a common technique used in undergraduate projects and contains difficult or "troublesome" concepts such as charge (Meyer, Land 2003; Moss et al. 2007). This approach will be coupled with an unstructured interview to allow students to compare their pre- and post-project mind-maps. Although a wide variety of complex techniques could be incorporated into a study of this type, SDS-PAGE was selected since it also had potential to relate back to the think-aloud sessions described in this thesis, one of which used an SDS-PAGE protocol. As a part of this, it could be beneficial to undertake further analysis of the think-aloud sessions presented in this thesis to investigate the student learning experience more generally (as opposed to focussing on the role of technology in their learning).

Since most of the data in this thesis was collected prior to the pandemic, there are benefits to returning to some areas of the study to establish what its' impact has been on the wider sector. One aspect of this work stands out in this regard, and that is the pre-/post-lab survey of UK HE modules. The distance learning strategies developed during the pandemic when students were not able to attend campus or had restricted access to the laboratory due to social distancing have undoubtedly given rise to changes in the way that laboratory education will be approached going forward as strategies and resources created during this time may be incorporated into the return to on-campus provision as pre-/or post-laboratory resources and the retention or change in the way that dry labs are used.

At an institutional level, within bioscience course provision at NTU, the findings of this study have been integrated into a new foundation provision that the researcher has been instrumental in designing and is now leading through its' first iteration, where pre-and post-laboratory sessions support laboratory classes. Not only this but a "mini-project" has been implemented so that foundation students work as a team to apply knowledge and skills from across their course to answer an employer-focussed question. The project requires students to draw on information from different modules on their course and so could be expected to support development of integrated networks of knowledge. As described in section 1.3, literature by researchers such as Holstein have demonstrated that within chemistry labs, problem-solving laboratory classes can have benefits over protocol-driven laboratory classes both in terms of integration of content understanding and development of metacognitive skills - which we would extrapolate to be similarly observed for bioscience students. Additionally, this approach will also foster desirable graduate skills as outlined in chapter 4 such as problem-solving, teamwork, and time management.

In future years, adoption of this type of contextualised problem-solving lab/project across the life of the course, culminating in the final year capstone project (which all bioscience students at NTU undertake), would be the ultimate aim. By building the complexity of the projects as students progress (as described by Seery's framework: see section 1.3 and figure 2) their learner journey should provide a set of skills and abilities that ensure graduates are well prepared for the world of work. This is particularly relevant in post-COVID education where (anecdotally) student engagement with traditional forms of teaching, such as lectures, is poor. In this situation, making more extensive use of practical education, which (as discussed in chapter one) is typically motivating for students would significantly enhance their knowledge and skill development. Extending this to include a diverse range of resources such as pre-recorded content developed during the pandemic, videos, quizzes and simulations could further scaffold student learning and preparation for the laboratory.

Whilst this may represent the goal within the NTU bioscience courses, this is not in itself the endpoint. Many universities have bioscience degree provision and being able to evidence and advocate for the benefits of widescale adoption of this type of approach would be an aspirational goal.

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9. Appendices

Appendix 1: Digital history survey as used with first year students in 2017-18. The question in the survey were consistent throughout the use of the study with the exception of the addition of social media questions on pages 22-23 that were added in 2016-17.

Participant Information

Project description, researchers and procedure
This survey is part of research in the School of Science and Technology to assess the impact of technology on student learning and staff practice in undergraduate laboratories. This research is being carried out by Jennifer Evans and Sarah Rayment and is being led by Karen Moss.
All undergraduate students in the School of Science and Technology are invited to participate in this research. Participation involves completing this survey which will take approximately 20 minutes to complete. Further surveys and opportunities for focus groups or interviews will occur throughout the duration of your course.

Anonymity and confidentiality
All information collected as part of this survey will be anonymous i.e. that responses will not be linked be to individual participants. You will be identified by a participant identification number which will be emailed to you with each survey or interview invitation. Information collected from this survey may be published as part of the project, but participants will not be identifiable. Information from this survey may also be used to improve the future student experience.

Consent, participation and withdrawal
Clicking the 'Next' button at the bottom of this page will indicate your consent to participate in this study.
Please complete the whole survey if possible.
Participation in this study is voluntary and you have the right to stop the survey at any time. You can withdraw your data from this study after you have submitted your answers for up to two weeks after completing this survey.
In order to withdraw your data after submission you need to enter two unique identifiers (for example your pet's name). *Please do not use your student number, name or email.*
If you wish to withdraw your data you must email the researchers below with your unique identifiers.

Ethics
This study has been approved by the School non-invasive ethics committee.

Contact Details
If you have any questions or concerns regarding this research, please contact:
Sarah Rayment: sarah.rayment@ntu.ac.uk
Jennifer Evans: jennifer.evans@ntu.ac.uk
Karen Moss: karen.moss@ntu.ac.uk

* Statement of agreement:

○ I have read and understood the statements above, and agree to participate in this project.

Withdrawal information

You can withdraw your data from this study after you have submitted your answers for up to two weeks after completing this survey.
Please make a note of what your unique identifiers are, if you don't know your identifiers then your data cannot be identified and therefore cannot be withdrawn.

* In order to be able to withdraw your answers from this study please provide two unique identifiers. For example:
• A memorable surname
• A pet's name
• Your favourite instrument
• A memorable city
• A street name

Please do not use an identifier that is easily traceable to you as a participant such as your student number, name or contact details.

Unique identifier 1

Unique identifier 2

Information about you

* Please enter your participant identification number

* Please select your age group:

- 21 or under
- 22-25
- 26-35
- 35 or over
- Prefer not to say.

* Which gender do you identify as:

- Male
- Female
- Neither of the above/other
- Prefer not to say

* What is your first language?

* Please indicate your highest level of education prior to starting your university course:

* Do you consider yourself to have a disability?

A disability is defined by the Equality Act 2010 as a physical or mental impairment which has a substantial and long-term adverse effect on your ability to carry out normal day to day activities. Disabilities can be hidden and include long-term conditions which can be controlled through medication, for example epilepsy, asthma, heart conditions, diabetes.

- Yes
- No
- Prefer not to say

Information about you

If you consider yourself to have a disability, please select all that apply to you.

- Autistic Spectrum Disorder or Asperger's syndrome
- Depression or other mental health difficulties
- Mobility related conditions
- Blind or partially sighted, or other sight related conditions.
- Deaf or hard of hearing, or other hearing related conditions.
- Dyslexia, dyspraxia or other specific learning difficulty.
- Other (please specify)

* Do you consider your condition to affect your experience in the lab, or your use of technology?

- Yes
- No
- Prefer not to say

Information about you

* Please select your course area:

- Biosciences
- Chemistry
- Computing
- Forensics
- Mathematics
- Physics
- Sport Science

Information about your course - Biosciences

* Please select your course:

- ◯ BSc Biomed Sciences (PT)
- ◯ BSc Biomedical Science (FT/SW/PT)
- ◯ BSc Biological Science (PT/FT/SW)
- ◯ BSc Microbiology (FT/SW)
- ◯ BSc Biochemistry (FT/SW)
- ◯ BSc Applied Biomedical Science (FT)
- ◯ BSc Pharmacology (FT/SW)
- ◯ FdSc Healthcare Science (PT)
- ◯ BSc Biological Science (Bio & Micro) (FT/SW)
- ◯ BSc Ecol & Environ Management (PT)
- ◯ BSc Biological Science (Biomedical Science) (FT/SW)
- ◯ BSc Biological Science (Ecol & Env) (FT/SW)
- ◯ BSc Biological Science (Phys& Pharm) (FT/SW)
- ◯ BSc Biochem & Micro (PT)
- ◯ BSc Physiology & Pharm (PT)
- ◯ MBiol Biochemistry (FT/ST)
- ◯ MBiol Microbiology (FT)
- ◯ MBiol Pharmacology (SW)

Information about your course - Chemistry

* Please select your course:

- ◯ MChem Chemistry (FT)
- ◯ MChem Chemistry with Professional Practice/International Study (SW)
- ◯ BSc Chemistry with Professional Practice (PT)
- ◯ BSc Pharmaceutical and Medicinal Chemistry (FT/SW)
- ◯ BSc Chemistry (FT/SW)
- ◯ BSc Chemical Sciences (FT)
- ◯ FdSc Chemistry (FT)

Information about your course - Forensic Science

* Please select your course:

- ◯ BSc Forensic Science (FT/SW)
- ◯ BSc Forensic Science (Physical) (FT/SW)
- ◯ BSc Forensic Biology (FT/SW)
- ◯ BSc Forensic Biology (Ecology) (FT)
- ◯ BSc Forensic Biology (Molecular Biology) (FT)
- ◯ FdSc Forensic Science (FT)

Information about your course - Computing

* Please select your course:

- ◯ BSc Computing (FT/SW)
- ◯ BSc Computer Science (FT/SW)
- ◯ BSc Computer Science (Games Tech) (FT/SW)
- ◯ BSc Computer Systems (Networks) (FT/SW)
- ◯ BSc Computer Systems Engineering) (FT/SW)
- ◯ BSc Computer Systems (Forensic and Security) (FT/SW)
- ◯ BSc Computer Science & Maths (FT/SW)
- ◯ BSc Computer Studies (SW)
- ◯ BSc Information and Communications Technology (FT/SW)
- ◯ BSc Information Systems (FT/SW)
- ◯ BSc Software Engineering (FT/SW)
- ◯ BSc Digital Media Technology (FT/SW)
- ◯ MComp Computer Systems Engineering (FT/SW)
- ◯ MComp Computer Science (FT/SW)

Information about your course - Mathematics

* Please select your course:

- ◯ BSc Computer Science & Maths (FT/SW)
- ◯ BSc Financial Maths (SW)
- ◯ BSc Mathematics (FT)
- ◯ BSc Sport Science & Maths (FT/SW)
- ◯ MMath Mathematics (FT/SW)

Information about your course - Physics

* Please select your course:

- ◯ BSc Physics (FT/SW)
- ◯ BSc Physics with Astrophysics (FT/SW)
- ◯ BSc Physics with Forensic Applications (FT/SW)
- ◯ BSc Physics with Nuclear Technology (FT/SW)
- ◯ FdSc Physics (FT)
- ◯ MSci Physics (FT)
- ◯ BSc Techn. Physics. (FT)

Information about your course - Sports Science

* Please select your course:

- ◯ BSc Coaching & Sport Science (FT/SW)
- ◯ BSc Exercise Nutrition & Health (FT/SW)
- ◯ BSc Sport & Exercise Science (FT/SW)
- ◯ BSc Sport Science & Management (FT/SW)

Information about you

* Have you completed a placement as a part of your course?

- ◯ Yes
- ◯ No

* Do you have any of the following IT qualifications?
(Please select all that apply.)

- ☐ GCSE IT - Grade C or above
- ☐ IT Key Skills Level 2 - Pass grade
- ☐ IT Key Skills Level 3 - Pass grade
- ☐ IT A-Level - Grade C or above
- ☐ European Computer Driving License (ECDL) - Pass grade
- ☐ No relevant IT qualification
- ☐ Other relevant qualification: e.g. Computer Science, BTEC qualifications, or other appropriate computing/IT qualifications (Please specify)

About your access to & use of technology

* Before coming to university, I had access to a computer connected to the Internet...
(Please select all that apply.)

- ☐ At home / student residence
- ☐ At work
- ☐ At university / college / learning centre
- ☐ Other location (please specify)

* This academic year at university, I have access to a computer connected to the Internet...
(Please select all that apply.)

- ☐ At home / student residence
- ☐ At work
- ☐ At university
- ☐ Other location (please specify)

In your day to day life, how often do you use the following technologies?

	Every day	A few times a week	Less than once a week	Less than once a month	I have never used this technology.
Desktop computer, laptop or netbook.	◯	◯	◯	◯	◯
Tablet	◯	◯	◯	◯	◯
Smart phone	◯	◯	◯	◯	◯

For a desktop computer, laptop or netbook: which operating system are you most familiar with?

- ◯ Apple
- ◯ Microsoft
- ◯ Linux
- ◯ I have never used this device
- ◯ Don't know

For a tablet: which operating system are you most familiar with?

- ◯ Apple
- ◯ Microsoft
- ◯ Android
- ◯ Other (please specify)
- ◯ Blackberry
- ◯ I have never used this device
- ◯ Don't know

For a smart phone: which operating system are you most familiar with?

- Apple (iOS)
- Android
- Microsoft (Windows)
- I have never used this device
- Blackberry
- Don't know
- Other (please specify)

About your access to & use of technology

* I access the internet:

- Every day
- A few times a week
- Less than once a week
- Less than once a month.

I have customised my computer* to suit my personal preferences (please see below for examples)

*For the purposes of these questions, "my computer" refers to a computer that you access and use regularly, or your tablet / smart phone if it has these capabilities.

- Yes
- No

If yes, please indicate which of the following you have customised:
(Please select all that apply.)

- Tool bar(s) and menu items.
- Mouse buttons (Or extra keyboard buttons)
- Background colours
- Wallpapers and screensavers
- Icon sizes
- Print size on screen
- Language settings
- Other (please specify)

About your access to & use of technology

I own the following technologies for my personal use:
(Please select all that apply.)
If you use your mobile phone for these functions, please select those functions too.
(e.g. if your phone plays music, select mp3 player)

- ☐ Smart phone
- ☐ Other mobile phone (not smart phone)
- ☐ iPod or mp3 player
- ☐ Tablet
- ☐ Laptop or netbook
- ☐ Digital camera
- ☐ Digital video camera
- ☐ Webcam
- ☐ Digital audio recorder
- ☐ Assistive technology : hardware or software (screen readers etc.)

In your personal and social life, how often do you do the following:
(Please select all that apply.)

	Every day	A few times a week	Less than once a week	Less than once a month	A few times a year	Never
Use social networking sites (e.g. Facebook, Twitter, G+)	○	○	○	○	○	○
Download podcasts	○	○	○	○	○	○
Use instant messaging or chat (e.g. Facebook messenger, Skype typed messages)	○	○	○	○	○	○
Use video calls (e.g. Facetime, Skype video chat)	○	○	○	○	○	○
Watch live TV or catch-up TV online (e.g. iPlayer, 4OD)	○	○	○	○	○	○
Watch on demand video (e.g. YouTube)	○	○	○	○	○	○
Upload video or photo content to the internet (e.g. Instagram, Youtube)	○	○	○	○	○	○
Participate in discussion groups or online chatrooms	○	○	○	○	○	○
Use wikis or blogs.	○	○	○	○	○	○
Maintain my own blog or website.	○	○	○	○	○	○
Take part in an online community through online gaming	○	○	○	○	○	○

About your access to & use of technology

* Where do you intend to do most of your studying in the upcoming university year?

- ◯ Home / Student residence
- ◯ Workplace
- ◯ University library, or other study area.
- ◯ Other (please specify)

When you study, do you usually ensure you have easy access to the internet?

- ☐ Yes, I like to have my smart phone available with the internet available.
- ☐ Yes, I like to have a desktop computer, laptop or netbook with the internet available.
- ☐ Yes, I like to have my tablet available with the internet available.
- ☐ No, I do not ensure I have the internet available when I study.

I am able to use my personal technologies (including assistive technologies) at university.

- ◯ Yes
- ◯ No
- ◯ I do not bring my personal technologies with me to where I learn.

If no, please briefly describe any difficulties you have encountered.

About your use of technology

* Before commencing your university course, how frequently did you:

	Every day	A few times a week	Less than once a week	Less than once a month	A few times a year	Never
Download, save and open files.	◯	◯	◯	◯	◯	◯
Put information into a pre-made form, downloaded from the internet. (A proforma / template)	◯	◯	◯	◯	◯	◯
Co-create resources or work with a peer online.	◯	◯	◯	◯	◯	◯
Use formulae to manipulate data a spreadsheet (e.g. Excel)	◯	◯	◯	◯	◯	◯
Produce professional diagrams using drawing packages (e.g. ChemDraw or BioDraw)	◯	◯	◯	◯	◯	◯
Use a Virtual Learning Environment (e.g. NOW, WebCT, Moodle)	◯	◯	◯	◯	◯	◯
Create graphs using a spreadsheet (e.g. Excel)	◯	◯	◯	◯	◯	◯
Insert images, tables and graphs into word processed files or presentations. (e.g. MS Word, Powerpoint)	◯	◯	◯	◯	◯	◯
Use cloud storage (e.g. Dropbox.com, NOW MyFiles, iCloud, SkyDrive)	◯	◯	◯	◯	◯	◯
Interact with staff or students online (e.g. email, discussion boards)	◯	◯	◯	◯	◯	◯

About your use of tablets

I can successfully complete the following tasks on a tablet.

	Yes	No	Not sure
Create a typed document.	○	○	○
Create a table in a typed document or spreadsheet.	○	○	○
Enter data into a table in a typed document or spreadsheet.	○	○	○
Use formulae in a spreadsheet to manipulate data.	○	○	○
Draw a graph	○	○	○
Insert a picture into a typed document.	○	○	○
Draw diagrams and sketches on a document.	○	○	○

About social media

Which of the following social media networks would you use in your personal and social life. Please select all that apply.

- ☐ Facebook
- ☐ Twitter
- ☐ LinkedIn
- ☐ YikYak
- ☐ WhatsApp
- ☐ Snapchat
- ☐ Other (please specify)

Which of the following social media networks would you use for professional networking. Please select all that apply.

- ☐ Facebook
- ☐ Twitter
- ☐ LinkedIn
- ☐ YikYak
- ☐ WhatsApp
- ☐ Snapchat
- ☐ Other (please specify)

During your studies, which of the following communication methods would you prefer to use: (Please select all that apply)

	to contact academics	to be contacted by academics
Email	☐	☐
NOW	☐	☐
Facebook	☐	☐
Twitter	☐	☐
LinkedIn	☐	☐
YikYak	☐	☐
WhatsApp	☐	☐
Snapchat	☐	☐

Other (please specify)

Technology and learning.

Do you think technology has a positive or negative effect on your learning?
Please explain your thoughts.

Appendix 2: Digital literacy scoring matrix showing how each question or activity is linked to a digital framework competency and the described skill within that competency as well as it's points value

Activity	Framework competency	Level	Point value	Description
		General questions		
Customise computer	Computer Literacy	Upskilling	2	Readily adopt new tools and explore their functionality
		In personal and social life		
Use social networking sites	Communication and Collaboration	Upskilling	2	Can identify and use different communication tools including social media tools
Download podcasts	Information literacy	enquiring	1	Identification and accessing digital resources
Using instant messaging or chat	Communication and Collaboration	Upskilling	2	Can identify and use different communication tools including social media tools
Using video calls	Communication and Collaboration	Upskilling	2	Can identify and use different communication tools including social media tools
Watching live TV or catch up TV online	Information literacy	Enquiring	1	Can identify and access digital resources
Watch on demand video	Information literacy	Enquiring	1	Can identify and access digital resources
Upload video or photo content to the internet	Media literacy	Experienced	3	Create or derive new multimedia content
Participate in group discussion groups or online chatrooms	Communication and collaboration	Experienced	3	Can participate in online networks, using relevant social media tools, applying knowledge of how to manage online digital identity
Use wikis/blogs	Information literacy	Enquiring	1	Can identify and access digital resources
Maintain my own blog or website	Media literacy	Creative	4	Understand how digital media work in terms of audience, viewpoint, design, Produce messages in a range of digital media, Link across media and communicate hypertextually
Take part in an online community through online gaming	Digital identity and employability	Upskilling	2	Can identify the basic rules of "netiquette" and conducting themselves online, manage reputation; Use digital technologies to present self
		Before starting the course/ in previous year of course		

Download and save data	Communication and collaboration/ Computer literacy	enquiring	1	Can use word processing/spreadsheet/presentation tools to present collated information
Put information into a pre-made form	Communication and collaboration/ Computer literacy	enquiring	1	Can use word processing/spreadsheet/presentation tools to present collated information
Co-create resources or work with a peer online	Communication and collaboration	Experienced	3	Can use online collaborative tools to participate in shared knowledge
Use formulae to manipulate data in a spreadsheet	Communication and collaboration/ computer literacy	Upskilling	2	Can use word processing/ spreadsheet/ presentation tools to write basic reports, essays, presentations
Producing professional diagrams	Computer literacy	Experienced	3	Specific skill required for a specific task, appropriately displaying data/content using more complex skill set.
Using a VLE	Learning technologies	Enquiring	1	Can access relevant online courses
Create graphs using a spreadsheet	Communication and collaboration/ Computer literacy	enquiring	1	Can use word processing/ spreadsheet/presentation tools to present collated information
Insert images, tables and graphs into word processed files or presentations	Communication and collaboration/ Computer literacy	enquiring	1	Can use word processing/spreadsheet/presentation tools to present collated information
Use cloud storage	Communication and collaboration/ Computer literacy	Upskilling	2	Can determine the most appropriate space for storing digital files
Interact with staff or students online	Learning technologies	Enquiring	1	Can use email and other tools, for communications with students, colleagues and collaborators

Appendix 3: Modified-SLEI survey including participant information sheet (as downloaded from Surveymonkey). Questions that were modified as a result of reliability testing and then retained are underlined.

Participant Information

Project description, researchers and procedure
This survey is part of research in the School of Science and Technology to assess the impact of technology on student learning and staff practice in undergraduate laboratories. This research is being carried out by Jennifer Evans and Sarah Rayment and is being led by Karen Moss.
All undergraduate students in the Biosciences and Chemistry and Forensics departments are invited to participate in this research. Participation involves completing this survey which will take approximately 20 minutes to complete. Further surveys and opportunities for focus groups or interviews will occur throughout the duration of your course.

Anonymity and confidentiality
All information collected as part of this survey will be anonymous i.e. that responses will not be linked be to individual participants. You will be identified by a participant identification number which will be emailed to you with each survey or interview invitation. Information collected from this survey may be published as part of the project, but participants will not be identifiable.
Information from this survey may also be used to improve the future student experience.

Consent, participation and withdrawal
Clicking the 'Next' button at the bottom of this page will indicate your consent to participate in this study.
Please complete the whole survey if possible.
Participation in this study is voluntary and you have the right to stop the survey at any time. You can withdraw your data from this study after you have submitted your answers for up to two weeks after completing this survey.
If you wish to withdraw your data you must email the researchers below with your participant identification number.

Ethics
This study has been approved by the School non-invasive ethics committee.

Contact Details
If you have any questions or concerns regarding this research, please contact:
Jennifer Evans: jennifer.evans@ntu.ac.uk
Sarah Rayment: sarah.rayment@ntu.ac.uk
Karen Moss: karen.moss@ntu.ac.uk

* 1. Statement of agreement

- ◯ I have read and understood the statements above, and agree to participate in this project.

Information about you

* 2. Please enter your participant identification number. This can be copied and pasted from your survey invitation

* 3. Please select your age group:

- ◯ Under 21
- ◯ 22-25
- ◯ 26-35
- ◯ Over 35
- ◯ Prefer not to say

* 4. Please select your legal gender:

- ◯ Male
- ◯ Female
- ◯ Prefer not to say

* 5. Please select your current university course

* 6. Please select your current university year.

Year

Attitude to technology

This questionnaire contains statements about how you feel about using the tablets available for student use within the main Superlab, RFB 106.
For the purpose of these questions *"tablets"* refers exclusively to these tablets.

You will be asked how often you feel this way.

There are no "right" or "wrong" answers. Your opinion is what is wanted.
Think about how well each statement describes what this laboratory is like for you.

Be sure to give an answer for all questions.
If you change your mind about an answer, just select another box.

Some statements in this questionnaire are fairly similar to other statements. Don't worry about this. Simply give your opinion about all statements.

7. I'm good with tablets

Almost never	Seldom	Sometimes	Often	Very Often
○	○	○	○	○

8. I like working with tablets

Almost never	Seldom	Sometimes	Often	Very Often
○	○	○	○	○

9. Working with tablets inspires me

Almost never	Seldom	Sometimes	Often	Very Often
○	○	○	○	○

10. I am comfortable trying new software on the tablets

Almost never	Seldom	Sometimes	Often	Very Often
○	○	○	○	○

11. Working with tablets is motivating

Almost never	Seldom	Sometimes	Often	Very Often
○	○	○	○	○

12. I do as much work as I can using the tablets

Almost never	Seldom	Sometimes	Often	Very Often
○	○	○	○	○

13. I feel comfortable using a tablet

Almost never	Seldom	Sometimes	Often	Very Often
○	○	○	○	○

Participant guidance

This questionnaire contains statements about practices which could take place in the main Superlab, RFB 106.
You will be asked how often each practice takes place.
The *"actual"* row is to be used to describe how often each practice actually takes place in this class.
The *"preferred"* row is to be used to describe how often you would like each practice to take place (a wish list).

There are no "right" or "wrong" answers. Your opinion is what is wanted.
Be sure to give an answer for all questions.
If you change your mind about an answer, just select another box.

Some statements in this questionnaire are fairly similar to other statements. Don't worry about this. Simply give your opinion about all statements.

Practice example.
Suppose that you were given the statement:
"Students choose their partners for laboratory experiments".
You would need to decide whether you thought that students actually choose their partners "almost never", "seldom", "sometimes", often or "very often".
You would also need to decide which of these you would prefer.

About your experience of technology in the laboratory

This section of the questionnaire contains statements about the tablets available for student use within the main Superlab, RFB 106.
For the purpose of these questions *"tablets"* refers exclusively to these tablets.

There are no "right" or "wrong" answers. Your opinion is what is wanted.
Be sure to give an answer for all questions.
If you change your mind about an answer, just select another box.

14. If I face difficulties in the the laboratory, I use the tablets to search for an answer

	Almost never	Seldom	Sometimes	Often	Very Often
Actual					
Preferred					

15. I use tablets in the laboratory to refer to my lecture notes to help me understand my experiment

	Almost never	Seldom	Sometimes	Often	Very Often
Actual					
Preferred					

16. Whilst in the laboratory I access further reading using the tablets to help my understanding

	Almost never	Seldom	Sometimes	Often	Very Often
Actual					
Preferred					

17. I use the tablets to help me link my laboratory work to "real world science"

	Almost never	Seldom	Sometimes	Often	Very Often
Actual					
Preferred					

18. I use the tablets to access additional information on how to use equipment/procedures safely

	Almost never	Seldom	Sometimes	Often	Very Often
Actual					
Preferred					

About your laboratory experience

This section of the questionnaire contains statements about laboratory practices in the main Superlab, RFB 106.
You will be asked how often each practice takes place.

There are no "right" or "wrong" answers. Your opinion is what is wanted.
Be sure to give an answer for all questions.

Some statements in this questionnaire are fairly similar to other statements. Don't worry about this. Simply give your opinion about all statements.

* 19. Students in this laboratory class get along well as a group

	Almost never	Seldom	Sometimes	Often	Very Often
Actual					
Preferred					

* 20. There is an opportunity for students to pursue their own science interests in this class

	Almost never	Seldom	Sometimes	Often	Very Often
Actual					
Preferred					

* 21. The material covered in our regular lectures/seminars is unrelated to our laboratory work

	Almost never	Seldom	Sometimes	Often	Very Often
Actual					
Preferred					

* 22. Our laboratory has clear rules to guide student activities

	Almost never	Seldom	Sometimes	Often	Very Often
Actual					
Preferred					

About your laboratory experience

23. <u>In our laboratory sessions, we are asked to design our own experiment to explore a topic</u>

	Almost never	Seldom	Sometimes	Often	Very Often
Actual	○	○	○	○	○
Preferred	○	○	○	○	○

24. The laboratory work is unrelated to the topics that we are studying in our lectures/seminars

	Almost never	Seldom	Sometimes	Often	Very Often
Actual	○	○	○	○	○
Preferred	○	○	○	○	○

About your laboratory experience

25. Students in this laboratory class help one another

	Almost never	Seldom	Sometimes	Often	Very Often
Actual	○	○	○	○	○
Preferred	○	○	○	○	○

26. <u>Within a laboratory session, students follow different procedures or use different samples to investigate the same idea.</u>

	Almost never	Seldom	Sometimes	Often	Very Often
Actual	○	○	○	○	○
Preferred	○	○	○	○	○

27. Our regular lecture/seminar work is integrated with laboratory activities

	Almost never	Seldom	Sometimes	Often	Very Often
Actual	○	○	○	○	○
Preferred	○	○	○	○	○

28. Students are required to follow certain rules in the laboratory.

	Almost never	Seldom	Sometimes	Often	Very Often
Actual	○	○	○	○	○
Preferred	○	○	○	○	○

About your laboratory experience

29. Students in this laboratory get to know each other well

	Almost never	Seldom	Sometimes	Often	Very Often
Actual	○	○	○	○	○
Preferred	○	○	○	○	○

30. Students are allowed to go beyond the regular laboratory exercise and do some experimenting of their own.

	Almost never	Seldom	Sometimes	Often	Very Often
Actual	○	○	○	○	○
Preferred	○	○	○	○	○

31. We use the theory from our lectures/seminars during laboratory activities

	Almost never	Seldom	Sometimes	Often	Very Often
Actual	○	○	○	○	○
Preferred	○	○	○	○	○

32. There is a recognised way of doing things safely in this laboratory

	Almost never	Seldom	Sometimes	Often	Very Often
Actual	○	○	○	○	○
Preferred	○	○	○	○	○

33. Our regular lecture/seminar work is not integrated with laboratory activities.

	Almost never	Seldom	Sometimes	Often	Very Often
Actual	○	○	○	○	○
Preferred	○	○	○	○	○

About your laboratory experience

34. Students are able to depend on each other for help during laboratory activities

	Almost never	Seldom	Sometimes	Often	Very Often
Actual	○	○	○	○	○
Preferred	○	○	○	○	○

35. In our laboratory different students do different experiments

	Almost never	Seldom	Sometimes	Often	Very Often
Actual	○	○	○	○	○
Preferred	○	○	○	○	○

36. The topics covered in lecture/seminar work are quite different from topics dealt with in laboratory sessions.

	Almost never	Seldom	Sometimes	Often	Very Often
Actual	○	○	○	○	○
Preferred	○	○	○	○	○

About your laboratory experience

37. It takes too long for me to get to know people by name in this laboratory class

	Almost never	Seldom	Sometimes	Often	Very Often
Actual					
Preferred					

38. What we do in the laboratory sessions, helps us to understand the topics taught in lectures/seminars

	Almost never	Seldom	Sometimes	Often	Very Often
Actual					
Preferred					

39. The instructor outlines safety precautions before laboratory sessions commence

	Almost never	Seldom	Sometimes	Often	Very Often
Actual					
Preferred					

40. The material covered in our regular lectures/seminars is related to our laboratory work

	Almost never	Seldom	Sometimes	Often	Very Often
Actual					
Preferred					

About your laboratory experience

41. Students work cooperatively in laboratory sessions

	Almost never	Seldom	Sometimes	Often	Very Often
Actual					
Preferred					

42. The students decide the best way to proceed during laboratory experiments

	Almost never	Seldom	Sometimes	Often	Very Often
Actual					
Preferred					

43. Laboratory work and lecture/seminar work are unrelated

	Almost never	Seldom	Sometimes	Often	Very Often
Actual					
Preferred					

Appendix 4: Example of rewording a question based on Cronbach-α analysis

An example of the strategy for rewording a question and re-evaluating in the subsequent survey can be seen in the openendedness scale. In the 2014-15 survey, the Cronbach-α values were 0.556 for the openendedness *actual* scale and 0.583 on the *preferred* scale. According to the criteria described by Field (2009) both of these values are lower than the ideal range of values (0.7-0.8). Three questions from the scale were identified which were problematic based on the inter-item correlations and the impact of their removal on the α value and so these were subject to review. Table 28 shows the inter- item correlations for the openededness *actual* and *preferred* scale. A score of 0.3 or higher is expected with other items on the scale to confirm that questions are addressing the same domain (see section 2.5). As can be seen in the tables, only one correlation on the *actual* scale and three preferred scale inter-item correlations meet this criteria (shown in the red boxes): of the three questions reviewed, questions 18 and 33 had no inter-item correlations above 0.3 with question 13 having two correlations in the acceptable range on the preferred scale. Looking in more detail at questions 13, 18 and 33 it was clear that the corrected item total correlations for these questions were also low compared to the accepted values (0.3). On the *actual* scale question 13 has a corrected item total of 0.193; question 18 is 0.181; question 33 is 0.100. For the preferred scale, the corrected item totals were 0.369 for question 13, 0.191 for question 18 and 0.103 for question 33.

In terms of Cronbach-α score, this could be increased from 0.556 to 0.579 on the *actual* scale if question 33 was removed although the change was small and did not increase it to the acceptable range. Similarly, small increases or decreases were observed if questions were removed on the preferred scale (question 33 would increase score to 0.615 from 0.583; questions 13 and 18 reduced the score to 0.520 and 0.547 respectively if removed).

Table 1: Inter-item correlations for the actual and preferred versions of the openendedness scale questions for the 2014-15 modified SLEI. Red boxes show the values that are in the acceptable range (0.3 or higher)

ACTUAL SCALE	8	13	18	23	28	33	38
8	1.000	.098	.121	.512	.111	-.022	.266
13		1.000	-.035	.172	.167	-.025	.263
18			1.000	.116	.128	.100	.183
23				1.000	.246	.088	.218
28					1.000	.079	.293
33						1.000	.133
38							1.000

PREFERRED SCALE	8	13	18	23	28	33	38
8	1.000	.083	.202	.269	.003	-.058	.149
13		1.000	-.008	.422	.149	.190	.367
18			1.000	.248	.261	.039	.253
23				1.000	.258	.090	.300
28					1.000	.035	.180
33						1.000	.121
38							1.000

Based on the data presented, the best strategy for questions 13 and 18 was clearly to attempt rewording the question as the Cronbach-α score would be reduced if they were removed but their inter-item correlations and corrected item totals are poor. The outcome of the investigation of question 33 is more equivocal: there would be small increases in Cronbach-α score if removed (not sufficient to reach the ideal range) and it has low inter-item correlations and inter-item totals. Given that the multiple items performed poorly on this scale, it was decided to attempt to reword this question with a view to removing it if improvements were not seen in the subsequent year rather than remove it at this point.

Question 13 was originally worded as: in this laboratory we are asked to design our own experiment to solve a given problem. It was reworded to "in our laboratory sessions we are asked to design our own experiment to explore a topic".

Question 18 was originally worded as: “in a laboratory session, different students collect different data for the same problem”. It was reworded to “within a laboratory session, students follow different procedures or use different samples to investigate same idea”.

Question 33 was originally worded as: “in our laboratory sessions, the instructor decides the best way to carry out the laboratory experiments”. This was reworded to “for our laboratory sessions the lecturer provides a method describing how to carry out an experiment”.

In the 2015-16 survey the Cronbach-α score for the *actual* scale had increased from 0.556 to 0.673 for the *actual* scale and 0.598 (from 0.583) for the preferred scale. In the inter-item correlation table for the *actual* scale, there were 14 items that did not meet the limit for acceptable values. Most of these related to questions 33 and 38. Additionally, question 33 had a low score for the corrected item total correlation (0.112) and removing it increased the Cronbach-α score for the actual scale to within acceptable limits (0.702).

Question 33 had poor inter-item correlations on the preferred scale as well as a very low corrected item total correlation score (-0.164). Removing question 33 increased the Cronbach-α score to 0.677 (compared to 0.598) on the *preferred* scale which is close to the ideal range. Given that there were still poor correlations with questions on both the *actual* and *preferred* scales as well as benefits to the Cronbach-α score, Question 33 was removed.

Removing questions from the survey

In the first iteration of the survey (2014-5), the rule clarity scale had a Cronbach-α score of 0.625 for the *actual* scale and 0.486 for the *preferred* scale. As can be seen in Table 29, there were no inter-item correlations that reached the threshold of 0.3 for question 30 on either the *actual* or *preferred* scale.

Table 2: Inter-item correlations for the actual and preferred versions of the rule clarity scale questions for the 2014-15 modified SLEI

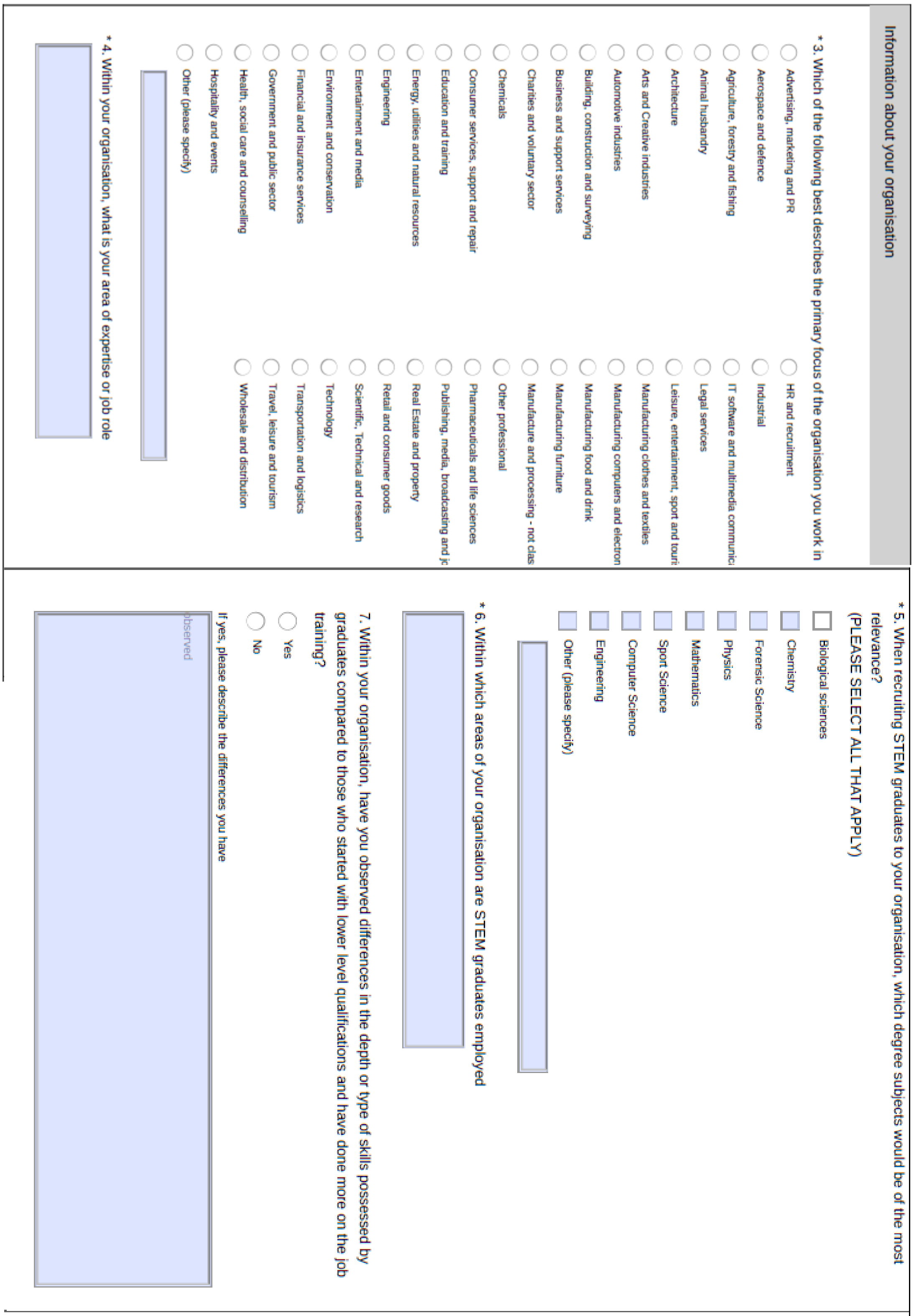
ACTUAL SCALE	10	15	20	25	30	35	40
10	1.000	.221	.344	.385	-.307	.343	.326
15		1.000	.207	.461	.142	.423	.250
20			1.000	.369	.138	.322	.269
25				1.000	.089	.461	.481
30					1.000	-.023	-.028
35						1.000	.291
40							1.000

PREFERRED SCALE	10	15	20	25	30	35	40
10	1.000	.020	.322	.392	.037	.215	.290
15		1.000	.005	.187	.197	.177	.115
20			1.000	.232	.260	.059	.052
25				1.000	.052	.311	.380
30					1.000	.025	-.103
35						1.000	.262
40							1.000

The corrected item total correlations which were produced as part of the Cronbach-α analysis were also below the threshold values: question 30 produced a value of 0.063 on the *actual* scale and 0.122 on the *preferred* scale. In addition, removing this question from the survey increased the Cronbach-α score to 0.743 for the *actual* scale which brings it into the ideal range as well as increasing the Cronbach-α score for the *preferred* scale to 0.570.

Given the poor correlation with the rest of the scale (both in terms of inter-item correlations and corrected item total correlations) and the marked benefits that removal would have in terms of reliability (Cronbach-α score), question 30 was removed.

Appendix 5: Copy of the final version of the survey that was given to employers. Question 9 of this survey displays all possible options but in the online platform used (Surveymonkey) participants would only have been presented with the options that they chose in the previous question.


Information about your organisation

*3. Which of the following best describes the primary focus of the organisation you work in

- Advertising, marketing and PR
- Aerospace and defence
- Agriculture, forestry and fishing
- Animal husbandry
- Architecture
- Arts and Creative industries
- Automotive industries
- Building, construction and surveying
- Business and support services
- Charities and voluntary sector
- Chemicals
- Consumer services, support and repair
- Education and training
- Energy, utilities and natural resources
- Engineering
- Entertainment and media
- Enviroment and conservation
- Financial and insurance services
- Government and public sector
- Health, social care and counselling
- Hospitality and events
- Other (please specify)
- HR and recruitment
- Industrial
- IT software and multimedia communic
- Legal services
- Leisure, entertainment, sport and touri
- Manufacturing clothes and textiles
- Manufacturing computers and electron
- Manufacturing food and drink
- Manufacturing furniture
- Manufacture and processing - not clas
- Other professional
- Pharmaceuticals and life sciences
- Publishing, media, broadcasting and jo
- Real Estate and property
- Retail and consumer goods
- Scientific, Technical and research
- Technology
- Transportation and logistics
- Travel, leisure and tourism
- Wholesale and distribution

*4. Within your organisation, what is your area of expertise or job role

*5. When recruiting STEM graduates to your organisation, which degree subjects would be of the most relevance?
(PLEASE SELECT ALL THAT APPLY)

- Biological sciences
- Chemistry
- Forensic Science
- Physics
- Mathematics
- Sport Science
- Computer Science
- Engineering
- Other (please specify)

*6. Within which areas of your organisation are STEM graduates employed

7. Within your organisation, have you observed differences in the depth or type of skills possessed by graduates compared to those who started with lower level qualifications and have done more on the job training?

- Yes
- No

If yes, please describe the differences you have observed

What skills do you look for in STEM graduates

* 8. When considering the skills you are looking for in a graduate, please select the 10 attributes you consider most important

- ☐ Specialist subject knowledge
- ☐ Relevant practical skills
- ☐ Ability to solve problems
- ☐ Experimental design skills
- ☐ Data analysis skills
- ☐ Ability to interpret data
- ☐ Scientific writing skills
- ☐ Project planning
- ☐ Effective oral communication skills
- ☐ Computer literacy (using a range of software across different devices)
- ☐ Creating and maintaining websites
- ☐ Other (please specify)
- ☐ Digital communication (e.g.email/skype)
- ☐ Collaborative working/file sharing (eg Google docs, Dropbox)
- ☐ Time management and organisation
- ☐ Awareness of e-security, data protection and intellectual property rights
- ☐ Ability to source and critically evaluate sources of information
- ☐ Teamwork
- ☐ Initiative
- ☐ Database construction and management
- ☐ Familiarity with specialist software
- ☐ Awareness of health and safety
- ☐ Specify, design or write computer programmes

What skills do you look for in STEM graduates

* 9. Having identified attributes that are important for graduates coming in to your organisation to have, please rank the top 5 in descending order (i.e. assigning 1 as being the most important, down to 5 being the least important of the selected skills)

- [ ] Specialist subject knowledge
- [ ] Relevant practical skills
- [ ] Ability to solve problems
- [ ] Experimental design skills
- [ ] Data analysis skills
- [ ] Ability to interpret data
- [ ] Scientific writing skills
- [ ] Project planning
- [ ] Effective oral communication skills
- [ ] Computer literacy (using a range of software across different devices)
- [ ] Creating and maintaining websites
- [ ] Digital communication (e.g.email/skype)
- [ ] Collaborative working/file sharing (eg Google docs, Dropbox)
- [ ] Time management and organisation
- [ ] Awareness of e-security, data protection and intellectual property rights
- [ ] Ability to source and critically evaluate sources of information
- [ ] Teamwork
- [ ] Initiative
- [ ] Database construction and management
- [ ] Familiarity with specialist software
- [ ] Awareness of health and safety
- [ ] Other (please specify)
- [ ] Specify, design or write computer programmes

What digital skills do you look for in STEM graduates

* 10. Thinking solely of the types of digital capabilites that you would look for in a graduate, please rank the top 5 skills in descending order (i.e. assigning 1 for the most important skill, down to 5 for the least important of the skills selected)

- Ability to analyse data using suitable tools
- Computer literacy (using a range of software across different devices)
- Ability to create and maintain internet content e.g. webpages
- Effective use of media and digital communication including email, social media and professional networks
- Knowledge of digital tools for collaborative working and information sharing (e.g. google docs, dropbox)
- Use of resources such as shared calendars to organise time
- Awareness of e-security, data protection and intellectual property rights
- Database construction and management
- Effective strategies to search for information online and critically evaluate it.
- Familiarity with specialist software
- Specify, design or write computer programmes

11. If familiarity with specialist software is important in graduate roles, please state which software packages you would consider relevant to your organisation

Using information and communication technologies

* 12. In graduate roles, how often would you expect individuals to do the following

	Daily	Weekly	Monthly	Quarterly	As required	N/A
Create a document or report using a word processing package e.g.MS Word	○	○	○	○	○	○
Create a presentation using a digital tool such as MS powerpoint, or prezzi	○	○	○	○	○	○
Embed images or multimedia objects such as videos into a file	○	○	○	○	○	○
Construct or manage a database	○	○	○	○	○	○
Use analysis tools (e.g Excel, SPSS) to record and analyse data	○	○	○	○	○	○
Specify, design and write computer programmes	○	○	○	○	○	○
Use specialist software	○	○	○	○	○	○
Manage their own time/organise meetings using shared calendars or other digital tools	○	○	○	○	○	○
Select and use appropriate file storage options	○	○	○	○	○	○
Construct and maintain webpages	○	○	○	○	○	○
Use relevant tools to plan projects individually or as a group	○	○	○	○	○	○
Select appropriate computational devices, interfaces and protocols	○	○	○	○	○	○
Design, construct or manage networked computer systems	○	○	○	○	○	○

Digital communication and collaborative working

* 13. In graduate roles, how often would you expect individuals to do the following

	Daily	Weekly	Monthly	Quarterly	As required	N/A
Use email to communicate with individuals or groups both within the organisation and externally	○	○	○	○	○	○
Use online conferencing software (e.g. skype) to hold meetings	○	○	○	○	○	○
Use social media (such as facebook or twitter), or professional networks (e.g. LinkedIn, researchgate)	○	○	○	○	○	○
Work collaboratively or share information using digital tools such as googledocs, dropbox or onedrive	○	○	○	○	○	○
Using Virtual Private Networks (VPNs) to securely connect to work network from remote locations e.g. home	○	○	○	○	○	○

Digital identity and security

* 14. Would you expect graduates entering your organisation to have an awareness of

	Yes	No
E-security	◯	◯
Data protection	◯	◯
Copyright	◯	◯
Intellectual property rights	◯	◯

* 15. In graduate roles, would you expect individuals to be able to do the following

	Yes	No	N/A
Identify legal and ethical security risks in data/information storage	◯	◯	◯
select online collaborative tools that take account of copyright and data protection	◯	◯	◯
enhance privacy settings online	◯	◯	◯
distinguish between social and professional networks	◯	◯	◯
be able to manage several digital identities	◯	◯	◯
incorporate information security when building software systems	◯	◯	◯
support and develop others through use of professional networks	◯	◯	◯

16. In terms of information security which of the following would you expect graduates to have an awareness of? (please select all that apply)

- ☐ use of passwords for security
- ☐ security risks of downloading files and apps from the internet
- ☐ how to manage security of multiple accounts/digital identities online
- ☐ how to identify security risks to systems and introduce preventative measures

Accessing, evaluating and sharing information

* 17. In graduate roles, how often would you expect individuals to do the following

	Daily	Weekly	Monthly	Quarterly	As required	N/A
Search online for resources or information	◯	◯	◯	◯	◯	◯
Critically evaluate the validity and reliability of source material	◯	◯	◯	◯	◯	◯
Use digital tools to design assessments	◯	◯	◯	◯	◯	◯
Use digital tools for professional development e.g. reflection or identifying development points	◯	◯	◯	◯	◯	◯
construct bibliographies or collate references in a management tool (e.g. Refworks)	◯	◯	◯	◯	◯	◯

Appendix 6: Mapping of the Employer survey to the NTU digital framework showing the competency and skill level, and whether there is a comparable question in the digital history survey

Activity	Framework competency	Level	Mapping to DHS statements
In graduate roles, how often would you expect individuals to do the following:			
Create a document or report using a word processing package e.g.MS Word	Information literacy/ communication and collaboration	Enquiring	
Create a presentation using a digital tool such as MS powerpoint, or prezzi	Communication and collaboration	Enquiring	
Embed images or multimedia objects such as videos into a file	Media literacy	Upskilling	Insert images, tables and graphs into word processed files or presentations
Construct or manage a database	Computer literacy	Experienced	
Use analysis tools (e.g Excel, SPSS) to record and analyse data	Information literacy	Upskilling	Create graphs using a spreadsheet; Use formulae to manipulate data in a spreadsheet
Specify, design and write computer programmes	Computer literacy	Creative	
Use specialist software	Computer literacy	Upskilling	
Manage their own time/organise meetings using shared calendars or other digital tools	Learning to learn	Upskilling	
Select and use appropriate file storage options	Computer literacy	Upskilling	Use cloud storage
Construct and maintain webpages	Computer literacy	Creative	Maintain my own blog or website
Use relevant tools to plan projects individually or as a group	Learning to learn	Experienced	
Select appropriate computational devices, interfaces and protocols	Computer literacy	Experienced	
Design, construct or manage networked computer systems	Computer literacy	Creative	
Use email to communicate with individuals or groups both within the organisation and externally	Communication and collaboration	Enquiring	Interact with staff or students online
Use online conferencing software (e.g. skype) to hold meetings	Communication and collaboration	Upskilling	Using video calls
Use social media (such as facebook or twitter), or professional networks (e.g. LinkedIn, researchgate)	Communication and collaboration	Upskilling	Use social networking sites
Work collaboratively or share information using digital tools	Communication and collaboration	Experienced	Co-create resources or work with a peer online

such as googledocs, dropbox or onedrive			
Using Virtual Private Networks (VPNs) to securely connect to work network from remote locations e.g. home	Communication and collaboration	Experienced	
Would you expect graduates entering your organisation to have an awareness of			
e-security	Computer literacy	Enquiring	
Data protection	Computer literacy	Enquiring	
Copyright	Computer literacy	Enquiring	
Intellectual property rights	Computer literacy	Enquiring	
In graduate roles, would you expect individuals to be able to do the following			
Identify legal and ethical security risks in data/information storage	Information literacy	Upskilling	
select online collaborative tools that take account of copyright and data protection	Communication and collaboration	Experienced	
enhance privacy settings online	Digital Identity and employability	Creative	
distinguish between social and professional networks	Digital Identity and employability	Enquiring	
be able to manage several digital identities	Digital Identity and employability	Experienced	
incorporate information security when building software systems	Computer literacy	Creative	
support and develop others through use of professional networks	Information literacy	Upskilling	
In terms of information security which of the following would you expect graduates to have an awareness of? (please select all that apply)			
Use of passwords for security	Digital identity and employability	Enquiring	
security risks of downloading files and apps from the internet how to manage security of multiple accounts/digital identities online	Computer literacy	Upskilling	
how to identify security risks to systems and introduce preventative measure	Computer literacy	Experienced	
How to manage security of multiple accounts/digital identities online	Digital identity and employability	Experienced	
In graduate roles, how often would you expect individuals to do the following:			
Search online for resources or information	Computer literacy	Upskilling	
Critically evaluate the validity and reliability of source material	Information literacy	Creative	
Use digital tools to design assessments	Learning technologies	Experienced	
Use digital tools for professional development e.g. reflection or identifying development points	Digital Identity and employability	Experienced	

construct bibliographies or collate references in a management tool (e.g. Refworks)	Information literacy	Experienced	

Appendix 7: Pilot study feedback page showing questions asked of pilot participants which were used to develop the final version of the survey.

Pilot study feedback

This section is designed to give participants in the pilot phase of the study an opportunity to provide feedback on all aspects of questionnaire design

17. When considering the language used in this survey please look at the statements below and state whether you "agree" or "disagree" with them.
If you have answered "disagree" to any of these questions, please comment below on where the problem areas were or how this could be improved.

	Agree	Disagree
Question and answer options were concise	◯	◯
The questions were written in a way that was easy to follow	◯	◯
It was clear what was meant by all of the answer statements	◯	◯

Any further comments

18. Did the questions in the survey cover all digital skills that are applicable to your organisation? If not, please comment below so that these can be incorporated in future versions of the survey.

◯ Yes

◯ No

Any further comments

19. If you have any further comments on the survey or it's design please comment below, we would welcome your feedback

20. If you would be interested in discussing your feedback with us, please comment below with contact details (email address or phone number) and we will be in touch shortly

Appendix 8: Published manuscript describing a survey of pre-laboratory practice across UK HE institutions alongside an institutional case study of development of video resources as pre-laboratory resources to support lab learning (Rayment et al., 2022a).

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.

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 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 build- ing), 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 motiva- tion 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 proto- col/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

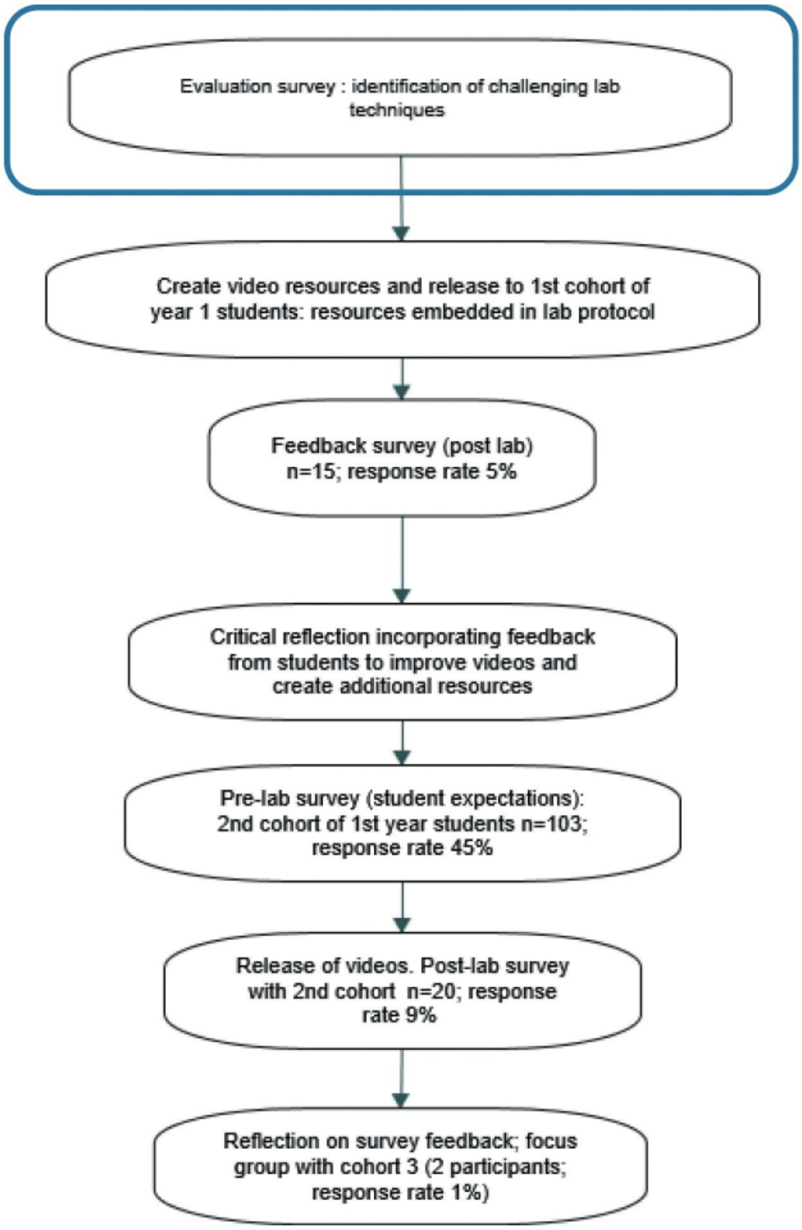


Figure 1. A schematic diagram of the development of the video case study methodology showing the survey tools used, reflective cycles and number of participants and response rates at each stage. The study highlighted in the box preceded the current study but provided information that was used in its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

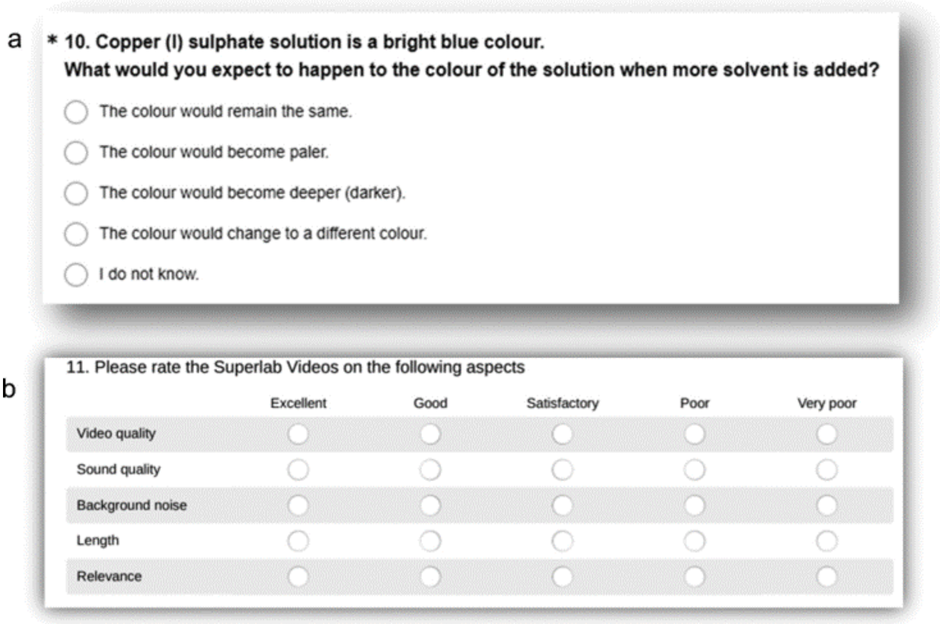
Survey design

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


a

*** 10. Copper (I) sulphate solution is a bright blue colour.**
What would you expect to happen to the colour of the solution when more solvent is added?

- The colour would remain the same.
- The colour would become paler.
- The colour would become deeper (darker).
- The colour would change to a different colour.
- I do not know.

b

11. Please rate the Superlab Videos on the following aspects

	Excellent	Good	Satisfactory	Poor	Very poor
Video quality					
Sound quality					
Background noise					
Length					
Relevance					

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%)

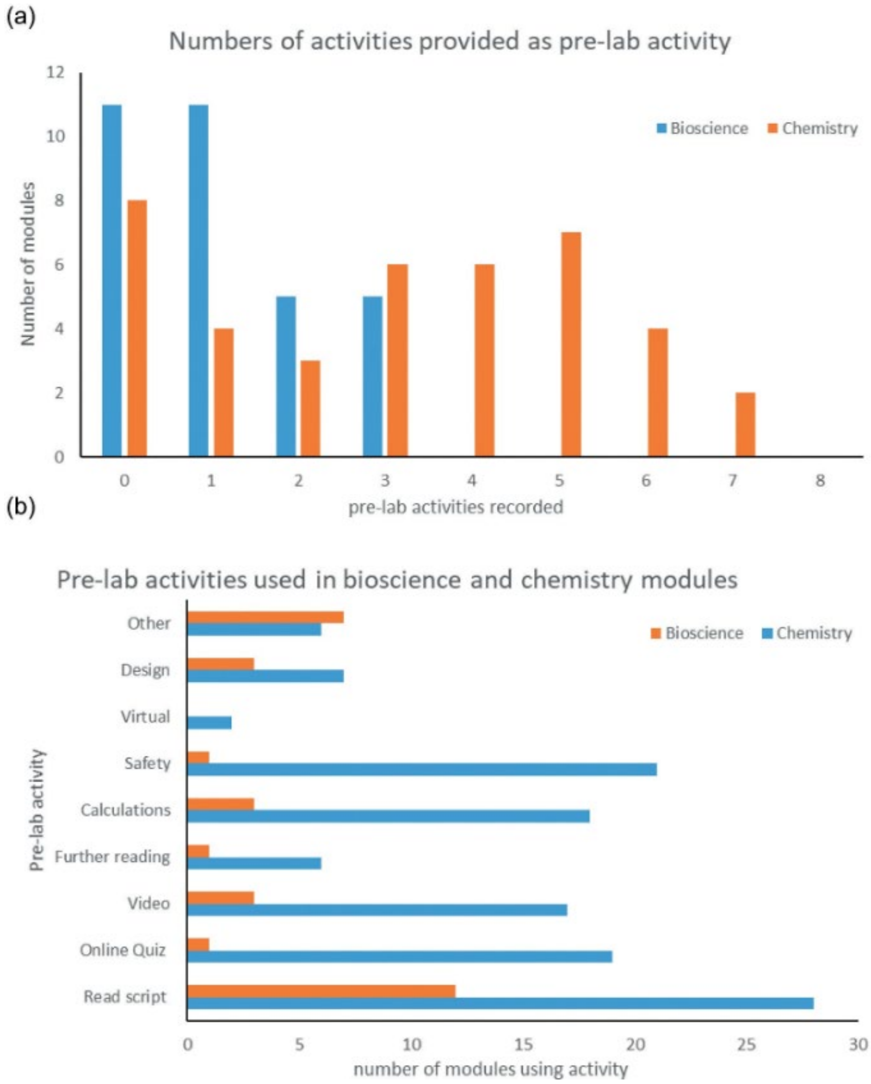


Figure 3. Data from the survey of UK HE institutions showing (a) a comparison of the number of pre-laboratory activities used in bioscience and chemistry modules. (b) a comparison of the number of bioscience and chemistry modules using different types of pre-laboratory activities.

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.

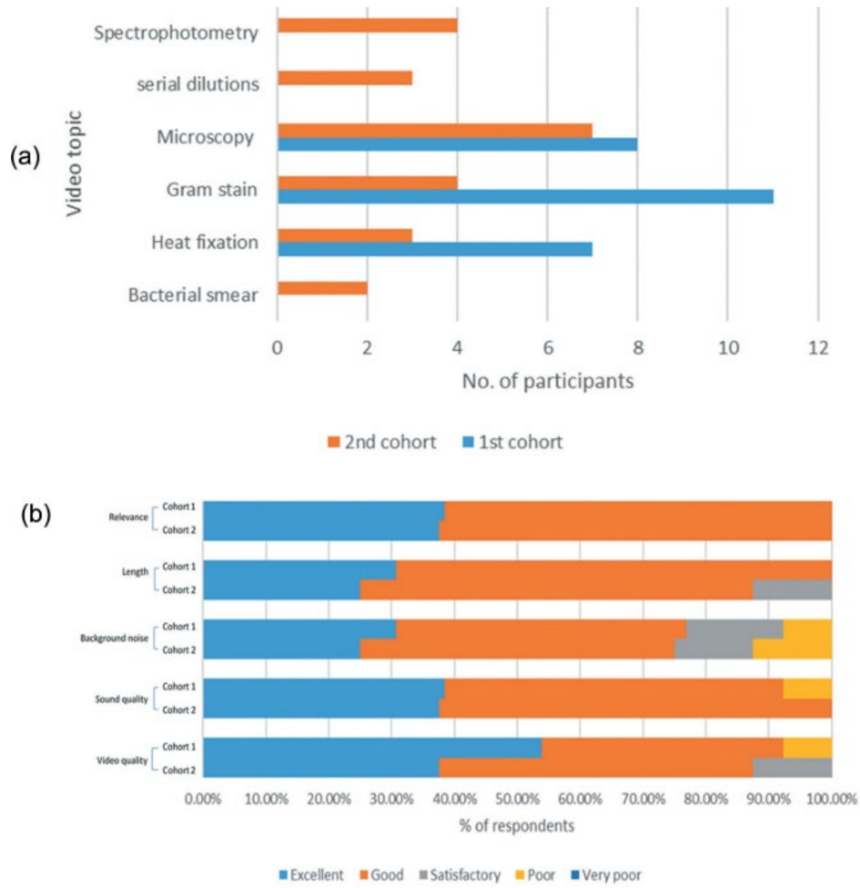


Figure 4. Case study survey data for both cohort 1 and cohort 2 showing the number of participants using different videos (a) and the participant responses for quality and relevance of the resources (b).

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.

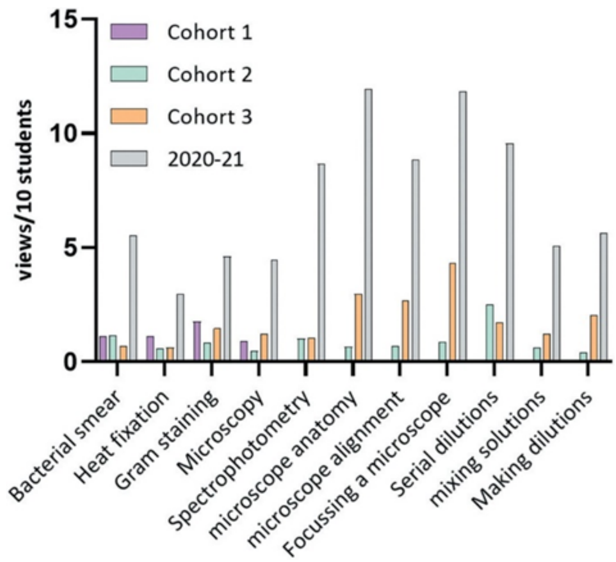


Figure 5. YouTube analytics showing the number of views that each video received over the course of the study (cohorts 1–3) compared to usage so far in the current academic year (2020–2021). views are expressed as views per 10 students within a cohort to standardise the data to account for differing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

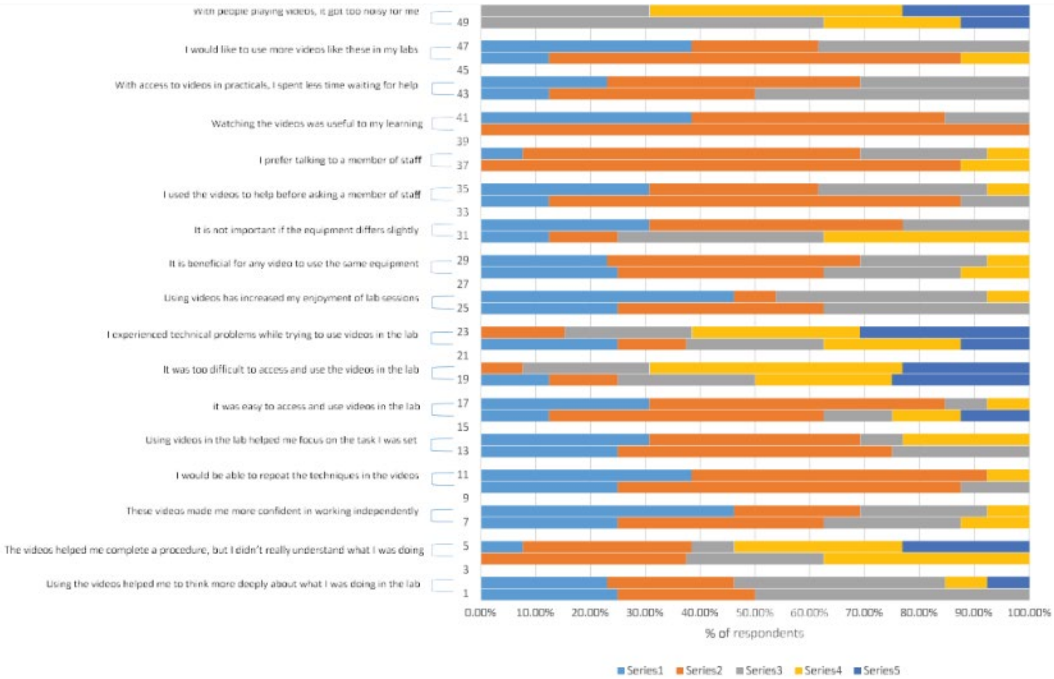


Figure 6. Representation of Likert-like scale data (participants were asked to what extent they agreed or disagreed with the statements provided) for the 1st and 2nd cohorts. Positive and negatively worded statements were included, with some addressing use of the videos within a laboratory setting, with 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 high- lighted 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 chem- istry) 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 sub- mitted 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 thevideos 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) high- lighted 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 engage- ment 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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Appendix 9: Published manuscript (Rayment et al., 2023) describing the use of a concurrent think aloud approach in the laboratory and semi-structured interviews alongside a survey of post-laboratory support practice across UK HE institutions.

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

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 of- ten 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 metacog- nition (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 prob- lems. 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 un- derlying 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 Widyan- ingsih, 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 cod- ing (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 metacog- nitive 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 moni- toring 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.

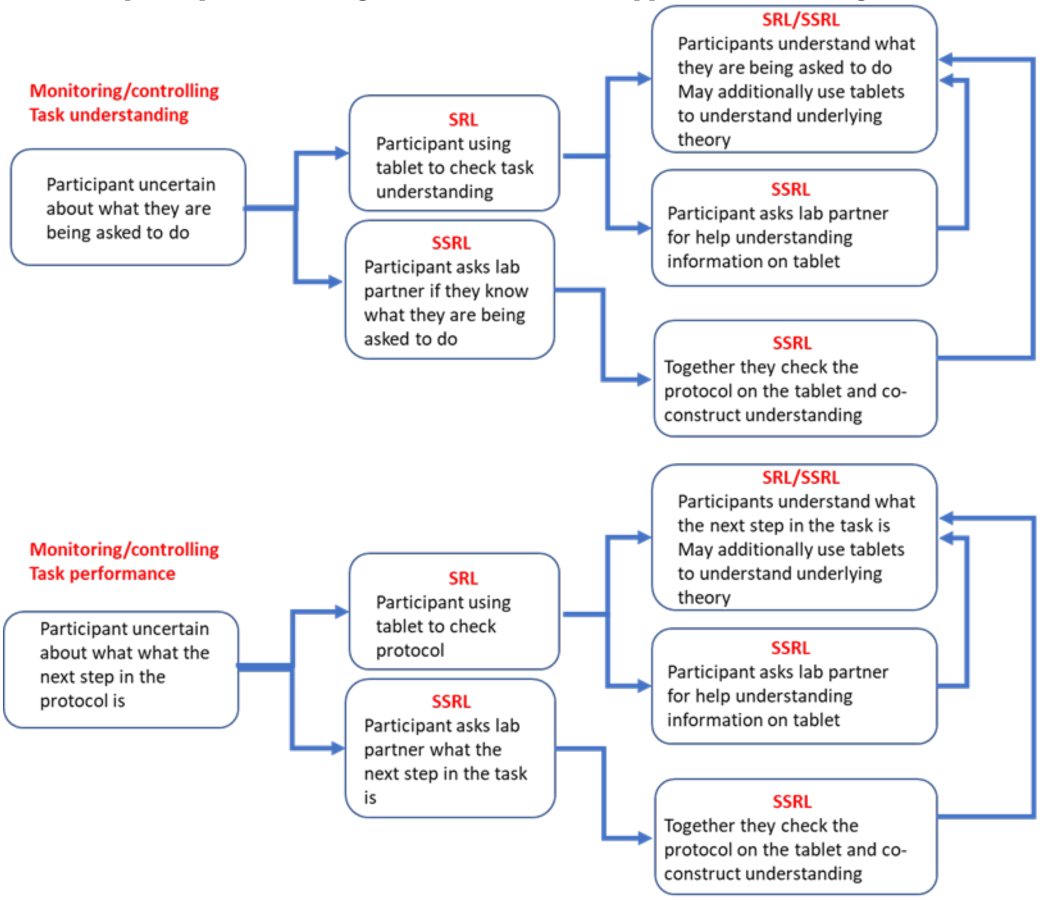

Figure 1. Schematic diagram showing the processes of participants in using technology to construct their understanding of a task or task performance. The upper diagram shows the process when students seek to clarify the task purpose, the lower when they seek to improve their conduct of that task.

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 applica- tions 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.

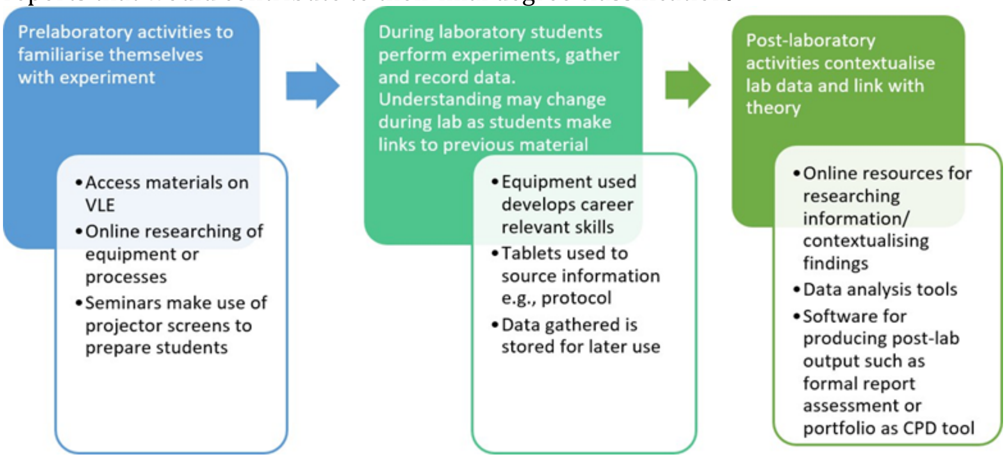

Figure 2. A schematic diagram demonstrating the role of technology in laboratory learning and the types of technologies involved. Data for pre-laboratory activities are shown on the left in blue; during the lab are shown in centre in pale green; with post-laboratory activities shown on the right in dark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

1.2. 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.

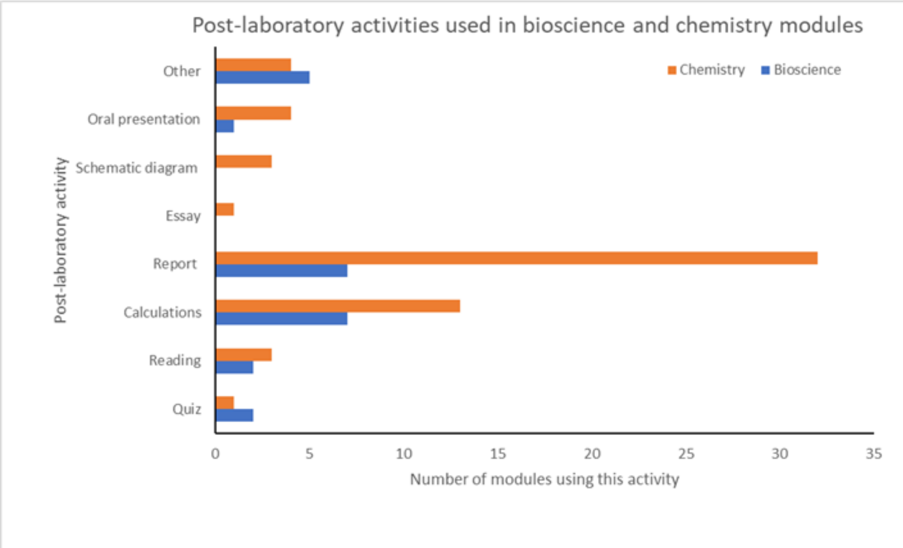

Figure 3. Frequency of post-laboratory activities described for UK HE modules in bioscience and chemistry.

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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S.D.S. and K.M.; visualization, S.R.; supervision, M.C., S.D.S., S.K. and K.M.; project administration, S.R. (S.R. and J.R.E. for survey). All authors have read and agreed to the published version of the manuscript.
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Appendix 10: Online version of the survey for academic staff aimed at investigating module level approaches to pre-laboratory and post laboratory support.

Participant Information

Participant information and consent.
Project description, researchers and procedure
This survey is part of research in the School of Science and Technology at Nottingham Trent University to assess the use of pre- and post- lab scaffolding around the laboratory component of taught undergraduate courses within the sciences and compare practice across the sector. This research is being carried out by Jennifer Evans and Sarah Rayment and is being led by Karen Moss.

You are invited to participate, in your capacity as a lecturer/facilitator working within an undergraduate science course. Participation involves completing this survey, which will take approximately 10 minutes to complete.

Anonymity and confidentiality
All information collected as part of this survey will be anonymous i.e. that responses will not be linked be to individual participants.

Although information about the discipline and subject area of the modules taught, and the university you are teaching at are collected as part of this project, this data will be used to compare practice within similar subject areas or institutions. This information will not be identifiable to an institution or module when published as university names will be converted into a numerical identifier and subject areas will be categorised into broad thematic groups.

Information collected from this survey may be published as part of the project, but participants will not be identifiable. Information from this survey may also be used to improve the future student experience or staff practice.

Consent, participation and withdrawal
Clicking the 'Next' button at the bottom of this page will indicate your consent to participate in this study.
Participation in this study is voluntary and you have the right to stop the survey at any time. You can withdraw your data from this study after you have submitted your answers for up to two weeks after completing this survey. In order to withdraw your data after submission you need to enter two unique identifiers (for example your pet's name). Please do not use your name or email. If you wish to withdraw your data you must email the researchers below with your unique identifiers.

Please complete the whole survey if possible.

Withdrawal information

You can withdraw your data from this study after you have submitted your answers for up to two weeks after completing this survey.
Please make a note of what your unique identifiers are, if you don't know your identifiers then your data cannot be identified and therefore cannot be withdrawn.

* In order to be able to withdraw your answers from this study please provide two unique identifiers. For example:
• A memorable surname
• A pet's name
• Your favourite instrument
• A memorable city
• A street name

Please do not use an identifier that is easily traceable to you as a participant such as your student number, name or contact details.

Unique identifier 1

Unique identifier 2

Ethics:
This study has been approved by the School non-invasive ethics committee.

Contact Details
If you have any questions or concerns regarding this research, please contact
Sarah Rayment: sarah.rayment@ntu.ac.uk
Jennifer Evans: jennifer.evans@ntu.ac.uk
Karen Moss: karen.moss@ntu.ac.uk

*Statement of agreement:

I have read and understood the statements above, and agree to participate in this project.

Module Information

We are interested in finding out about teaching practice in relation to pre-lab and post-lab exercises in undergraduate practical lab-based sessions within your University. Please complete a separate form for each module that you lead.

What is the discipline of the module that you lead

- ☐ Bioscience
- ☐ Chemistry
- ☐ Forensic Science
- ☐ Physics
- ☐ Mathematics
- ☐ Computer Science
- ☐ Sport Science
- ☐ Engineering

What is the subject area for the module you lead within your discipline e.g microbiology, analytical chemistry, crime scene analysis?

What level is the module taught at?

- ○ 4
- ○ 5
- ○ 6
- ○ 7

What institution is this module being taught at

- ○ Nottingham Trent University
- ○ Other (please specify in the box below)

Pre-lab activities

Are the lab sessions in this module assessed?

- ○ No
- ○ Yes - formative assessment (no marks/credit)
- ○ Yes - summative assessment (mark/credit)
- ○ Yes - a mix of formative and summative assessment

Do you do a *pre-lab* seminar/lecture with your students before entering the lab?

- ○ No
- ○ Yes - optional
- ○ Yes - required (attendance contributes to overall module mark).
- ○ Yes - non-completion of session prevents entry to the lab.

If you do have a *pre-lab session*, does it occur on the same day as the lab session

- ○ No
- ○ Yes
- ○ Sometimes

Please estimate the student attendance rate for your*pre-lab sessions*

- ○ 0-40%
- ○ 41-60%
- ○ 61-80%
- ○ 81-100%

Do your students complete a *pre-lab exercise* before entering the lab? (Pre-lab exercises could include such activities as reading resources, videos and online quizzes.)

- ○ No.
- ○ Yes - optional.
- ○ Yes -required (completion contributes to module mark.
- ○ Yes - non-completion prevents entry to the lab

Please estimate the student completion rate for your *pre-lab activities* as a percentage:

- ◯ 0-40%
- ◯ 41-60%
- ◯ 61-80%
- ◯ 81-100%

What *pre-lab activities* do you require students to do for this module?
(If you use different pre-lab activities for different practicals within the module, please tick each that applies)

- ◯ Read protocol/script
- ◯ Take online quiz
- ◯ Watch a video
- ◯ Further reading e.g. journal article, textbook
- ◯ Complete relevant calculations
- ◯ Complete a safety exercise
- ◯ Hot pen writing
- ◯ Write an essay
- ◯ Draw a schematic diagram
- ◯ Virtual simulation
- ◯ Experimental design/development
- ◯ Other (please describe the activity in the box below)

Post-lab activities

Do you require your students to complete a *post-lab activity*

- ◯ No.
- ◯ Yes- optional.
- ◯ Yes - required

What *post-lab activities* do you require students to do for this module? (If you use different post-lab activities for different practicals within the module, please tick each that applies.)

- ◯ Take an online quiz.
- ◯ Watch a video.
- ◯ Further reading e.g. journal article, textbook.
- ◯ Complete relevant calculations.
- ◯ Hot pen writing.
- ◯ Write a report.
- ◯ Write an essay.
- ◯ Draw a schematic diagram.
- ◯ Prepare and deliver an oral presentation.
- ◯ Other (please describe the activity in the box below)

Does you *post-lab activity* require any form of data handling?

- ◯ Yes.
- ◯ No.

* Do you lead additional modules that you wish to provide information for?

- ◯ Yes
- ◯ No

Appendix 11: Interview questions for semi-structured interviews taking place in the technology in learning study alongside the think aloud protocols in lab. The question shown in red was used in the pilot study but removed in the main study due to the similarity/overlap making it redundant to have both questions.

Students use of technology in learning Interview schedule

Welcome

Thank participant for agreeing to take part in this study and indicate that the study is intended to investigate the impact of technology on their personal learning experience during their course

Remind participants that they can stop at any time.

Questions

The purpose of this interview is to think about the use of technology, particularly if and how you use technology to support your lab learning.

In general, what do you think is meant by the term "technology"? (can reword question to "how would you define technology?" if this is unclear/misunderstood)

1. Give examples of what technology means in everyday life
2. Give examples of technology that can be used in education
3. What other uses do you think technology has?

Statement: for the purposes of the rest of the interview, when we use the term "technology", we will be thinking of it in the terms you have described. If, as part of the discussion, you find that you want to expand or revise this definition the include this in your answer.

How do you use technology in your everyday life? (can be clarified to personal and social life)

1. What kind of technologies do you use in your everyday life?
2. How often do you use these technologies?
3. How do you use these technologies?
4. How comfortable do you feel with these technologies?

When you think about your course, how do you use technology to support your learning?

1. What kind of technologies do you use in your learning?
2. How often do you use these technologies?
3. How do you use these technologies?
4. How comfortable do you feel with these technologies?

Has your use of technology changed since you came to University? And if so, how?

1. Is it changes in frequency of use or type of technology?
2. Do these changes relate to facilities/equipment that you didn't previously have access to?
3. Have these changes related to changes in your personal/social life?
4. How do you feel about these changes?

How confident do you feel with trying to use new technologies?

1. Do you feel differently depending on whether these are in your everyday life or your learning?
2. Are there times when using (new) technology is a cause of anxiety?
3. Does it make a difference to your comfort with technology whether you choose to use it or you are presented with it as something you have to use

Thinking about your course, since coming to university how have you prepared for laboratory classes?

1. Do your lecturers require you do anything before coming into the lab?
2. Do you undertake different/extra activities than those you are required to do?
3. How does technology feature in how you prepare for your time in the lab?
4. Are there differences in how you prepare for labs now compared to your first year/when you started your course?

Moving on to think about lab classes. What technologies are used in the labs you work in?

1. Does it vary according which modules you are doing?
2. Are these familiar technologies?
3. Are there any benefits or drawbacks to having access to these technologies?

What technology do you use when you are in the lab?

1. Does it vary according to the module you are doing?
2. Are there different types of technology you use for different purposes whilst in the lab?

How do you feel about using technology in the lab? (Not just the tablets).

1. How do you feel about going into the lab in general?
2. Does the technology affect how you feel about going into the lab?

Moving on to think about what you do after lab classes, what activities do you undertake to help you think about what you've been doing in the lab?

1. Do your lecturers require you do any activities after the lab? (can offer an example E.g. write a report if required)
2. Do you undertake different/extra activities than those you are required to do?
3. How does technology feature in what you do after a lab (post-lab)? As follow up activity for that session?
4. Are there differences in how follow up on labs now compared to your first year/when you started your course?

Finally, I would like to think about why you undertake lab work as part of your course. What do you think the benefits of lab work are?

1) Does it impact on your perception of yourself as a scientist?

Does doing lab classes impact on your understanding of the topics covered on your course? And if so, when do these changes in understanding occur?

1. Does learning occur before/during/after the lab
2. Where does technology fit into this learning process

Thank the participants for their time and ask whether they have any further questions or comments.

Appendix 12: Cross-tabulation summary of all descriptive codes generated during the think aloud pilot and main study and their alignment to the structural codes. Codes generated during the pilot phase are highlighted in yellow. Codes which are unique to the pilot study under each structural code are written in red text.

Lab scientist	**lab preparation**	**Post laboratory**	**technology**	**Tech use**	**technology in lab**	**Attitude**
not a scientist until in a job	ongoing learning	late labs discourage post lab activity	furniture is technology	Streaming TV	understanding lab content	slow at typing
sense of pride	pre-lab calculations	change in understanding is a thought process	technology in research	producing work	stress adds to confusion in the lab	lab is professional environment
varied skill and knowledge levels is frustrating	self-motivation	writing links lab with theory	technology is electrical equipment with a specific function	identifying spelling mistakes	labs can be stressful	learn by making mistakes
advising peers increases confidence	pre-lab prep reduces mistakes	portfolio for future career	technology is complex	technology can increase focus	prefer working alone	singing reduces anxiety
labs give feeling of doing real science	read through seminar	calculations	technology accesses the internet	use phone in lectures	managing stress	faulty equipment
technology increases confidence	first year to catch up	no activities post-lab	technology are machines	phone radiation	Prefer paper	social media distracts from work
puts theory into practice	less prepared	lab introduction too long	pipettes not technology	banking	paperless lab	added pressure
scientists have professional standards	lab entry	more post-lab consolidation needed	perception of technology depends on role	online shopping	singing reduces anxiety	streaming
frustrating to not use data	directed research	review lecture that links to practical	technology is man-made	online journal articles	no pre-lab prep for ERD labs	mixed confidence
report writing links content and labs	acquire equipment	post-lab seminar	water bath	artificial intelligence	strip tests	being compared to others
learn by doing	re-write protocol for understanding	hands on experience	technology saves time	research home automation	faulty equipment	difficult to ask for help
technology in labs applies theoretical concepts	peer support	important to get right	technology doesn't have to be electrical	home security	plate reader	no guidance
labs help content understanding	timetable	technology not needed for learning	glasses	identity theft	improve accessibility	competitive
practicals make science real	no change	do more activities than in first year	lights	bag	first year to catch up	social inhibition
labs are enjoyable	review seminar material	work online	technology in shop	christmas lights	pipettes not technology	dislike waiting
doing science makes you a scientist	bring items from home for testing	simulation	technology helps information sharing	technology for fitness	repetitive	frustrations impact learning
practicals and lab write ups develop job skills	focussed on doing the experiment	broad topics in first year	smartcard	reluctant to use new technology	more focussed in lectures	anxiety that mistakes will affect learning
lab technology prepares for future career	second year has a higher workload	second year labs applied, career based	lab technologies gather or analyse data	communication	no knowledge gain in labs	need instructions

tablet	smartcard	different application of same equipment	technology in medicine	easier to read typed notes	frustrations impact learning	written instructions
	work more independently	re-write protocol for understanding	technology is electrical	dictaphone	change practicals	no degree without technology
	flexible working	re-write notes	technology is a tool created for a specific purpose	online training	lab introduction too long	need technology for degree
	read protocol in lab	online submissions	kitchen appliances	multiple devices simultaneously	technology not needed for learning	anxiety about going into lab
	make notes	no change	transport	more confident	water bath	library one to one support
	intimidating	reflection	technology uses electricity	watching videos	different technology in different labs	labs are beneficial for learning
	take second year labs more seriously	link to theory less clear in labs than lectures	technology helps us	computer does everything	expect new technology	Excel is stressful
	no pre-lab prep	portfolio helps learning	technology makes life easier	streaming	measuring weight	labs give feeling of doing real science
	laptop for researching	focussed on doing the experiment	Computers for learning	web browsing	chemicals	technology saves time
	university app	learning resources	technology is prevalent	excel used more	new techniques	no impact on lab interest
	laptop	library services	centrifuges	bluetooth speaker	technological problems	complexity of technology causes anxiety
	researching information for understanding	writing aids understanding	Lab equipment	online quiz	use data outside lab	loss of social skills
	read protocol	lab reports help understanding	tablets in lab	more lab time and increased complexity	tablet training	no difference
	mobile phone	theory concept understanding changes post-lab	computers	enjoy new technology	life long learning	anxiety if lab assessed
		technology impacts concept understanding	researching information for understanding	relaxation	peer support	support with new technology
		scientists have professional standards	mobile phone	change in how we learn	labs give feeling of doing real science	technology can be a distraction
		researching information in the lab		bathroom appliances	demonstrate equipment	technology increases confidence
		frustrating to not use data		library one to one support	fewer practicals at college	anxiety based on technology capabilities
		report writing links content and labs		Excel is stressful	reflection	social expectations increases anxiety

		health and safety technologies		new software	support with new technology	ask for help
		books		re-write notes	technology can be a distraction	lecturer support
		operated by lab staff		TV	make labs less repetitive	technology is convenient
		technology in labs applies theoretical concepts		technology strongly influences university life	puts theory into practice	technology impacts concept understanding
		check emails		hobbies	pipette	technology integral to a lab
		taking photographs		timetable	technology changes taught material	technology helps information sharing
		make notes		mobiles do everything	screen projectors	smartcard
		researching information for assessment		glasses	lecturer support	reliance on unfamiliar learning technology causes anxiety
		understanding comes after the lab		apps or software	writing aids understanding	cost of equipment causes anxiety
		labs help content understanding		demonstrate equipment	technology is convenient	fear of breaking new technology
		practicals make science real		fewer practicals at college	theory concept understanding changes post-lab	mistakes ruin experiments
		organ bath		no difference	technology impacts concept understanding	learn by doing
		paper		anxiety if lab assessed	technology integral to a lab	operated by lab staff
		exporting data		eyestrain from overuse	technology helps information sharing	unfamiliar equipment causes anxiety
		use software appropriate for assessment		lights	lab technologies gather or analyse data	taking photographs
		understanding changes during the lab		learning resources	researching information in the lab	intimidating
		take second year labs more seriously		library services	frustrating to not use data	technology helps us
		recorded lectures		technology in shop	projector screen	support software
		pens		*screen projectors*	bunsen burner	exporting data
		technology involved in change in understanding		use phone to find information	electrophoresis	labs are enjoyable
		laptop for researching		technology is convenient	health and safety technologies	technology makes life easier
		ebooks		second year has a higher workload	learn by doing	no pre-lab prep

		practicals and lab write ups develop job skills		technology integral to a lab	operated by lab staff	technology helps you learn new things
		write a report		technology helps information sharing	read protocol in lab	technology makes information immediately accessible
		increased frequency of use		smartcard	technology in labs applies theoretical concepts	lab equipment becomes familiar through repeated use
		Lab equipment		reliance on unfamiliar learning technology causes anxiety	microscopy	lab technology prepares for future career
		portfolio		headphones	taking photographs	comfortable with new technology
		computers		work more independently	more facilities available at university	constant connection to technology
		revision		scientists have professional standards	headsets	comfortable with technology
		laptop		projector screen	understanding comes after the lab	mobile phone
		researching information for understanding		technology in medicine	labs help content understanding	
		read protocol		no typing notes at college	practicals make science real	
		mobile phone		health and safety technologies	organ bath	
				news and media	some technology module specific	
				books	no drawbacks	
				flexible working	paper	
				calendar	exporting data	
				operated by lab staff	understanding changes during the lab	
				check emails	technology makes life easier	
				kitchen appliances	take second year labs more seriously	
				transport	no pre-lab prep	
				make notes	technology helps you learn new things	
				more facilities available at university	pens	
				music	technology involved in change in understanding	
				games	some technology shared across modules	
				researching information for assessment	technology makes information immediately accessible	
				lecture note taking	technology is prevalent	
				headsets	centrifuges	

				technology applies across learning and personal life	write a report	
				support software	increased frequency of use	
				paper	lab equipment becomes familiar through repeated use	
				use software appropriate for assessment	Lab equipment	
				technology makes life easier	tablets in lab	
				Computers for learning	lab technology prepares for future career	
				recorded lectures	tablet	
				more frequent use than at college	spectrophotometer	
				technology helps you learn new things	computers	
				social media	university app	
				pens	laptop	
				laptop for researching	read protocol	
				ebooks	comfortable with technology	
				technology makes information immediately accessible		
				technology is prevalent		
				communication		
				increased frequency of use		
				Lab equipment		
				tablets in lab		
				tablet		
				spectrophotometer		
				computers		
				comfortable with new technology		
				revision		
				university app		
				constant connection to technology		
				laptop		
				researching information for understanding		
				read protocol		
				comfortable with technology		
				mobile phone		