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

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This thesis is dedicated to all the people who have helped me throughout the past decade.

To my partner Steve, I wouldn't be here without your endless support – you are my rock, and I am so happy that we are a team and soon we will be Dr and Dr.

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Abstract

This study investigates staff practice and student learning in large-scale multidisciplinary technology enhanced teaching laboratory at Nottingham Trent University. This complex environment is anticipated to result in a high cognitive load on students which could make learning challenging. Digital experiences are investigated using quantitative methods to characterize the students' experiences with technology and in the laboratory: these include the custom designed Digital History Survey and probing student attitudes to the laboratory using a modified form of the Student Laboratory Environment Inventory (Fraser and Wilkinson 1993). This longitudinal study involved students from across a range of sciences – the data presented here focuses on experiences of undergraduate chemistry and forensic students.

The research question for this study is “What is the impact of introducing technology into the chemistry laboratory teaching environment on student experience and staff practice?” However, to explore this, one must first gain an understanding of the laboratory environment more broadly, therefore this study also covers some underpinning elements of laboratory learning more broadly within the Nottingham Trent University context.

To look more deeply at the impact of technology on learning in the lab a series of semi-structured interviews were undertaken with staff members teaching in the laboratory and undergraduate student participants from chemistry courses to explore the aims, purpose, and motivations of stakeholders within the teaching laboratory environment. Although there is some agreement between staff and students regarding the purpose of and aims for laboratory sessions, there are some noticeable differences. Key themes arising from student participants’ discussion of the technology enhanced laboratory environment are peer influences; the importance of preparation and the challenge of the laboratory is a stressful environment.

This study concludes that students within this environment do not perceive an impact on their learning by the technology around them but focus rather on the challenges of being within a laboratory environment more generally. In contrast, staff participants indicated an impact of the technology on some of the laboratory-specific skills developed within the teaching laboratory environment, particularly in relation to the recording of data and solutions were proposed to resolve these issues.

1. Introduction

The Superlab at Nottingham Trent University is a large multidisciplinary category 2 laboratory that opened in 2012. It is capable of holding more than 150 students and hosts teaching laboratory sessions for students studying Bioscience, Chemistry and Forensics courses at Nottingham Trent University. It is a technology enhanced laboratory with many integrated technological features designed to enhance large group teaching while maintaining the containment procedures required by the category 2 nature of the laboratory including tablet computers for students to use as laboratory workbooks, large screens, projectors, and visualisers to display information, and microphone/earpiece system to facilitate communication in a large environment.

The technology available for student use within the Superlab environment is as follows:

- Tablet devices to retrieve and enter data. At the time of this study, the devices were Lenovo Windows touch-screen devices, with detachable keyboards. These come equipped with MS office, a variety of science-specific programmes such as ChemDraw and spectroscopy processing software, and also have a small stylus attached to the side for use on the screen if required.
- Teaching stations are situated around the laboratory with computers and visualiser cameras to allow demonstrations, and these connect to large screens situated around the teaching laboratory to display information to students.
- Staff microphone and student earpiece system to allow staff to talk to large groups of students even in a noisy laboratory environment.

The laboratory itself is situated within a larger laboratory building with an additional adjacent instrumentation laboratory, and upstairs are a smaller and more traditional wet and dry laboratory. Tablets are available in the wet laboratory; however, paper is permitted in this environment. Subsequently in 2017 the interdisciplinary Science and Technology Centre (ISTeC) opened. This laboratory is more similar to the traditional teaching laboratories with paper permitted, however tablets are present, and computers are available directly outside of the laboratory spaces.

When teaching commenced in the Superlab it was thought to be a novel environment, and as such two posts were developed to allow research on the student experience and staff practice within the technology enhanced laboratory environment.

This project commenced using qualitative approaches, and developed to use a mixed methods approach to consider student's attitudes towards the Superlab as a teaching laboratory as well as their use of and familiarity with technology, and the impact that the presence of technology has on the student's learning. Staff practice was also considered as a part of this project and is represented in comparison with student outcomes.

1.1 The student journey in the Superlab

The Superlab is a containment level 2 environment (CL2) or biosafety level 2 laboratory (BSL-2)(Gov.uk 2021), meaning that there are strict restrictions in place regarding access and material handling that are there to protect users and the wider public. In a CL2 environment access is restricted and disinfection procedures are required on entering and exiting the laboratory to prevent the release of any harmful materials. For that reason, anyone working in the Superlab environment are not permitted to bring anything into or out of the laboratory that cannot be thoroughly disinfected. Students have CL2-specific personal protective equipment (PPE) including blue laboratory coats that are stored within the individual small laboratory coat lockers in the Superlab entrances, as shown in figure 3, along with items a student may require in the laboratory environment, such as an earpiece for the microphone system, a spatula and permanent marker for labelling glassware. These containment procedure causes a clear difference from more traditional laboratories as paper notebooks are not permitted within the laboratory environment, and tablet devices are used in their place for accessing materials and recording data.

The Superlab is a large warehouse-like environment, with high ceilings, large windows and one main large room equipped with long standing height laboratory benches where students can undertake experiments. There are two large fume hood bays with A typical laboratory session may vary in terms of equipment used and experiments performed, as well as software used by the students, however a generalised student journey in the Superlab is shown in figure 4.

Figure 1: A view across the Superlab, showing Bioscience students at work on the open bench-tops, reproduced with permission from Nottingham Trent University. This image shows a clear view of approximately half the length of the laboratory, with several long benches and many students undertaking experiments simultaneously.

Figure 2: A student standing at a fume hood in the Superlab, with the camera looking into the fume hood bay, reproduced with permission from Nottingham Trent University. This image shows the high ceilings and bright lighting of the environment, as well as the large fume-hood bays.

1.2 The Superlab environment

Figure 3: The Rosalind Franklin building ground floor plan, showing the Superlab in purple, decontamination areas and lab coat lockers in blue, and personal locker spaces in green.

The Superlab environment is situated within the Rosalind Franklin building (NTU 2022), which hosts preparation facilities (shown in grey) and NTU's Analytical Chemistry laboratory (lime green) housing a variety of analytical equipment. The analytical chemistry laboratory is not directly connected to or contained within the containment area, and therefore all samples must be disinfected before transport between the two laboratories.

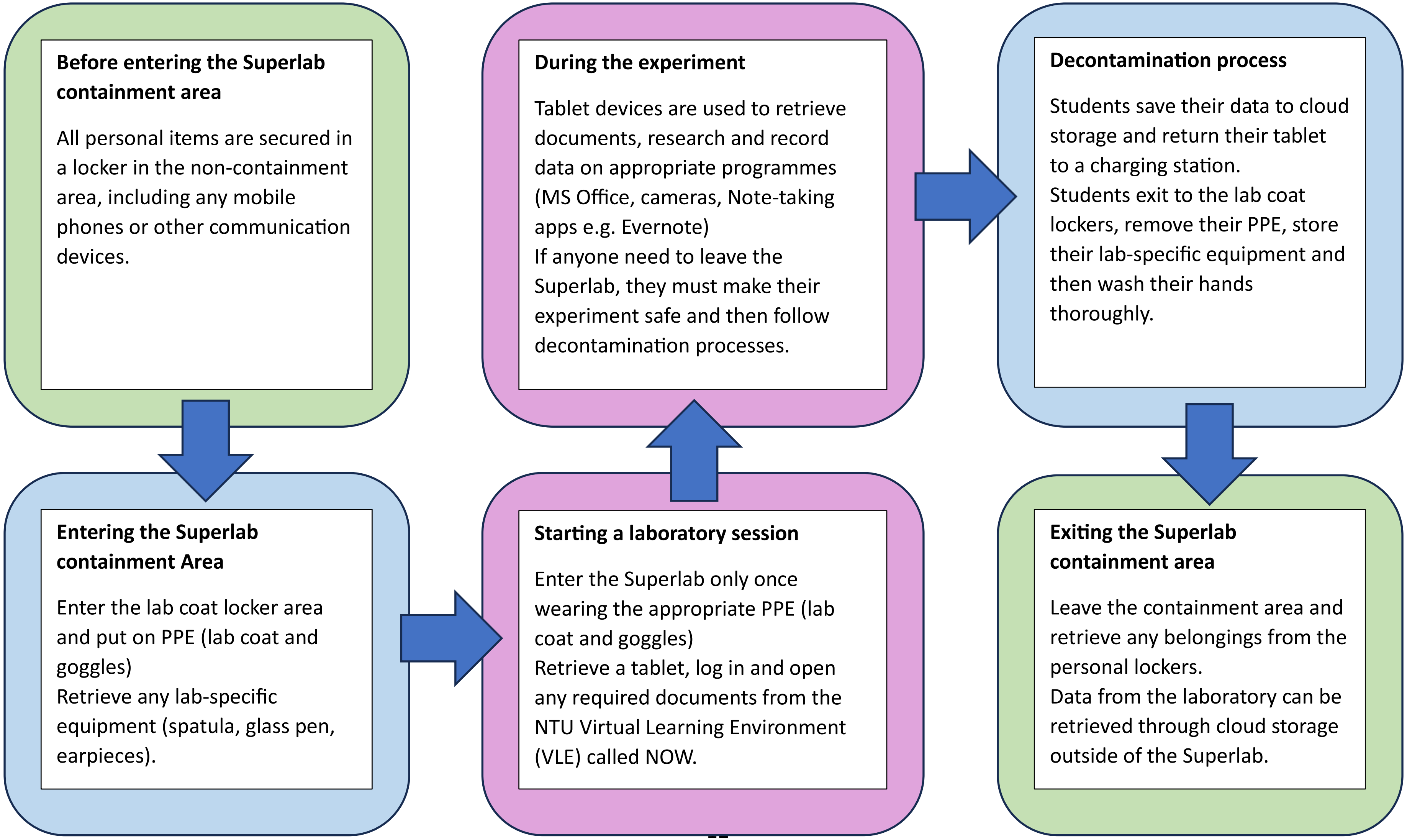

Figure 4: A typical student journey through the Superlab. There is variation by module, level and staff member, but the features indicated are common to all teaching sessions in the Superlab and relate to the containment procedures and their restrictions on student data management within the environment.

2. Literature review.

2.1 Learning Theory

This section is an overview of learning theory as it applies to the teaching laboratory, including constructivism and experiential learning theory. To explore a student's experience of a learning environment, it is first important to understand how a student learns. The understanding of the psychology of learning has developed over the last 60 years, resulting in a wide variety of models to describe and illustrate how people process information and learn during their learning experiences (Willison 2020). Several models of understanding and measuring learning in the teaching laboratory are discussed within this in this section.

2.1.1 Theroetical views of learning

Constructivism

The social constructivist view of learning was developed by Piaget (Ferguson 2007) and further developed by Vygotsky (Rosa and Montero 1990) and Bruner (Cameron 2001), initially for understanding a child's development of language (Smith 2009), as Piaget holds learners as central to the learning process. Learners are viewed as active participants in their own learning, requiring that they engage with phenomena to overcome misconceptions and learn from their experiences. How effectively a student learns within an instructor-designed session depends on a variety of factors, which are summarised in Scott et al. (1987) *"Learning outcomes depend not only on the learning environment but also on the prior knowledge, attributes and goals of the learner."* Vygotsky develops upon Piaget's theory to expand that learning of language often occurs in a social environment (Daniels 2007), and the interaction between the adults and the child is crucial to development. Bruner further refined the concept of social constructivism in a manner that is particularly relevant to formal education and teaching practical, by reinforcing the importance of scaffolding within effective education by modelling tasks, breaking it down into steps and moderating frustration during learning (Smidt 2011). Accommodating the steps taken by a student when learning a concept requires educators to first recognise the understanding of students throughout the learning process. Researching student understanding of concepts is common within constructivist research in education (Ferguson, 2007) (Opie et al., 2004) and has been suggested by Shiland (1999) as a compatible framework for developing pedagogy within the laboratory.

Cognitivism

Cognitivism is a view of learning that focuses on the processes undertaken by students while learning. Cognitivism is one of many behaviourist theories that can be used by educators to understand their student's mental processes (Curzon & Tummons, 2014). In contrast to constructivism where the environment and learning design are of primary concern, in the cognitivism the student's academic abilities and prior learning development are the most important impact on variation in student outcomes. Models of cognitive understanding can be used within constructivist approaches to researching learning (Hord et al., 2016) (Krahenbuhl, 2016), and these models will be discussed within a constructivist framework in this chapter.

2.1.2 Experiential Learning Cycle – Learning by doing.

Kolb's (2014) experiential learning theory developed in the 1980's (Kolb, 1984) builds upon Piaget's social constructivism and integrates the cognitive aspects of learning with behaviour elements, aiming to reconcile the two competing fields of cognitivism and constructivism. Experiential learning identifies learning as a process, that can only be identified once a transformation is complete, as a reflective process (fig. 5). Kolb indicates that ideas are malleable and changeable, rather than fixed, and will change in response to experiences. This change occurs because of destabilization (Glazier et al., 2017), where new information causes conflict with prior held beliefs or understanding, resulting in changing of ideas to accommodate new understanding when considered in a critically reflective manner (Morris, 2020). Piaget referred to this destabilization as disequilibrium, and it also has commonalities with cognitive dissonance as proposed by Festinger (1957) where new information does not agree with prior held beliefs, and yet it is possible for a subject to hold two incompatible beliefs at once. Through the process of learning, this dissonance is exposed, analysed, and resolved by the subject.

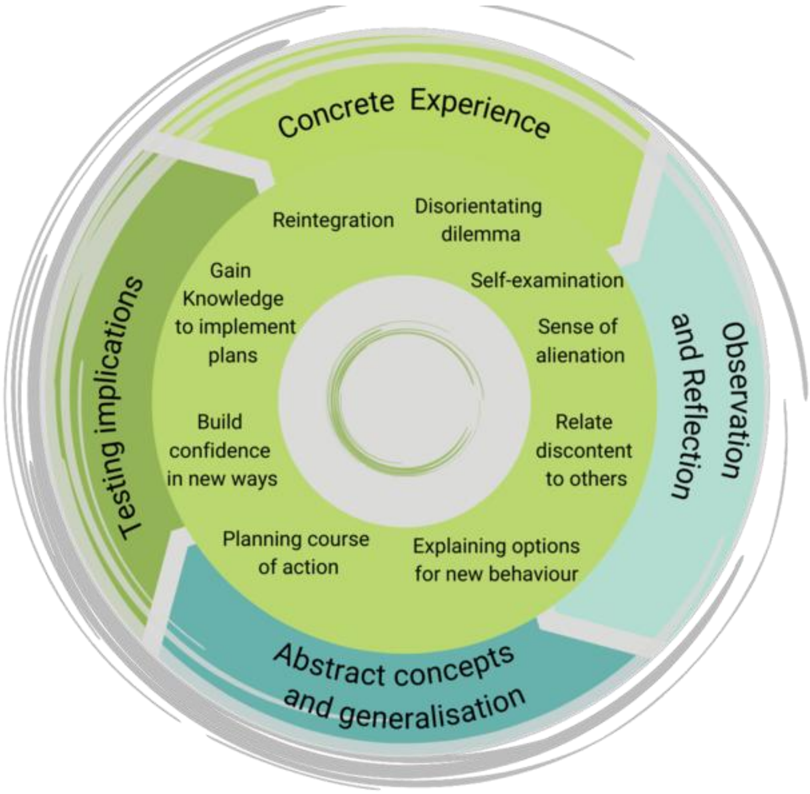

Figure 3: Kolb's Experiential Learning Cycle, reproduced under creative commons licence (O'Brien, R, Creative Commons image)

It is important note that cognitive disequilibrium or dissonance can be a barrier to learning, as observation of physical phenomena that does not agree with current beliefs can cause cognitive disequilibrium in students, can allow students to reconsider their beliefs, challenging misconceptions (Martindill & Wilson, 2015), however it is possible the observation presented may simply be discarded if the student is unable to reconcile the phenomena with their own understanding. because if the level of difference between prior understanding and newly experienced phenomena is too large then learners can become frustrated with the challenge and conversely if the challenge is too small, learners can become bored and disengage (Adcock, 2012).

Morris undertook a systematic literature review to define "concrete experience" by reviewing papers based in experiential education and their pedagogic development, with the following common themes:

- Hands on participation
- Contextual activities – based in real life and linked to society.
- Critical reflection
- Problem solving of real-world problems.
- Novel problems causing temporary destabilization (Glazier et al., 2017).

It has been noted by (Morris, 2020) that the Experiential learning cycle could be considered to lack foundation, and particularly that the terms used within the cycle, such as "concrete experience" which they regard as ill defined.

Despite this shortcoming, Kolb's Experiential Learning Cycle remains widely influential (Seaman et al., 2017) and highly referenced, even in recent studies (Castro, 2023), and has been used to aid understanding of student's learning in both in-person teaching laboratories (Abdulwahed & Nagy, 2009) and technology-based activities including online learning (Hui Yang, 2021) and virtual computer laboratories (Konak et al., 2014).

2.1.3 The Psychology of Learning

Models of learning relevant to laboratory learning are discussed further in this section. To aid exploration of students' experiences, these models are used to explain student's mental processes while learning and different models are appropriate for different types of learning and different learners (Tustin & Barton, 2003).

Information processing model, cognitive load and working memory.

The information processing model is a proposed system for human memory identified in Atkinson & Shiffrin (1968) suggests that external inputs are processed by a sensory register, held in a short-term store, and processed to a long-term store. This model has commonalities with the working memory model, as developed by Baddeley & Hitch (1974) which details the working memory as the mental space that is currently available to be used for a task (fig. 6). It is described as an element of short-term memory comprising of the following:

- the phonological loop, which is responsible for auditory and language information,

- visuospatial sketchpad which is responsible for spatial reasoning and coordination as well as visually observed phenomena

-in the central executive which is responsible for decision-making and synthesising and rationalising the other two groups of information.

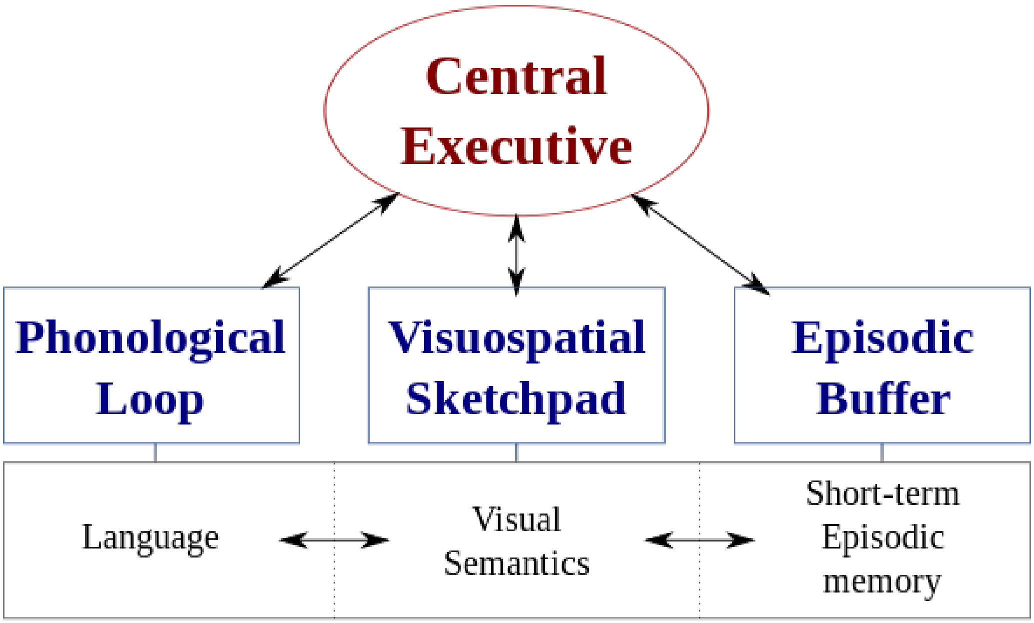

Figure 4: Working memory model, reproduced under creative commons license. (Mirek, Creative Commons image)

Cognitive load (Kirschner, 2002) of a task is the amount of information that is being processed in undertaking a task. This information typically has not yet been transferred to long-term memory, and may be information that is novel, unfamiliar or does not need retaining to long-term memory. There is a limit to the capacity of this memory space, which can be exceeded during cognitively intensive activities with (G. A. Miller, 1956) indicating this working memory limit is approximately 7 items of information that can be managed at any one time, with Miller indicating that this should be considered to be between 5 and 9 items. However further research has suggested that this limit is variable and must be considered in context with a wide variety of impacts such as transitive processing (Cowan 2012).

The total cognitive load for any given activity has several elements, as explained by (Paterson, 2017):

- the intrinsic load which is the required information for performing the task

- the extraneous load, which is unnecessary information presented during the task

- the germane load which is where a subject is using mental resource to synthesise models and develop understandings or connection between ideas

If a person is confronted with too much information to process or if the information is too complex or unfamiliar, the working memory limit can be deemed to be exceeded (Oberauer et al. 2016). This contributes to a phenomenon known as cognitive overload (Sweller, 2011) and results in the subject finding it challenging to cognitively process the information being presented.

Working memory includes an episodic buffer which is a phenomenon that allows similar or linked components to be grouped together (A. Baddeley, 2000). This can be referred to as chunking (Thalmann et al., 2019), where items in the working memory are grouped together to increase the cognitive capacity of a participant. The capacity of a participant to chunk items together is linked to their level of expertise in an area (Stieff et al., 2020). Daneman and Carpenter (1980) undertook a small-scale study on the working memory processing and storage capacity and found that it varied between individuals, which can account in variation in individual cognitive load of a task. An example of chunking within Chemistry would be a crystal structure unit cell: a novice may view several atoms arranged in space separated by different distances and bonds while an expert would see the shape of the lattice and immediately recognise the lattice name (e.g., body-centred cubic).

Within the information processing model, Chew (2021) identifies two further elements contributing to complex learning, choke points and pitfalls (fig. 7). Pitfalls are common actions undertaken by students, that impact on student's long-term learning negatively.

- Multitasking and distractions – these increase the amount of information a student is required to simultaneously process and increases the chances of cognitive overload.
- Students often prefer the least effective study strategies preferring time effectiveness and surface learning to deep learning and time investment.
- Overconfidence in their level of understanding.

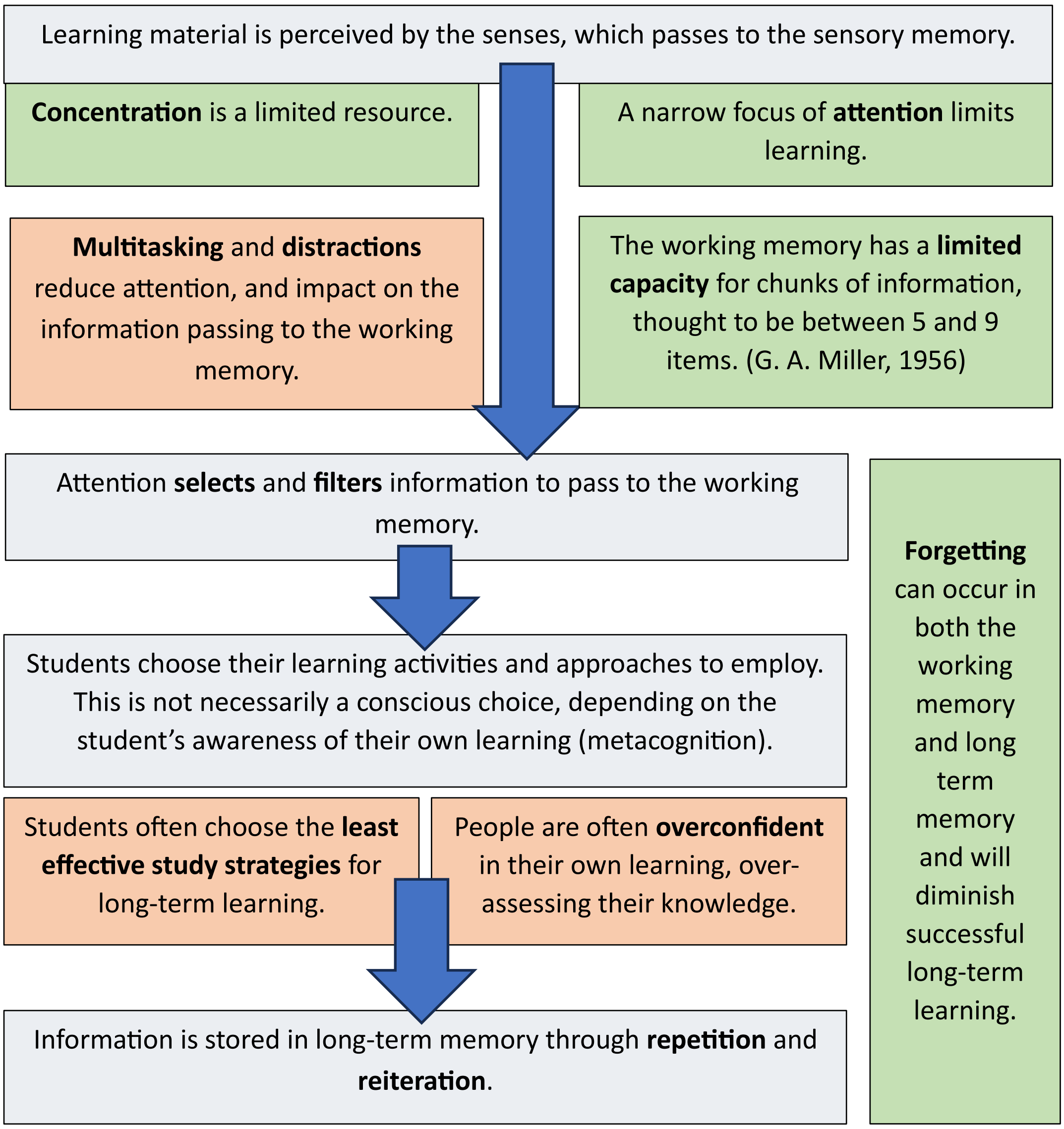

Figure 5:Choke points and pitfalls in learning modified from (Chew, 2021)*. Pitfalls are coloured orange; choke points are green.*

A learner receives learning material via their senses, and they process it via their sensory memory. Their attention is a limiting factor here, and the narrow focus of attention can restrict the amount of sensory information that is effectively, resulting in selection and focussing of the information that is processed. Multitasking and distractions increase the amount of sensory input, and therefore can saturate the attention, reducing the amount of useful or relevant information that is selected. This information now passes to the working memory where information is held for short-term processing such as decision making and short-term recall, which has a limited capacity. If a large amount of information or highly complex information is being selected through the attention phase, then the working memory will become overloaded resulting in poor transferral to long term memory.

Choke points are crucial points within the learning process where cognitive resources are limited, and learning can be negatively impacted. These cognitive challenges can be managed and mitigated with careful design of learning activities (Chandler & Sweller, 1991).

Another model to consider when investigating teaching and learning is the 3P model of learning (John B. Biggs and Moore 1993), which has 3 steps, Presage, Process and Product.

- **Presage** is the broader context of learning and encompasses student characteristics such as motivation, ability and prior knowledge, as well as teaching contexts such as the teacher's characteristics, curriculum content and teaching methods.
- **Process** is the teaching-learning process which encompasses the in-situ elements of the teaching process, such as activities within a classroom.
- **Product** is the outcome of the learning process, which is often quantified as student achievement.

The 3P model is useful within higher education teaching contexts, as students can have a wide variety of personal characteristics which can impact on the way they approach their learning (Clinton 2014). The 3P model has been used to investigate higher education contexts to investigate teaching and learning environments, as the Presage factors can account for variables such as change in the teacher, curriculum or teaching methods used and accounts for the community that develops between a teacher and their students, as well as peer interactions (Kember et al. 2020).

2.1.4 Models of learning

Meaningful learning

Ausubel proposed the concept of meaningful learning where new information is rationalised relative to existing learning and changes a student's conception, and that information can be further applied to solve problems (Ausubel, 1963). For meaningful learning to take place, the learning is required to be "social, collaborative, intentional, authentic and active."(Jonassen & Strobel, 2006), therefore careful design of the learning activity is necessary. Authentic learning has been defined in a variety of ways, Han and Resta (2020) group these into three broad categories:

- Authentic learning is that which has cultural context or links to community. In this view of authentic learning, learners are participants within the learning process but not necessarily immediately independent at early stages of learning.
- Authentic learning is learning that accommodates a learner's personal context. In this view of authentic learning, students must be able to connect learning experiences with their own personal lived experiences.
- Authenticity is a quality within the learning process, that is developed within the learner. More specifically, Van Oers and Wardekker (1999) define authenticity within learning as a personal quality that is developed throughout the learning process, and that the learner must develop during the process in relation to the learning, rather than learning being constructed around previously held cultural or personal contexts.

Ausubel's assimilation theory shows that a learning event can result in acceptance or rejection of the new phenomena, depending on the cognitive processes that occur for the learner. Engaging in a meaningful learning activity does not immediately result in the development of conceptual understanding and can indeed result in obliterative subsumption where new concepts are rejected or fail to integrate within a learner's current knowledge.

Domains of learning

There are three domains of learning – the cognitive, affective and psychomotor domains. These domains were developed between 1950 and 1975 by a variety of researchers, which are clearly defined by both Bretz (2001) and Hoque (2016).

The cognitive domain

Cognitive skills are those associated with traditional academic learning. Bloom's taxonomy (Hoque, 2016) is a model of the cognitive learning domain that suggests that students can develop skills allowing conceptual learning to varying levels of mastery and creates a hierarchy of cognitive skills (fig. 8). Lower order skills such as knowledge are located at the bottom of the pyramid, which is representative of rote-learning, where students learn information through repetition, recalling facts without being able to explain them (Mayer 2002). Higher order skills are located at the apex of the pyramid, such as evaluation which is includes critical reflection (N. E. Adams, 2015). Throughout the development and revision of this taxonomy, the exact labels of each level of the taxonomy and order of these labels have varied over time (Krathwohl, 2002). A single learning activity can require a student to draw on different levels of this taxonomy at the same time, or at varying times in the same activity (Krathwohl, 2002).

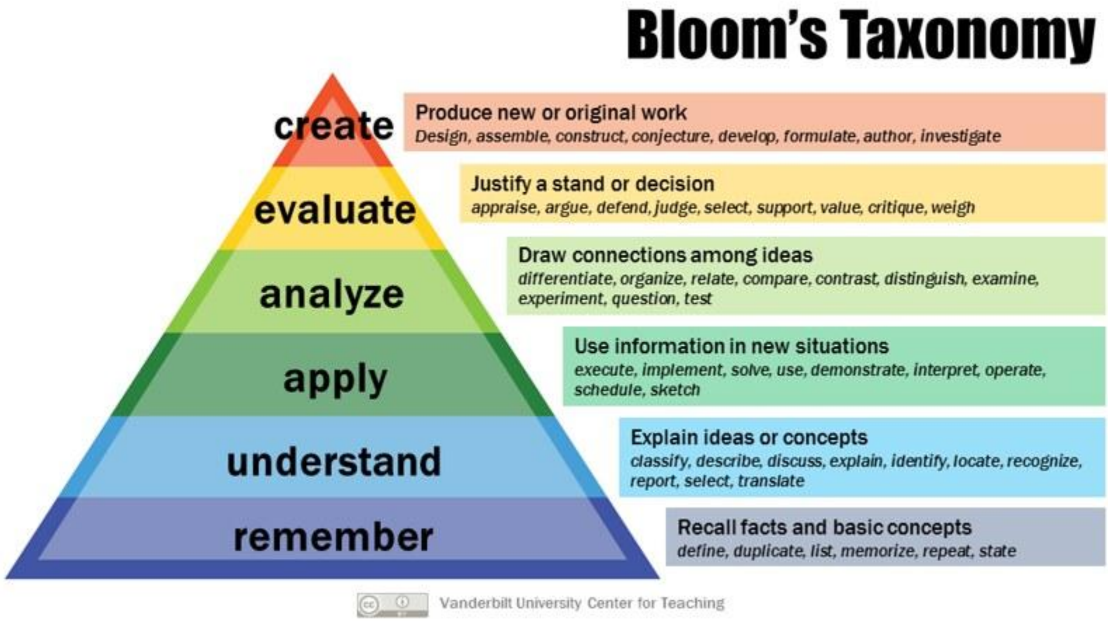

Figure 6: Bloom's Taxonomy reproduced under creative commons license (Vandy CFT, Creative Commons image).

As a student gains mastery of a concept, skill, or method, they will gain skills from the higher levels of Bloom's taxonomy and be more readily able to use the higher-level thinking skills to critique, refine and reflect upon their experiences. Students will use skills from all levels of Bloom's taxonomy at all stages of their university career, but as their skills and confidence increase, they will be able to move between the levels more readily. Students at the beginning of their studies will tend to be focussing more on the lower levels, with remembering and understanding new types of apparatus and new reagents, whereas students later in their studies will no longer need to actively remember practical techniques that they have undertaken several times before as they will have transferred to long term memory.

The psychomotor domain

Psychomotor skills are those that relate to the physical manipulation of the body within space. Three popular taxonomies have been developed to represent this highly complicated domain, identified by Hoque (2016). These are described in table 1. These skills are important for the laboratory environment as learning how to manipulate equipment safely is often an important aspect of the laboratory environment (McKeachie et al., 1999).

Simpson's (1966) psychomotor taxonomy		(Dave, 1970) psychomotor taxonomy		Harrow's (1977) psychomotor taxonomy	
Category	**Description**	**Category**	**Description**	**Category**	**Description**
Perception	Applying perceived sensory information to a motor activity.	Imitation	Copying a displayed behaviour.	Reflex movements	Automatic reactions
Set	Preparation or motivation to act.	Manipulation	Following instructions	Basic fundamental movement	Simple movements that can be combined into complex ones
Guided response	Copying a displayed behaviour.	Precision	Performing a skill with precision	Perceptual movements	Movements in response to environmental cues
Mechanism	Converting learned responses into habitual activities, with a high degree of proficiency	Articulation	Combining skills	Physical activities	Activities requiring strength, vigour, or agility
Complex overt response	Skilfully performing complex actions without direct attention.	Naturalization	Combining skills with ease with minimal exertion	Skilled movements	Activities that require a level of efficiency
Adaptation	Modifying learned skills as required			Non-discursive communication	Body language
Origination	Creating new movement patterns				

Table 1: Psychomotor taxonomies as developed from Hoque (2016) and Neagru et al. (2020) with additional information from Wu et al. (2007)

The affective domain

The affective domain is the emotional element of learning, including motivations and attitudes (Casey & Fernandez-Rio, 2019) (Hoque, 2016) and have a large impact on the way a student will approach challenging material. The affective domain is challenging to measure and often less emphasised within educational research (Galloway et al., 2016), possibly in part because affective characteristics are latent and not able to be measured directly, resulting in research often relying on self-reported measures (McCoach et al., 2013). The affective domain encompasses the following, adapted from Hoque (2016) with examples from the teaching laboratory:

- **Receiving phenomena:** The student's capacity to actively listen and receive information, such as listening attentively to a demonstration within the laboratory.
- **Responding to phenomena:** The active participation of the learner in a learning activity, including following instructions in a laboratory manual or actively participating in discussions in the laboratory.
- **Valuing:** The student's ability to perceive value of an object, behaviour or phenomenon and articulate the value of that item to another. Depending on a student's motivations, they may value different objects, behaviours, or phenomena within the laboratory to higher or lower levels.
- **Organisation:** The student's ability to prioritise tasks according to their own set of values, for example some students may prize time efficiency, while others may value accuracy, and they may organise their time differently to match these values.
- **Characterisation**: The student's ability to allow their values to control their behaviour, for example a student who values academic performance may take additional measures to ensure that their attainment in assessed portions of the teaching laboratory are to a high standard.

Novak's theory of education (Novak, 2010) integrates the three domains of learning with Ausubel's theory of meaningful learning and indicates that for meaningful learning to take place, knowledge needs to be inter-connected across all three domains in each learning experience, and by providing learners with meaningful learning experiences, they not only learn the content, but they learn how to learn (Bretz, 2001).

Student's approach to learning, surface, and deep learning

University education aims to develop higher order thinking skills (E. Smith & Reid, 2018), as identified in Bloom's Taxonomy. Higher order thinking skills are challenging to develop and to encourage development, educators need to carefully design learning experiences students need to engage in these learning experiences in an effective manner.

Beauchamp & Kennewell (2010) propose that for a given activity, it is possible for students to engage with that activity on a variety of levels – from passive consumption to active engagement, although some designed learning activities lend themselves more readily to active participation, and that the way an activity is designed impacts on how a student will interact with the activity on a cognitive level.

Deep learning was identified as part of an investigation into students' conceptions of tasks by Marton & Saaljo (1976), where two types of students were identified, those that wished to memorise facts – described as surface learners, and those who wished to connect the new information with their prior understanding – described as deep learners. The description of deep learning is comparable to Ausubel's description of meaningful learning. Surface learning, by contrast, focusses on the completion of a task, and often focusses on memorisation of facts and rote learning (Biggs, Moore

1993). A variety of motivational factors have been identified subsequently that may affect a student's approach to learning (Biggs, Moore 1993), for example self-conception of success, social motivation, and achievement related. Biggs and Moore (1993) suggest a further approach to learning, the achieving approach, who have a pragmatic and efficient approach to their learning. The strategy employed is to achieve maximum attainment, motivated by a desire to which may not result in true deep learning.

Metacognition

Awareness of one's own learning approach is crucial in taking advantage of learning experiences to the greatest effect and is part of the metacognitive process (Biggs, Moore 1993). Metacognition is a term first used in the 1970's to describe a student's understanding of their own learning process particularly in relation to learning language (Mahdavi 2015). As Bloom's taxonomy levels represent different levels of cognition, it can be drawn that metacognition is a students' ability to employ the different skills from Bloom's taxonomy to facilitate their own learning.

suggests that in the case of learning language, metacognition can be divided further into 5 stages:

- Preparing and planning for learning
- Selecting and using strategies
- Monitoring learning
- Orchestrating strategies
- Evaluating learning.

Learning in these stages can be viewed as a cyclical exercise, with a student building on their learning in successive learning experiences building upon each by reflecting on the previous one(Blank 2000). Although metacognition was originally developed to describe student's understanding of their own cognition in a language-learning situation, it has been subsequently used in a variety of environments including STEM laboratory-based learning (Case et al. 2001).

2.1.5 Learning theory

Research undertaken as part of this project will be rooted in the theories of constructivism, experiential learning, and metacognition as described in this section. The information processing model, meaningful learning and conceptual levels of learning will be used extensively to describe the types of learning taking place within the teaching laboratory environment.

2.2. Pedagogic approaches to the teaching laboratory.

2.2.1 What is the teaching laboratory?

Moeed (2011) notes that practical work, laboratory work and experimental work all have been used within the literature, and that research has attempted to classify practical work through a variety of means. As this study is taking place in a specific institution, a definition has been developed that most fits the environment in which the research is to be undertaken.

For the purposes of this study, terms are defined as follows:

- A teaching laboratory is defined as an environment that is purpose-built or adapted for the use of teaching Higher Education students science using practical experimentation. Often these laboratories are fitted with apparatus or instrumentation specific to the subject.
- A teaching experiment is an experiment designed by academic staff and undertaken by students in a laboratory to achieve a learning outcome or set of learning outcomes. These are referred to interchangeably within the literature as experiments, practicals, or laboratory sessions.
- Teaching external to the laboratory environment will be referred to as Non-Laboratory Teaching. This may take the form of a variety of learning activities, for example seminars, workshops, self-directed study, or lectures.
- A laboratory course is a group of these teaching experiments that are designed to meet a broad range of learning outcomes. Due to differing delivery structures in HE institutions, a laboratory course can be delivered in a variety of ways. It may be one continuous block of teaching which is delivered separately from non-laboratory teaching, or it may be several teaching experiments paired with a set of non-laboratory teaching to comprise a thematically grouped module or block. A laboratory course may also refer to all the teaching experiments throughout a student's stage of learning, for example a term, year, or course.
- Pre-laboratory sessions or activities are sessions or activities that are undertaken by students prior to the teaching laboratory session, designed to facilitate their operation, learning or development during the teaching laboratory session.
- Post-laboratory activities are activities undertaken after the students have left the teaching laboratory that are linked to the activities undertaken within the teaching laboratory. An example of a post-laboratory activity would be a laboratory report.

The history of the teaching laboratory

Teaching laboratories as we currently recognize them, have been used extensively since the early 1800s (Elliott et al. 2008) and were initially developed for the training of competent chemical technique practitioners to facilitate the development of early chemistry discoveries. The requirement for laboratories is emphasized both by accreditation bodies for undergraduate chemistry degree programmes both in the UK (Royal Society of Chemistry 2022) and internationally (American Chemical Society 2022) and the Quality Assurance Agency for Higher Education (QAA 2022). The importance of the teaching laboratory is reinforced by academic perspectives regarding the laboratory as a crucial and inherent element of science learning (Kerr et al. 1963).

Kirschner (1992) argues that in research and teaching, there can be a conflation between the epistemology of science and the pedagogy of the teaching laboratory. Kirschner suggests that the developed and sophisticated epistemological approach of a scientist to a research problem significantly differs to the approach of a student to a teaching laboratory or experiment, and as such a difference in purpose, aims and design is necessary, effectively advocating for scaffolding to develop the epistemology of the students to reach a more professional developed level. The epistemology of undertaking science is often referred to as the “Scientific Process”, as is detailed as an aim of laboratory teaching by Osborne (2011).

Teaching laboratories are now often recognised as core part of science teaching with experiments or laboratory teaching being referred to as “central” to science education(Millar 1987), “ubiquitous” (Kohler 2008) and even “sacred” (Tobin 1990). Hofstein and Lunetta (2004) emphasise the importance of the laboratory in modern Chemistry education as a format to promote inquiry in learning. Despite this broad consensus that laboratories are central and integral to science teaching, questions have been raised about their effectiveness in teaching students science (Hawkes 2004), which is supported by the study by Abrahams and Millar (2008) which found that while the majority of students find experiments enjoyable, only 38% found the experiments to be useful and effective as teaching methods.

2.2.2 Instructional methods in the teaching laboratory

As is the case other learning environments, a variety of instructional styles can be implemented effectively within the laboratory. As the instructional design has an impact on both the cognitive load of a task, and the ability for students to engage on differing metacognitive levels, it is important to review instructional styles in relation to the teaching laboratory.

Instructional models in teaching

Active learning

A central pillar of the constructivist view of education is the instructional approach “Active Learning” which requires students to participate actively in the learning process rather than being passive recipients or vessels for information provided in a more didactic manner (Grabinger, Dunlap 1995).

Active learning has been implemented in undergraduate STEM learning external to the teaching laboratory (Freeman et al. 2014) with the outcome of reducing failure rates and increased performance in assessments of understanding. Active learning has also been implemented in a course of non-laboratory and laboratory-based sessions (Hake 1998) with successful outcomes regarding engagement, assessments of understanding and problem-solving skills. (Cavinato 2017) developed an active learning laboratory course for teaching analytical chemistry in USA college level education, and identified successes and challenges that arise from the active design.

The laboratory is not necessarily an inherently active learning environment, as it is possible for students to approach the laboratory in a very passive manner (Wilson 1969). This is commonly referred to as “cookbook chemistry” (Venkatachelam, Rudolph 1974) and correlates with the less engaged approaches of surface learning and the achieving approaching aiming for maximum attainment. Significant effort in laboratory design has been attempting to reduce students’ tendency to approach the teaching laboratory in this outcomes-focussed manner (Bertram et al. 2014), (Boyd-Kimball, Miller 2018), (Gallet 1998), (Modell et al. 2004). Outcomes-focussed approaches to the teaching laboratory are characterised by a high emphasis by the students on making a product or obtaining a dataset which will be referred to in this project as the *Practical Outcome for consistency*, due to the variety of terms applied within the literature.

Flipped learning.

Flipped learning is a form of active learning where a student is required to partake in a group learning environment that is not limited to a learning environment (Seery 2015). Students typically review material or undertake activities prior to a scheduled session, and then the scheduled sessions are redesigned to be active rather than passive sessions. Flipped learning is an effective method of lowering cognitive load in educational settings (Karaca, Ocak 2017). The flipped method of teaching does have its own challenges (Akçayır, Akçayır 2018) but it is generally well received by students who have positive perceptions of flipped classroom settings (Jeong et al. 2016).

STEM education has additionally been "flipped" by the introduction of SCALE-UP (Beichner et al. 2000) where the traditional lecture environment is effectively transformed into an experimental one, although perhaps not a traditional laboratory. SCALE-UP is a student-centred active learning approach to teaching where students are provided with content external to the teaching sessions, and the sessions themselves include activities such as discussions, experiments, or research activities. The SCALE-UP environment is designed in a particular way to facilitate this approach to learning, with round tables to facilitate group work, and access to technology to allow the access to and sharing of information.

Instructional models within the teaching laboratory

Types of laboratories

A variety of instruction styles applicable to the teaching laboratory have been identified (table 2) which have different pedagogic approaches and outcomes, described thoroughly by Domin (1999). Coppola (2016) acknowledges these 4 styles, also proposes a fifth style, known as Studio instruction which has similarities to the SCALE-UP method as developed by Beichner et al. (2000), in that it is a student led problem-based laboratory where the laboratory space itself is redesigned to accommodate both theory and practice more readily in the same space. However, SCALE-UP emphasises the redesign of the lecture space to accommodate practical work, while studio instruction advocates for the redesign of the laboratory space.

Table 2:Laboratory instruction styles, as defined by Domin (1999)

STYLE	DESCRIPTOR		
	Outcome	**Approach**	**Procedure**
EXPOSITORY	Predetermined	Deductive	Given
INQUIRY	Undetermined	Inductive	Student generated
DISCOVERY	Predetermined	Inductive	Given
PROBLEM-BASED	Predetermined	Deductive	Student generated

The differing types of teaching laboratory can result in a difference in student's perceptions of their own conceptual development of understanding of chemistry in the teaching laboratory, as identified by Domin (2007), with expository teaching laboratory activities resulting in conceptual development after the laboratory session, and problem-based teaching laboratory activities resulting in conceptual development occurring within the laboratory.

Instructor styles

As the activities undertaken within the laboratory have an impact on the student's learning, differing styles of instructors have also been identified. Velasco et al. (2016) identified four styles with differing approaches to operating within the teaching laboratory.

- **Waiters** – these instructors wait to be consulted for assistance by the students and have minimal involvement in the students' activities within the teaching laboratory.
- **Busy bees** – these instructors are highly active within the teaching laboratory, answering questions and providing advice and typically assist students in groups.
- **Observer**s – these instructors focussed on monitoring student operation within the teaching laboratory.

- **Guides-on-the-side** – these instructors are highly engaged with the students in the teaching laboratory, regularly offering guidance and praise. These instructors often initiate conversation with the students to probe their understanding in a one-on-one manner.

2.2.3 Aims of Teaching Laboratory Sessions

Staff perceptions of the aims of the teaching laboratory

Johnstone and Al-Shuaili (2001) make clear distinction between aims and objectives in relation to the laboratory, and these definitions will be used for this discussion. Aims of the laboratory are general statements of what the academic intends to achieve, while Objectives are experiment-specific outcomes for students. The aims of the teaching laboratory are wide ranging and can encompass a variety of both subject specific and transferable skills however there has previously been a lack of consensus over the purpose of laboratory sessions within instructional design (White 1996).

In the context of higher education, Kirschner and Meester (1988) undertook a review of studies of the laboratory environment and discovered that the aims of the laboratory identified in research are often related to the instructional method employed within the laboratory environment. This review identified 120 specific objectives, which were grouped into 2 end-terms and 8 student-centred more general objectives, as represented in table 2. This study is effective in displaying the wide-ranging aims of teaching within the laboratory environment but does not successfully identify which aims are course-wide and which are isolated to an individual experiment or set of experiments. This list of 120 aims may have limited use in a teaching context, as it may be challenging when designing a laboratory course and identifying aims for students, as the students may be overwhelmed by the sheer number of aims covered, especially with the degree of specificity, however the set of 2 end-terms and 8 student-centred objectives are more concise, however do over-simplify complex ideas.

By way of example, Kerr et al. (1963) investigated the aims of practical sessions in school and college level as perceived by both students and teachers and consequently defined a simple set of aims. These aims align within the sections of importance identified by Hofstein (2004) as important elements of learning within the laboratory "learning to be a scientist, learning science and doing science". Differing aims of laboratory sessions may require different types of laboratory work, as identified by (Domin 1999). The teaching laboratory environment is also thought to offer unique outcomes that are difficult to facilitate through traditional teaching methods, such as using equipment or other laboratory manipulative skills, the teaching laboratory may not be as effective at teaching problem solving or more subject knowledge focussed outcomes (McKeachie et al. 1999). Abraham (2011) suggests that it is possible that the instructional methods being employed are not necessarily appropriate for the aims identified by the instructors. Hofstein (2004) indicates that for the teaching laboratory to be an effective teaching environment, instructors must be provided with appropriate knowledge, skills, and resources to allow effective instructional design, and instructors must be aware of their students' processes of thinking within the laboratory. As the possible aims of the teaching laboratory are very varied, these are represented in a literature review table (table 3), with sources for each aim set.

Student perceptions of the aims of the teaching laboratory

Galloway et al. (2016) suggest that students believe that the main purpose of the laboratory is to develop manipulative skills, and that the student's perceptions of their control of their own laboratory experience has a significant impact on their understanding of their learning within the laboratory.

Kerr et al. (1963) suggest that students often unclear on the purpose of laboratories. One possible cause for this is the identified that while the teaching laboratory has such diverse aims, they are also not necessarily well defined in the laboratory manual (Meester, Maskill 1995), which could lead to difficulty in students identifying the aims of a session. If students are unclear on the purpose of laboratories, then it may be difficult for them to make appropriate decisions about their learning within the laboratories. It has often been reported in literature the students arrive at laboratories underprepared (Carnduff, Reid 2003) (Moffatt 1994). Lack of appropriate preparation and taking ownership of the learning experience can be regarded as surface learning (Biggs, Moore 1993). If students are making “surface learning” decisions throughout the course than a lack of preparation is almost be expected as doing minimal work and leaving the laboratories quickly as possible would fit in with this approach.

Table 3: A table of the aims of the laboratory, collated from selected literature. The selection of aims displayed in this table is not intended to be exhaustive but represents the variety in discussion of aims within the literature.

	QAA Subject Benchmark Chemistry 2022 *	**RSC Accreditation of Degree Programmes 2022 ****	Kirschner, Meester (1988)	**Kerr et al (1964)**	**Domin (1999)**			**Kimball & Miller (2018)**	**Johnstone and Al Shuaili (2001)**
			Literature review of Higher Education	**School level**	**Inquiry**	**Discovery**	**Problem Based**	**Problem Based**	
Safety	X	X							
Risk assessment		X							
General experimental competence, including using apparatus or technique	X	X	Student-centred objective	X	X				X
Understand quantities/concentrations		X							
Understand chemical terminology		X							
Observation and recording data		X	Specific objectives	X					X
Reporting data		X	Specific objectives						
Data analysis including interpretation		X	Student-centred objective						X
Scientific thinking			Specific objectives	X					
Experimental design, project design, Hypothesis formation		X	Student-centred objective		X		X	X	X
Independence in practical work	X	X	Specific objectives						
Critique an experiment (accuracy, precision, reliability, and validity)		X	Specific objective						
Critical Thinking			Specific objectives					X	
Problem solving (in relation to the laboratory), formal operational thought	X		Student-centred objective	X	X	X	X	X	
Confidence			Specific objectives					X	
Learning from mistakes	X								
Professional behaviour		X	Specific objectives						
Data analysis		X	Specific objectives						

	QAA Subject Benchmark Chemistry 2022 *	RSC Accreditation of Degree Programmes 2022 **	Kirschner, Meester (1988)	Kerr et al (1964)	Domin (1999)			Kimball & Miller (2018)	Johnstone and Al Shuaili (2001)
			Literature review of Higher Education	**School level**	**Inquiry**	**Discovery**	**Problem Based**	**Problem Based**	
Improve student attitudes to chemistry			End Term	X	X			X	X
Student ownership or independence			Specific objective		X				
Improved retention of information / concepts			Student-centred objective			X			
Motivation including enjoyment						X			X
Applying understanding			Student-centred objective				X		
Practical exam requirements				X					
Elucidate theoretical work to aid comprehension			Specific objectives	X					
Verification of facts				X					
Finding facts by investigation			Specific objectives	X					
Making phenomena real				X					X
Communication of experimental process			Student-centred objective						
Understanding the scientific method			End term						
Organisation and time management			Specific objectives						

QAA Subject Benchmark Chemistry 2022 * This benchmark statement has aims for a whole course, and it is challenging to isolate laboratory-specific aims.

RSC Accreditation of Degree Programmes 2022 ** Has course-wide aims, and it is challenging to isolate laboratory-specific aims.

2.2.4 Strengths of the teaching laboratory as a learning environment

Hands-on teaching where students interact with an activity has been found to improve procedural replication of the activity (Schwichow et al. 2016), which is important for students to obtain manipulative techniques that are expected of students within the laboratory (QAA 2022), (Royal Society of Chemistry 2022).

Scientific experimentation has the possibility of being very memorable (Cerini et al. 2003), which can improve the likelihood that an experimental activity has a greater impact on understanding than a non-experimental activity, as a more memorable event is easily recalled. If a student successfully reconciles the memorable phenomena with underlying theory and existing knowledge, will aid recall long-term (Martindill, Wilson 2015).

2.2.5 The teaching laboratory as a complex learning environment

Information processing in Chemistry

Chemistry is often referred to as a difficult subject for students to study (Carter, Brickhouse 1989), (Johnstone 2000), there are many reasons for students having trouble in chemistry, which will extend to studying chemistry within the teaching laboratory. This section aims to explore the more commonly cited elements contributing to difficulty in learning Chemistry.

Representational models and symbolism in chemistry.

Johnstone (1993) suggested that one complicating factor in chemistry teaching is the requirement to move between three different models of thinking (fig. 9).

Macrochemistry – phenomena observable within the laboratory, such as colour changes.

Submicrochemistry – abstract physical phenomena that are not readily observed, such as atoms or molecules.

Representational chemistry – symbolic representation of phenomena, such as chemical equations, diagrammatic structures, and mathematical representations.

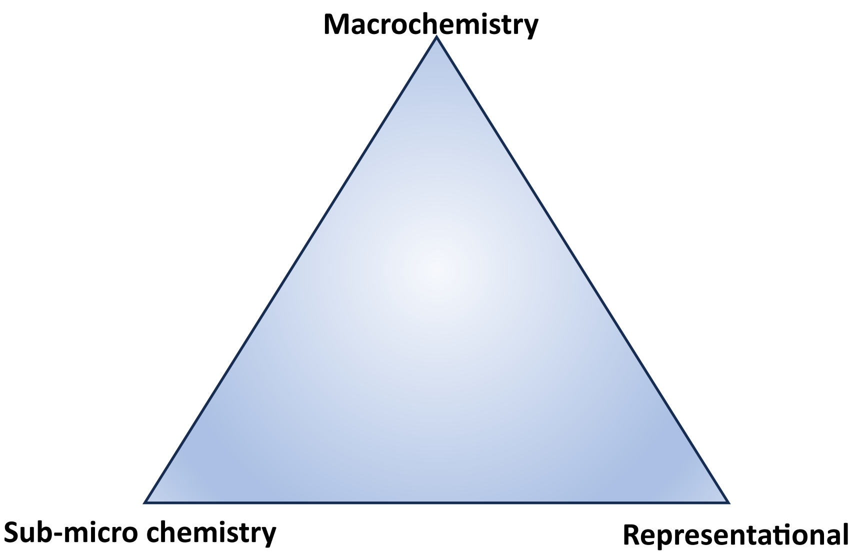

Figure 7: Johnstone's triangle of chemistry learning, reproduced from Johnstone (1993)

Students are required to seamlessly move between these representations during the learning process, meaning they need to conceptually link the different representations (Novak 2010; Schmidt 2021) to obtain meaningful understanding. These multiple representations can be regarded as different items for the working memory to process, which can result in overload of the working memory should a student fail to integrate the representation or submicro levels with the observable phenomena presented within a teaching laboratory (Tsaparlis 2014).

Misconceptions and troublesome knowledge and threshold concepts in Chemistry

Taber (2002a) identifies that chemistry is an unusually abstract subject, and that this can cause challenges in learning chemistry. Taber has undertaken extensive work in defining the misconception which is when a student's beliefs or understanding of phenomena are contrary to commonly held scientific understanding. Often these are based on commonly held ideas, and there are many examples identified so far (Taber 2002b) (Tümay 2016).

(Perkins 1999) defines troublesome knowledge as that which is difficult for learners to reconcile with their current understanding, often leading to high levels of cognitive disequilibrium and discard of the concept unless carefully managed in the learners.

Threshold concepts are a boundary to a new conceptual space, typically a concept that changes how a student views associated information (Meyer, Land 2005). Threshold concepts must be transformative, irreversible, and integrative to the student's understanding of related knowledge, but they must also be troublesome (Land et al. 2005). As students can struggle to fully accept or understand these concepts, there is said to be a degree of liminality, where understanding may oscillate between previously held understanding and the new transformative position of understanding (Talanquer 2015). Extensive research has been undertaken into identifying threshold concepts in Chemistry studies, many of which are likely to be considered by students within the laboratory environment. Lists of threshold concepts and troublesome knowledge are generally qualified as non-exhaustive.

- Claus et al. (2023) detail both mathematical and chemical misconceptions faced within an analytical chemistry environment, particularly of note for this research is the identification of statistical understanding guiding decision-making during experimentation.
- Moss et al. (2007) detail fourteen separate threshold concepts in chemistry identified by undergraduate science students on an interdisciplinary science programme, with additional threshold concepts in physics and biology and maths.

Misconceptions, troublesome knowledge, and threshold concepts can all be considered as a group of types of knowledge that are likely to cause cognitive dissonance or disequilibrium and therefore may often be barriers to learning. An example of this may be a student struggling to undertake and understand a volumetric acid/base titration if they have not understood the chemical concept of acid/base, which can be generated by the colloquial misuse of the word "acid".

It is possible that some of these misconceptions can persist throughout education as those identified at earlier levels often have a commonality with those at higher levels.

Mathematical understanding and preparedness

Mathematical ability is important for success within science (Scott 2012), including within the laboratory where students will often have to calculate weights, concentrations, yields and statistical measures.

There are elements of mathematical manipulation that have been identified as threshold concepts, such as algebraic manipulation (Moss et al. 2007) and statistical understanding (Claus et al. 2023) which may contribute to the perceived difficulty of mathematics, however a theme that is often discussed is under-preparedness of students. (Scott 2012) assessed the mathematical ability of students undertaking a secondary level chemistry course and identified a prevalence of poor mathematical understanding of mathematical operators, suggesting a degree of under-preparedness in these students for further study.

The concept of "number anxiety" was identified in the late 1950s and is often cited as a reason students may disengage from mathematical problems and is now more generally referred to as "maths anxiety" (Dowker et al. 2016). Maths anxiety is linked to performance in mathematical assessments, can impair a person's working memory and therefore impair successful learning, and can also have an impact on a person's well-being (Luttenberger et al. 2018). Maths anxiety is also a predictor of whether a person will proceed with a career with high levels of integrated mathematics (Chipman et al., 1992). Maths anxiety has been extensively researched as detailed by Dowker et al. (2016) with links to gender and age identified, however it is asserted that it is not yet fully understood, with further research being required to fully understand and therefore support individuals with this anxiety impacting on their performance.

Information processing within the teaching laboratory

Johnstone et al. (1994) attempted to apply the cognitive load model to the laboratory and found that it did not account for all complexities in the laboratory, and this section attempts to identify some additional challenges faced by students within the teaching laboratory.

Teaching laboratories are often very busy places with a great amount of equipment and information for students to absorb and process which can affect students' ability to learn by causing cognitive overload (Johnstone 1982; Johnstone 1984; Johnstone and Wham 1979). When operating in an environment with large amounts of information to process, working memory can become easily saturated causing an impediment to effective learning. Another challenge is that students are presented with information in a variety of formats, such as verbal instruction, written instructions, diagrams, and observations of demonstrations which can lead to a phenomenon known as the split-attention effect (Tarmizi & Sweller, 1988) which increases a participants' cognitive load. Students working in laboratories often confronted with large amounts of extraneous information, known as noise (A. H. Johnstone, 1997), with some examples being shown in figure 8.

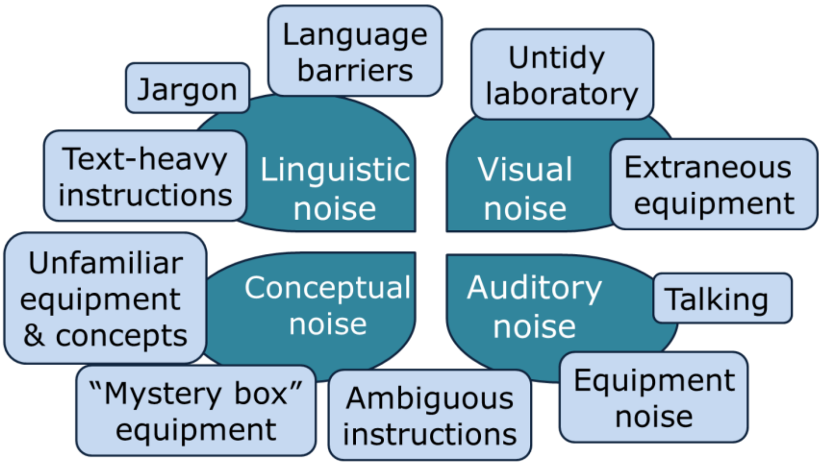

Figure 8 :Sources of "noise" within the laboratory, developed from Johnstone 1982..

In the teaching laboratory, a student may need to rapidly switch between tasks, completing both complex motor and cognitive tasks in short succession while coping with a wide variety of input from the environment. Hattie and Yates (2014) details the hidden tax of this task-switching, when discussing "multi-tasking" as a commonly held fallacy in teaching. Multi-tasking is identified as not detrimental to learning, however there is a cognitive "cost" associated with task-switching which contributes, as noise does, to cognitive overload. The cognitive cost of switching task is dependent on the individual, how familiar the task is and how frequently the task switches. Often people who identify themselves as effective multitaskers are poorly organised and used their memories inefficiently, resulting in a poorer performance in laboratory tests.

Sweller (1988) identifies problem solving as a particularly high cognitive load task, and it a common feature within Chemistry learning both in and out of the laboratory (Bodner & Domin, 2000), with the problem-solving laboratory being recognised as a specific subset of laboratory instruction style (Domin, 1999).

Additionally, Gunstone (1990) suggests that traditional laboratory work has a high degree of emphasis on manipulative skills, and this can become the sole student focus which is an impediment to learning as students are less likely to undertake the critical reflection required for effective learning (Domin, 2007).

Complex learning environments

Complex learning (van Merrienboer et al., 2003) (van Merriënboer & Sweller, 2005) is characterised by many learning objectives and goals for an activity, which is true of many teaching laboratory environments with wide ranging aims and objectives resulting from diverse instructional methods. Additionally teaching laboratories have a requirement for students to process large volumes of information, possibly for multiple sources, and therefore high inherent cognitive load (A. H. Johnstone, 1982), resulting in a highly complex learning environment. The teaching laboratory environment requires careful management and design to ensure effective learning (Seery et al., 2019).

Methods of researching within teaching laboratories

As the teaching laboratory is a complex environment, a wide variety of elements can be investigated to provide insight into students' experiences, learning and perceptions. These were reviewed during the development of the methodology for this project, and a selection of approaches to investigating the teaching laboratory are summarised below.

Observing what students do in the teaching laboratory

- Sedumedi (2017) used an observational scheme to observe physical activity and decision making in the teaching laboratory.

Direct assessment of learning or recall of theories taught in the teaching laboratory.

- Martindill and Wilson (2015) used an assessment and questionnaire to measure understanding of concepts taught in lab, factual recall and application of knowledge gained. Outcomes were compared with a control non-practical group who undertook “non-practical but engaging” activities.
- Sedumedi (2017) had students undertake pre- and post- event testing of understanding to measure conceptual gain.
- Byrne (1990) and Lewthwaite (2014)detail studies where students undertook cognitive assessment of content taught within a laboratory context, for example using concept inventory style tools, as initially developed by Hestenes et al. (1992).
- Modell et al. (2004) studied a physiology laboratory using a pre- and post-test prediction and rationale model, testing for understanding in their participants.

Student perceptions of the laboratory, using either qualitative, quantitative, or mixed methods.

- Moeed (2011) had students recall practical activities undertaken throughout the year to assess how memorable the activities were, and then were asked what they thought they had learned through the experiences.
- Abrahams and Millar (2008) propose a way of measuring the effectiveness of practical work, by comparing the student’s learning to the instructor’s intentions.
- Jalil (2006) had students reflect on the structure of a practical course in relation to their understanding, enjoyment, achievement, and difficulty, particularly relating to theory-first or laboratory-first delivery.
- Wilkinson and Ward (1997) undertook a comparative study between student and staff expectations of secondary school laboratory work, identifying a number of discrepancies between the two perceptions.

Assessment of student’s description of their affective domain experiences

- Galloway et al. (2016) interviewed students and coded their experiences for references to the affective domain and compared it to a cognitive test score.
- Environment inventories are survey scale tools that measure aspects student perceived experience of an environment (Fraser 2014), and they have been successfully deployed in educational environments.

Assessment of laboratory output including both formative and summative work

Formative work is that which is assessed for the purpose of feedback informing future work, whereas summative assessment often occurs at the end of a unit of assessment, and are intended to measure student learning, producing a grade or score (Dixson & Worrell, 2016).

- Pickering (1987) reviewed the laboratory books of students and categorised how were recording their observations and activities within the teaching laboratory and comparing the different recording styles to the time taken to complete an exercise within the teaching laboratory to investigate student approaches to the teaching laboratory.
- Logan et al. (2015) required students to produce a poster at the end of a laboratory course, and the posters were assessed both by the instructor and the student's peers.

2.3. Technology-Enhanced Learning

What is technology?

In technology-enhanced learning literature, often the term technology is poorly defined, with "technology", "media" and "digital technology" being used interchangeably. Additionally, Kirkwood & Price (2014) indicate that Technology Enhanced Learning is poorly defined and often used interchangeably for both the technology in place in a learning environment, and the learning that is taking place.

For the purposes of this study, the following definitions will be used:

- **Tools** are items that used manually to complete a task, typically designed to complete a specific manual task, examples would include a pencil, a screwdriver.
- **Technology** is any device used by a student to complete a task in a more efficient or effective manner than they could otherwise, this can include both digital and non-digital technologies, examples include digital and analogue telephones.
- **Digital technology** is a sub-group of technology and refers to computer-enabled technologies, whether connected to the internet or not, examples include laptops, smart phones, and software applications.
- **Analogue technology** is a sub-group of technology that includes technology that is not computer-enabled, for example a toaster.
- **Technology Enhanced Learning (TEL)** is any learning experience that makes use of digital technologies.

2.3.1 What is Technology-Enhanced Learning?

Technology-enhanced learning (TEL)is a pedagogical approach where digital technologies are employed to facilitate learning, it can also be referred to as digital learning or e-learning and can include many different digital technologies or approaches (Clay, 2020). Digital technology is an extremely broad term, incorporating a wide array of learning technologies, and each digital technology can be incorporated into different teaching approaches to facilitate various kinds of learning (Kirkwood & Price, 2014). A challenge of defining types of technology-enhanced learning is that the literature varies between describing the type of learning taking place, such as Computer supported collaborative learning (CSCL) and the platform or device that is being used to undertake the learning such as mobile learning, importantly it is possible to combine different varieties of technology enhanced learning in a single experience, for example a student could undertake mobile learning as part of a blended learning course. Commonly found types of digital technology enhanced learning are described in Table 4.

Table 4: Examples of technology enhanced learning terms.

Technology Enhanced Learning Type	**Description**	**Defining feature**
Computer supported collaborative learning	Collaborative learning that takes place predominantly or completely in a computer-accessed space such as a discussion board, where groups of students work collaboratively to collectively learning and develop. (Dillenbourg et al., 2009) (Ludvigsen & Arnseth, 2017)	Learning type (Collaboration)
Mass collaboration	A mass-learning model where large numbers of people engage through an online network to share information to reach a common goal. (Cress & Fischer, 2017) (Zamiri & Camarinha-Matos, 2018) Mass collaboration is applicable to large-participant learning experiences, even those that are not situated within a formal course, such as Wikipedia.	Learning type and scale (Collaboration, mass participation)
Mobile learning	Learning using portable handheld devices such as mobile phones or tablets. This type of device can be carried to different environments, allowing for a changing learner experience as their personal context changes. (W.-H. Wu et al., 2012)	Platform type (mobile devices)
Virtual learning	Learning that is delivered, undertaken or received through a virtual environment, which can be a simulation, virtual learning environment (VLE) or another method. (Keller, 2005) (Thi Hue Dung, 2020)	Delivery type (online)
Blended learning	A model of delivery where material is delivered both in the physical world in-person, and also in online spaces. (W. W. Porter et al., 2014)	Delivery type (blended)

Digital technology can be applied at various levels which has resulted in different models of digital learning. Each model considers digital technology from a slightly different perspective or viewpoint and can be used in combination with one another to most effectively review or design a learning experience, as some consider user experience, some consider the production of content, and some consider the pedagogy of the social experience of learning. Commonly cited examples are discussed in this section but are not intended to be an exhaustive list.

Technology Enhanced Learning Frameworks

Bloom's Taxonomy has been expanded to include digital skills examples for each of the different levels. (Sneed, 2016) lists a variety of possible technologies that can be used to achieve the thinking skills identified within the taxonomy, for example blogging and podcasting are identified as examples of creating. Importantly, the taxonomy focusses on the thinking skills being developed and the tasks being undertaken to complete the task, rather than the individual technologies that are implemented.

The TPACK (Technological, Pedagogical and Content Knowledge) model focusses on the knowledge a teacher requires to teach in a technologically enhanced teaching environment and emphasises that teachers must develop their own understanding and pedagogy to take advantage of technology (Koehler et al., 2013). Teachers are required to develop the following:

- **Content knowledge** – understanding of the subject matter relating to the content being taught.
- **Pedagogical knowledge** – understanding the methods of teaching.
- **Technology knowledge** – understanding of the technology to be used. This is challenging as technology is developing at a rapid rate.
- **Pedagogical content knowledge** - understanding of the ways in which to effectively teach the content knowledge.
- **Technological content knowledge** – understanding of how the subject matter and technology are inter-linked.
- **Technological pedagogical knowledge** – understanding of how to effectively teach when using digital technologies, and the impacts of those technologies on the learning experience.

TPACK (Technological, pedagogical content knowledge) is the culmination of the above and is indicated to be more than all the elements combined, in that additional information can be key to consolidating the different parts to form the whole.

Salmon's 5-stage model is designed for community based online learning, aiming to develop a collaborative mutually supportive group of learners exploring knowledge in an online space (Salmon, 2013). This is focussed on the teacher-student relationship and student independence in an online space.

- **Access and motivation** – engages learners in the online learning environment or community to enhance participation and engagement. This is effectively an introduction phase but can be present throughout a course to continually prompt learners to re-engage.
- **Online socialisation** – allows learners to define their online identities within the course and identify others within the course to support one another.

- **Information exchange** – prompts learners to exchange information, contributing to the learning environment.
- **Knowledge construction** – characterised by collaborative learning between participants facilitated by instructors or teachers.
- **Development** – learners develop independence in the online learning environment and can use it effectively to support their learning.

The RAT (Replacement Amplification Transformation) model (Hughes et al., 2006) identifies the change to the learning experience that introduction of technology can have. This is seen as a hierarchy, with opportunities to transform learning being seen as desirable and simple replacement described as a missed opportunity for development (H. L. Anderson et al., 2022).

- **Replacement** – the technology-enabled solution is functionally identical to that of the non-technology enabled solution, for example text in a book, or text on a web page.
- **Amplification** - the technology-enabled solution amplifies the traditional learning experience by improving efficiency or impact, for example inclusion of additional media or functionality.
- **Transformation** – the technology-enabled solution completely transforms the learning experience and allows a new form of learning that was not previously feasible, for example collaborative learning tools facilitating group learning for a distance-learning cohort of students.

The SAMR (Substitution, Augmentation, Modification, Redefinition) model focusses on defining the purpose of the integration of technology within an educational context (A. C. Thomas & Thomson, 2022).

- **Substitution** – to directly replace an element of a learning experience with a digital technology solution and no functional change.
- **Augmentation** – to improve upon the learning experience with the addition of digital technology, however the task outcomes remain consistent.
- **Modification** – to redesign a task to encompass the use of digital technology, changing the learning experience with altered capacity to aid learning.
- **Redefinition** – to employ digital technology to redesign a task, changing the learning objectives by allowing tasks that were previously inconceivable.

The ADDIE (Analyse, Design, Develop, Implement and Evaluate) approach is a model that integrates digital technology into course design (Kurt, 2018). It is important to realise that the points listed below are not intended to be followed in a linear fashion, and that the ADDIE approach can be used to redevelop existing courses as well as design new courses.

- **Analyse** – identifies the outcomes of the learning experience and the learner's prior knowledge, as well as the learning environment.
- **Design** – the development of course plans, material and digital content for use by the learners.
- **Develop** – the digital object is constructed by a development team.
- **Implement** – the delivery method is refined, and facilitators are trained.

- **Evaluate** – the ADDIE process is a reflective one, requiring formative evaluation in each stage of the process, but advocates summative evaluation of a developed course.

Design thinking is a model for solving problems and has been used in a variety of contexts including education (Dorst, 2011). The principle of design thinking is to develop user-centred solutions to overcome problems, and is a cyclical process requiring prototyping, testing and re-design (Dell'Era et al., 2020). Design thinking is less well defined than other frameworks considered, as it is implemented in a wide variety of ways (Kimbell, 2011).

2.3.2 Strengths of Technology-enhanced learning

The benefits of TEL are wide-ranging, so for ease of consideration, this section is grouped by the primary beneficiary - the student, the institution, or society. Several studies in this section are detailed within Jisc's Tangible Benefits project report (jisc infoNet, 2008).

Student benefits

Attainment – An e-assessment intervention applied at the University of Glamorgan was designed to monitor student development and identify students that were struggling, but the students were able to use this as a way of monitoring their own learning too, encouraging them to continually study throughout the year, and resulting in an increase in pass rates and attainment for associated content (Jisc infoNet, 2008).

Digital Skills – digital skills are often listed amongst the desirable skills of graduate students, particularly those relating to communication and information management (Cortez et al., 2020). Information technology skills are identified as a transferable key skill that should be developed by both Bachelors and Masters studies within the RSC accreditation documentation (Royal Society of Chemistry, 2022).

Community – Online spaces can be accessible to students studying remotely and facilitate the sense of community. The University of Wolverhampton used an e-portfolio system with Nursing and Midwifery courses, and one of the benefits identified in student testimony was the ability to remain in contact with their cohort during the placement sections of their course (Jisc infoNet, 2008).

Continuing Professional Development – TEL is being used extensively in continuing professional development, particularly through the increasing uptake of the e-portfolio to demonstrate continuing learning (Jisc infoNet, 2008).

Flexibility – Technology-enhanced learning is identified as a way of supporting flexible pedagogies that are designed to promote choice for learners. Flexibility in course design is identified as beneficial for students, as it allows choice of assessment methods learning preferences and pacing of learning (Gordon, 2014).

Institutional benefits

Cost and efficiency - Introducing TEL can allow institutions to increase the number of students they are capable of teaching or reduce the costs of teaching (Jisc infoNet, 2008), although TEL can have an initial outlay cost, this can be an effective way of managing resources in a financially constrained environment.

Retention – use of technology can facilitate the retention of students who may otherwise leave education, by facilitating the identification of these students and subsequent intervention. A study at the University of Exeter found that international students regarded online materials as user-friendly, which was linked to an improvement in retention and achievement (Jisc infoNet, 2008). An e-assessment intervention at Leeds Metropolitan university was used to identify students who were struggling with numeracy or digital skills, allowing for support from the academic team to prevent student disengagement (Jisc infoNet, 2008).

Societal benefits

Accessibility – Students with disabilities can have their access needs met through TEL, for example the straightforward application of screen-readers, contrast filters and zoom functions. TEL can also allow access to sites that would otherwise be inaccessible can help remove access barriers for those with mobility related disabilities, as is shown by the archaeological podcasts used by Swansea University (Jisc infoNet, 2008).

Widening Participation and Equality - Remote or distance learning can allow students who are unable to attend in person studies due to workload or disability to undertake courses, even allowing students to attend courses internationally (Jisc infoNet, 2008) (Gordon, 2014).

2.3.3 Challenges of Technology-enhanced learning

As with all teaching models, technology-enhanced learning has its own specific challenges and while the availability of technology is often a catalyst for change, development of courses and adoption of technology can present difficulties (Laurillard, 2008). This section aims to explore the most commonly reported challenges.

Cognitive load and technology-enhanced learning.

Sweller (2020) considers "educational technology" or technology-enhanced learning within the model of cognitive load, indicating that the presence of technology can have both positive and negative impacts on the cognitive load of instruction in technology-enhanced learning, which is consistent with the conclusions of Skulmowski and Xu (2022). Sweller (2020) does identify some instructional effects present in cognitive load theory that are important to consider when designing technology-enhanced learning,

- **Split-attention affect** (Tarmizi & Sweller, 1988) – having multiple sources of information such as sound, text and observation can negatively impact on a student's capacity to learn.
- **Working memory depletion** (Sweller, 2011) – the addition of technology can contribute to the cognitive load of undertaking a task, resulting in cognitive overload and negatively impacting on a student's ability to learn.
- **Worked examples** – worked examples are a solution that will reduce the additional cognitive load of problem solving, by splitting information into smaller more manageable amounts.
- **Modality** – if information is presented in multiple formats, it can increase the cognitive load of a task, e.g., pictures and text that are required to be processed concurrently. This can also be termed "dual channels" (Mayer & Moreno, 2010)
- **Transience** – if information is presented in a transient manner, and not permanent, then this can increase the cognitive load of a task, as students are required to remember information.

- **Redundancy** – if information is repeated in instructions, it can increase the cognitive load of a task.
- **Expertise reversal and element interactivity** – experts require less guidance or steps when undertaking a task and may require a more interactive form of instruction. This exists in balance with redundancy, as information may need repeating for a novice, but becomes redundant for an expert.

As is true for traditional learning, careful design can mitigate instructional effects within technology enhanced learning (Mayer & Moreno, 2010).

Student and staff familiarity with digital technologies

A variety of aspects can affect a participant's familiarity with and adoption of digital technology solutions, these are discussed below.

Adoption and barriers to use.

Gartner's hype cycle is a model for understanding how rapidly a technology is adopted in relation to its release date, the cycle has 5 stages detailed below (Blosch & Fenn, 2018). A product in the descriptions specifically relates to digital technologies, although is not limited to the higher education environment.

Innovation Trigger – The release and subsequent discussion in media causes a significant uptake in usage immediately upon release amongst "early adopters" of a product.

Peak of Inflated Expectation – Popularity of the product spreads and the expectation of the performance of the product increases.

Trough of Disillusionment – Users become impatient with development timelines, unfulfilled potential of products and use them less, sometimes leading to negative attitudes towards the product.

Slope of Enlightenment – Challenges in the user experience are resolved by persistent users and developers, leading to effective use of the product and benefits of the product are identified. When shared by users, this can lead to a gradual increase in positive attitudes towards the product.

Plateau of Productivity – Once benefits of the product are identified, the riskiness of adoption is mitigated and institutional adoption becomes more common, with the product potentially becoming ubiquitous in the environment.

However, Prinsloo and Van Deventer (2017) suggest that the early adoption of digital technology in educational environments is unusual, suggesting that universities are more likely to adopt a digital technology once it is more widely accepted within the education sector.

Abrahams (2010) proposes adoption and diffusion theory as a method of understanding the adoption of digital technologies in higher education, identifying that the uptake of digital technologies was multi-dimensional, with a wide variety of factors being identified.

Barriers to early adoption by faculty of digital technologies identified by Abrahams (2010) include:

- Faculty understanding and confidence in the digital technology and availability of instruction and support.

- Faculty concerns relating to the quality of technology-enhanced learning in comparison to traditional methods.
- Perceived institutional issues relating to cost, support and time requirement of adoption.
- Resistance to change.
- Some faculty members possessing a negative attitude to digital technology as a whole, or a preference for human interaction.
- Concern about challenges of digital technology use amongst those who are less confident with using digital technologies.

Abrahams suggests that the complexity of the issues relating to adoption is an important field of research to increase the adoption of digital technologies in higher education, and that the adoption diffusion framework provided would be an effective tool for identifying institution-specific challenges and the degree to which each issue is affecting each situation.

One significant institutional barrier to the uptake of digital technologies in teaching environments is the initial investment of time and money (Flavin, 2016), which is suggested as a possible reason for limiting use to transmission of information rather than transformative teaching.

2.3.4 TEL in Chemistry Education

Wu et al., (2021) undertook a literature review detailing the spread of types of TEL used in Chemistry over almost a decade. A wide variety of technology enhanced learning experiences were identified, including variation in the devices used to access the learning experience, differences in the “learning tools” or types of digital technologies being applied to the learning experiences, and an increased proportion of time spent using a digital technology device per session as the years progressed. It was of note that, despite an increase in the use of distance and self-service learning more generally in higher education in this period, the studies identified in this review were predominantly in fixed locations such as classrooms or laboratories, and that digital technologies were still predominantly used to access materials rather than learn online, which would register on the lower levels of transformation in the TEL frameworks identified earlier in this chapter. For example, using the RAT framework, examples identified by (S.-H. Wu et al., 2021) would be classified as replacement or augmentation rather than truly transformative teaching.

2.4 Project aims

The aims of this project are as follows:

1. To investigate the teaching laboratory as a learning environment including intended purpose, student and staff priorities for the teaching laboratory, and student perception of learning in the laboratory.
2. What is the current pre- and post- laboratory practice within the institution and sector?
3. What are the digital experiences of our students, and how does this impact on the student's perceptions of the technology enhanced teaching laboratory?
4. What are student and staff attitudes to the teaching laboratory more generally, and more specifically the technology enhanced teaching laboratory?
5. How does the presence of technology in the teaching laboratory affect student's actions and attitudes within the technology enhanced teaching laboratory?

2.5 Theoretical Approach

There are many approaches that have been used in research in education, the five most prevalent are:

- Cognitivism
- Behaviourism
- Constructivism
- Connectivism

In addition to these, other research frameworks have been proposed and applied within research, however they are less prevalent within the area of educational research (Roux et al. 2021).

Cognitivism focusses on the way the brain processes information, rather than on the behaviour of the participants actions or intent (Smidt 2011). Stoliescu (2016) describes the development of cognitivism over time from a strict logical framework representing the organisation and recall of information, where meaning or knowledge was a fixed entity that was consistent between participants, to the Connectionists who had more flexible view of cognition, with more complex cognitive processes such as analogy being held as important, and communication of information being viewed as essential to learning . Cognitive research in education can encompass experiments such as pre- and post-tests to measure learning gain or neuropsychological tasks. These cognitive tests may be undertaken in combination with neuroimaging (Stoliescu 2016). The aim of cognitivist research is to develop models that assist in understanding how the brain processes, retains and recalls information, with neuro-cognitive testing still used within medical settings (Mjaanes and Nerrie 2025).

Behaviourism, which differs from cognivitism by observing the behaviours of participants rather than considering their mental processes, was originated by Watson in the late 1800s, and further developed by Skinner in the early 1900s (Zhou and Brown 2017). Behaviourism states that learning is identified by developing new behaviours through conditioning in response to interactions with their environment, either classical or operant conditioning (Pritchard 2017). Classical conditioning is a behaviour training method that reinforces a stimulus-driven natural response, while operant conditioning is founded in reinforcing desired behaviour through reward or discouraging undesired behaviours through punishment or consequence (Pritchard 2017). Some critics of behaviourist approaches to learning suggest that it over-simplifies the complex learning process by disregarding elements such as emotion and thoughts (Brau et al. 2022).

Constructivism, also known as sociocultural theory (McGill 2023), has its origins in the Piagetan social constructivist theory of learning, and was further developed by Bruner, Vygotsky and Ausubel (Novak 1993). Constructivism holds that knowledge is constructed by an individual in relation to the context of their environment and experiences, combining the consideration of mental processes present in Cognitivism with the environmental impact of Behaviourism (McGill 2023). More specifically, within a research context, a constructivist approach would require a researcher to not aim for a "single scientific objective truth", and instead accept a participant's reality, and that there can be many varied individual perceptions of an experience that are all valid (Ferguson 2007), even if differing participants' realities conflict. Constructivist research has the fundamental principle that each person constructs their own understanding of reality, and therefore qualitative and inductive research methods tend to be used to facilitate participants constructing their own narrative of their experience (Shannon-Baker 2023).

While constructivism and cognitivism may seem in opposition to one another, a third approach combining cognitive changes during learning with the context of the learning environment has been proposed by Otero as described by Wood et al. (2014). This framework describes the learning process as the construction of individual understanding within the social context of a shared learning environment as described by sociocultural learning theory and allows the models of cognitive science to be used to represent conceptual learning while also appreciating the social and cultural impacts on the learning environment.

Connectivism is a more recent approach to education, developed with technology enhanced learning in mind, more specifically e-learning environments (Goldie 2016). Goldie (2016) describes how the implementation of technology in relation to learning creates a challenging environment for more traditional approaches to research on learning, as learning is no longer prompted by interactions between a learner and an instructor, facilitator or environment – instead a learner can explore a network of information in a self-directed manner. Siemens (2005) developed Connectivism in the mid-2000's and detailed several founding principles, fundamentally that learning is a process of making connections between ideas, and that the ability to make these connections autonomously is more crucial to the learning process than the actual knowledge held. As the Superlab environment is not a strictly e-learning environment, employing connectivism in this research would not be appropriate at this stage, as there is no formal e-learning network connecting learners together. However, this approach could be an interesting way of reviewing student development in technology enhanced learning environments in the future, particularly if a course undertook a Massively open online course (MOOC) style approach to instruction combined with in-person teaching laboratory sessions.

As this project focusses on student experiences and staff operation within the Superlab environment, a primarily constructivist approach will be used to allow for the presentation of varied interpretations of the environment and experiences of participants within the Superlab. However cognitive science models will be referenced as illustrative models to help understand learning processes where appropriate.

The following research frameworks were considered prior to commencement of this project:

Grounded Theory (White and Cooper 2022) is qualitative, data-driven systematic methodology. Importantly in grounded theory, research must not begin with a hypothesis, and instead the theory must be driven by the data, with the researcher identifying patterns or themes within the data.

Phenomenology research focusses on participants' understanding of a phenomenon, identifying themes and through iterative review, aiming to construct a "single common meaning" from several participants' experiences (Casey 2007).

Phenomenography research has similarities to phenomenology, in that it focusses on participant's perspectives, however whereas phenomenology aims to construct meaning, phenomenography aims to document a participant's perception or interaction with a phenomenon (Bowden and Walsh 2000). Phenomenography allows for differences in experience and embraces the variety in responses in an aim to exhaust the possible ways of experiencing a phenomenon (Orgill 2007).

Table 5: Strengths and weaknesses of research frameworks commonly used in discipline based educational research.

Framework	Strengths	Weaknesses
Grounded Theory	Prevents preconceptions about participants or environments to from impacting on the research. Allows exploration of poorly understood phenomena that do not have extensive research foundations.	Requires the research to be disconnected from existing research and prior preconceptions, making undertaking research as a practitioner challenging when the subjects are one's own students.
Phenomenology	Provides deep insight and understanding of phenomena, particularly lived experiences. Centred around participant experiences and encourages self-reflection.	Does not encourage representation of variation in experiences. High-detail accounts from a small number of individuals may be difficult to generalise to wider populations. Time consuming, as data collection should be to be exhaustive per participant.
Phenomenography	Encourages variation in experiences between participants. Centred around participant experiences and encourages self-reflection. Allows categorisation of experiences to assist practitioners in deploying research in practice.	Requires larger sample sizes, as aims to test until no more concepts arise. Generalising findings into groups or themes can cause loss of detail in interpretations. Time consuming due to the iterative nature of exhaustive data collection from varied participants.

3. Quantitative Research

To explore the student experiences of both digital technologies, and the Superlab environment on a large scale, quantitative research methods were employed. The intent was to collect data in a longitudinal manner, to allow consideration of student experiences over time, and identify any trends in student attitudes or familiarity with technology.

3.1 Measuring Digital Experiences

To understand student's usage of technology within the Superlab, it is necessary to first investigate students' technology usage more broadly. Digital literacy encompasses a student's ability to apply a digital skill to a new environment, and familiarity with similar technology external to the teaching laboratory could facilitate student's operation within the Superlab.

In this section, participants can refer to anyone in an educational context including both staff and students, as both are participants interacting with digital technology in the learning environment, and as such have digital experiences.

3.1.1 Measuring participants' digital experiences.

The field of measuring digital experiences of participants is a rapidly changing one, in part because digital technology is so rapidly evolving, that the expectancy of familiarity and competency changes to keep pace. As such, there is a lack of consistency in the terminology of the field of assessing digital experiences of participants, with digital literacy, ICT literacy, digital skills and digital competence all being used almost interchangeably (Ilomäki et al., 2011) without strict definitions or criteria for each term being widely accepted (Nguyen & Habók, 2023a). Institutions tend to develop their own rubrics for measuring digital experiences, and often this is a time-sensitive framework, with references to specific skillsets or technologies becoming outdated quickly (Tinmaz et al., 2023). Hakkarainen (2009) suggests that the challenge of measuring digital experiences and skills may be linked to difficulty in defining the "object" to be researched due to the complex social and cultural elements of digital technology usage and proposes that thorough measurement of technology-enhanced learning may require complex mixed-methods research from multiple viewpoints, analysing a wide variety of data sources.

Models of digital experience

Understanding the prior experiences of participants allows for appropriate scaffolding for development of digital experiences, and models developed to allow the investigation of digital experiences of participants are discussed below. For a variety of reasons digital experiences of participants can differ greatly within a single cohort even of apparently similar participants, these barriers to digital experience development are explored later in this chapter.

Digital usage

Byungura et al. (2018) developed a framework by which first year Higher Education students in Rwanda were surveyed to allow their familiarity with digital technologies to be quantified, this identified some shortcomings in the student's digital familiarity and allowed the researchers to suggest support methods to overcome the gap in digital familiarity. Fütterer et al. (2023) investigated the impacts of familiarity on distance learning experiences during the COVID-19 pandemic, identifying two groups of students – those familiar with digital technology and those less familiar with digital technology. Measuring frequency of use or access to digital technologies does not however measure how participants are using the digital technologies, and the level of skill or sophistication the participants are using the products with (Kvavik, 2005).

Digital competence

Digital competence is a term used to describe a participant's ability to use digital resources and their own skills to meet complex demands. Ferrari proposes the following definition:

> "*Digital Competence is the set of knowledge, skills, attitudes (thus including abilities, strategies, values and awareness) that are required when using ICT and digital media to perform tasks; solve problems; communicate; manage information; collaborate; create and share content; and build knowledge effectively, efficiently, appropriately, critically, creatively, autonomously, flexibly, ethically, reflectively for work, leisure, participation, learning, socialising, consuming, and empowerment."* (Ferrari, 2012)

Digital competence can also be referred to as "digital skills" (Ilomäki et al., 2011). A challenge facing the measurement of digital competencies is that the competencies required of a participant can vary depending on context (Pettersson, 2018), and educational contexts are variable. Frameworks are available (Redecker, 2017), but are often broad, allowing for contextual determination of the individual digital skills required to determine a participant to be "digitally competent" (Ferrari, 2012). (Covello, 2010) emphasises that it is important to measure a participant's digital competence directly, preferably through an assessed task. However, it is also possible to research participants' perceptions of their own digital competence (Tomczyk, 2021) (Kryukova et al., 2022) (de Obesso et al., 2023). Indirect measurement does afford logistical advantages, however self-reporting can lead to reporting bias where participants can over-report confidence in socially perceived desirable characteristics (Delgado-Rodriguez, 2004a).

Digital literacy

Bawden (2008) details the complex history and origins of the term "Digital literacy", indicating that it is a phrase that has been used extensively since the 1990s, but with a lack of clear definition, resulting in extensive studies to explore possible definitions. As such, a wide variety of digital literacy frameworks have been developed and are used in differing contexts (Iordache et al. 2017). Martin and Grudziecki (2006) developed a framework to define digital literacy in a way that is not tied to individual technologies, making it robust in the face of digital technology development (Fig 9). This framework focuses on ideas or processes rather than digital technologies, emphasising the links to information literacy and critical reflection within digital technology use (Tinmaz et al., 2023).

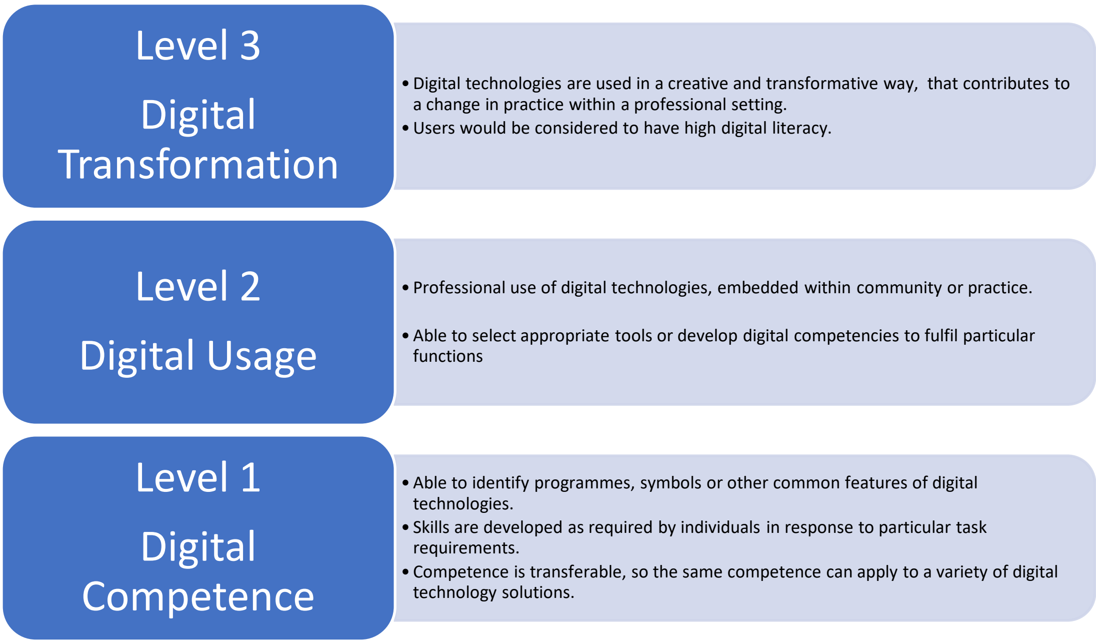

Figure 9: Levels of digital literacy, adapted from Martin & Grudziecki (2006).

Martin and Grudziecki (2006) identified three levels within digital literacy (fig 9). Digital competence is the capacity to use the technology effectively, including the encompassing skills and attitudes required to complete tasks and meet demands, which is consistent with digital competence as described by Ilomäki et al. (2011). Digital usage is used to describe where digital technology becomes embedded within practice, rather than supplemental to the task, and technology is accepted as part of the culture of the practice. Digital transformation is the highest level within digital literacy, where a participant is using digital technologies creatively. Digital transformation is characterised by the impact it has on either a participant or organisation. Digital transformation is not a requirement for a participant to be considered digitally literate, and a participant may engage with digital technologies at different levels depending on the digital technology and the task at hand. The DigEULit model represents how a participant uses technology to interact with technology within society, and has some commonality with the 3P model of learning (Fig 10), using a three step model with a social context, task and tangible outcome of the development process.

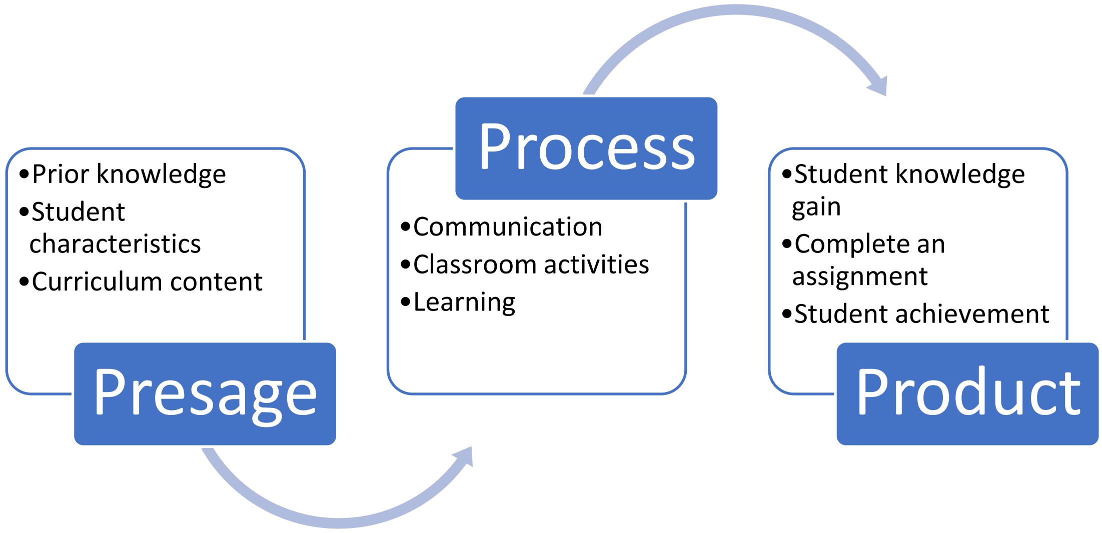

Figure 10: 3P model of learning, developed from Biggs & Moore (1993).

In the EUDigLit model, a task or problem arises out of a user's life context. The user identifies the competencies that they require to undertake the task and the resources they will need. The user then can acquire any digital competencies they require, and make use of those competencies to develop a new digital artefact.

Presage

- Any task or problem is embedded within the life context of the person facing it.
- The task is analogous to the curriculum content in the 3P model. It represents the external prompt of the user to develop understanding, knowledge, or skills.
- The existing digital usage skills of the person would be analogous to the prior knowledge of the user, and will be impacted upon by their own characteristics, such as prior access to technology and any access needs.

Process

- The EUDigLit model identifies a problem-solving phase, where a user needs to identify appropriate resources to tackle their problem.
- Any new digital competencies would be identified and obtained in this phase.
- Resources must be accessed and managed in an appropriate manner.
- Resources are evaluated, interpreted and analysed by the user to create new knowledge.
- Resources are combined using digital tools to produce a digital artefact that disseminates new knowledge, media output or re-presented information.

Product

- The outcome or solution to the problem/task is analogous to the Product of the 3P model.
- The solution is implemented in the user's life context, and prompts development in their community of practice, for example through sharing of best practice.

It is important to note that digital literacy exists in parallel with other types of literacy, such as information and media literacy, and often the different literacies will interact with one another, or overlap in terms of definition (Koltay, 2011). Although the DigEULit framework is widely cited, it has not represented an end to the research on digital literacy, with subsequent projects being undertaken (McLoughlin 2011; Belshaw 2012; Gruszczynska et al. 2013; Neumann et al. 2017)

To measure digital literacy, it is suggested that participants are assessed against a defined set of skills, and as digital literacy includes elements of digital competence, that a practical test should be included in assessments of digital literacy (Covello, 2010). Covello (2010) reviewed the strengths and weaknesses of three digital literacy measurement tools and emphasises the importance of logistical impacts as well as social and cultural context in choosing an assessment method.

Elements affecting participants' digital experiences "digital divides"

Age - Digital natives and the digital divide

The "digital native" theory as developed by Prensky (Prensky, 2001a) (Prensky, 2001b) suggests that there is an observable difference in the approach to digital technologies taken by younger participants and older participants. Younger participants who have grown up in a society where digital technologies were ubiquitous are termed digital natives, while older participants who developed in a society without the presence of digital technologies are termed "digital immigrants", or "physical natives" (Ball et al., 2019). Younger participants are often assumed to be more capable with digital technologies (Margaryan et al., 2011). The difference in approach and use of to digital technologies is referred to as the a "digital divide" (Ball et al., 2019b) (Warschauer, 2003), although this term has been applied to other disparities in access to digital technologies. The terms "Digital native" and "digital immigrant" are falling out of popularity, even being referred to as a myth (Selwyn, 2009) (Margaryan et al., 2011), perhaps because it is viewed in terms of age, rather than access to and experience of digital technologies.

Helsper and Eynon (2010) suggest that considering the digital natives vs digital immigrants problem exclusively as a function of age is over-simplified, and that generational differences, and both amount and breadth of experiences with technology all contribute to a participant's "digital native-ness", and that even older participants who were raised in the "physical native era" could be considered to be digitally native. To counterpoint this, young participants who could be considered to be of an appropriate age to be digitally native, and therefore would be anticipated to be highly digitally literate were actually found to be using digital technologies in unsurprising and simple manners (Selwyn, 2009). Brown and Czerniewicz (2010) criticize the use of digital natives as a term to consider the digital experiences of participants, as it over-generalises the manner in which participants interact with digital technologies as a homogenous phenomenon, when there is much more variation in reality, and although some participants in the study would be characterised as digitally literate digital natives, many others of a similar age group would not fulfil the characteristics of a digital native, primarily due to access to technology, additionally a group of older students were identified as "digital natives" regardless of age. Research on university students undertaken by Margaryan et al. (2011) identified that students who were of the appropriate age to be within the "digital native" generation were indeed not fluent in using digital technologies, and that how a student uses technology is more reflective of digital competence or literacy rather than frequency of use.

Access to technology

The “digital divide” has also been used as a term to represent the divide in access to digital technology caused by other elements, such as or economic, cultural or geographic divides (Cullen, 2001).

Economic factors - Lindblom and Räsänen (2017) undertook research in Finland and identified a disparity in the availability of access to digital technology linked to class or status and concluded that those who have more frequent access to digital technologies are likely to be those who frequently usage, indicating that frequent use may be a measure of affluence, rather than digital competence.

Cultural impacts - Cullen (2001) describes the divide within the context of New Zealand, and identified that physical access was a barrier, but so too was a lack of support and attitudinal barriers stemming from cultural or societal beliefs.

Gender - Singh (2017) discusses the “gender digital divide”, identifying that structural inequality, cultural ideas, and lack of access to resources as a barrier for females to engage with digital technologies. Gender differences in engagement with technology have also been identified in America (Warschauer, 2007) , the UK and China (N. Li & Kirkup, 2007)and is identified as a global issue (Galyani Moghaddam, 2010).

Disability - Goggin (2017) suggests the concept of digital inequalities, which can encompass differences in how digital technologies are used by disabled people, and the societal influence on how disabled people engage with digital technologies and technology enhanced environments in comparison with those without disabilities. Although, as discussed in the benefits of technology-enhanced learning, digital technologies often have the capacity for accessible features that are not otherwise available in traditional formats, this is not always the case for disabled users of digital technologies. Dobransky and Hargittai (2016) investigated internet usage of Americans with disabilities and found that disability does have an impact on internet usage, both in relation to internet use, and the types of activities undertaken online. Accessibility audit tools have been developed to overcome some of these challenges, however barriers do remain (Cain & Fanshawe, 2021). It is also possible that participants may have intersecting elements impacting on their capacity to engage with digital technologies, such as disabled people from deprived neighbourhoods who were found to not benefit from the presence of technology in an attempt to lessen the disabled digital divide (Macdonald & Clayton, 2013).

Teachers’ digital experiences - The TPACK framework indicates that to be effective teachers in a technology-enhanced teaching environment, teachers must have appropriate levels of digital technology-related knowledge in the various domains (Koehler et al., 2013). This is supported by the DigCompEdu framework for the development of digital skills in educators (Redecker, 2017), which indicates that educators require digital competencies in order to engage effectively in technology-enhanced learning environments. Extensive research has been undertaken into measuring teacher’s digital skills (Claro et al., 2018), (Rubach & Lazarides, 2021), (Saikkonen & Kaarakainen, 2021). While some studies have identified short-falls in (Fernández-Cruz & Fernández-Díaz, 2016)d(Fernández-Cruz & Fernández-Díaz, 2016), more recent studies undertaken after the COVID-19 pandemic have identified a high degree of digital usage and competencies both in Greece (Perifanou et al., 2021) and Russia (Serezhkina, 2021). Myyry et al. (2022) suggests that the COVID-19 pandemic may have been an accelerating factor in the development of digital competence in teachers in Finland.

3.1.2 Measuring digital experiences of Chemistry students

Measuring the digital literacy of participants was deemed to be time consuming, and at the time of data collection, a tool was not readily available that would work within the research setting. Requirements for the tool were that it would be affordable and available for use and that it could be easily applied remotely to a large range of participants. Despite extensive searching, it was not possible to find a tool that met the requirements of the researchers to measure digital literacy, so the project refocussed on the elements of digital literacy that could be measured – digital competence and digital usage. Since this research project commenced and data was collected between 2014 and 2018, a variety of tools and frameworks have been made available to measure digital literacy of participants, however they are still lacking consistency of definitions or approach (Nguyen & Habók, 2023b).

Jisc (2013a) developed a tool that was intended to assist educators in understanding their students' access to technology, known as the "Learner profile" tool. The "Learner profile" tool was part of the "Learner experience of e-learning" project that was subsequently developed into the "Developing Digital Literacies" project which explored students' digital experiences, encompassing case studies and guidance for institutions on implementing digital technologies with students and staff (Jisc, 2013b) and formed the basis for the NUS benchmarking tool, published in 2016 (Jisc, 2016).

The "Learner profile" tool was adapted to form a tool to assess students' access to digital technology, with sections added to investigate self-assessed competence and confidence in undertaking tasks that were identified as common within the teaching laboratory. This tool was titled the "Digital History Survey". The learner profile focussed primarily on what digital technologies the students had access to and their experiences of digital technology both a learning and personal context. Additions were made to form the Digital History Survey covering:

- references to digital technologies were modernised as required, as technologies became available.
- participants were assigned a "participant identifying number" through the invite or data entry process which allowed their responses throughout the project to be tracked longitudinally if they responded to more than one survey point or tool.
- self-reported formal qualifications related to digital technologies, such as ECDL (European Computer Driving License), GCSE Information Technology or Information Technology Key Skills qualifications.
- familiarity with operating systems on mobile devices to compare with the operating systems present within the Superlab,
- a frequency scale question detailing common laboratory-specific digital technology tasks such as using spreadsheet functions, word processing and cloud storage,
- a self-assessment of competence question set relating to common laboratory-specific digital technology tasks such as word processing, inserting pictures into documents and using formulae in a spreadsheet.

As familiarity with tools, material or an environment can have an impact on cognitive load (Du et al., 2022), measuring student's familiarity with technology is a useful indicator of their likely cognitive load as a result of the technology in the teaching laboratory.

The purpose for implementing this tool was developed to avoid assumptions of digital literacy or competence being assigned to young participants and prevent furthering the “digital natives” concept.

The survey was made available to students in the first term of their studies, and wherever possible the tool was advertised to students in-session to increase uptake. In 2014/15, all students undertaking courses were invited to undertake the survey on paper. In subsequent years, students were surveyed using the SurveyMonkey online platform with invites by email, and new year 1 and graduating students were selected as participants to allow investigation of student digital experiences at the start and end of the degree program, while managing the volume of data collected. Response data is available in table 6.

In 2014/15 students from all years were permitted to respond to the survey tool, however in subsequent years, to target advertising efforts and manage the workload of processing data a more directed approach was taken. From 2015 to 2018 only new year 1 students and students in their final year of studies were able to respond to the survey. These students were chosen to allow review of changes in new cohorts and also review of development of skills by the end of a student’s the course.

Table 6: Response data for the Digital History Survey.

Subject Area	Student group	2014-15	2015-16	2016-17	2017-18
Chemistry	New	106	51	52	38
	Graduating	49*	26	16	16
Forensic Science	New	27	5	8	6
	Graduating	61*	3	0	1
*2014/15 – Returning students rather than graduating final year students were permitted to respond, so data is not directly comparable.					

3.1.3 Ethical Approval

All tools and amendments within this research underwent review and approval by Nottingham Trent’s School of Science and Technology Non-Invasive Ethical Review Panel.

3.1.4 Results of digital history survey

This project was undertaken in combination with a co-researcher, as such data for several subject areas were collected simultaneously. Data presented in this section relates solely to students on Chemistry or Forensic Science courses that are based within the same department at Nottingham Trent University.

Descriptive data

Qualifications

The proportion of students without formal digital-technology related qualifications remains quite consistent throughout the 4 years of data collected, except for 2016/17 graduating students, but this may be due to the very low response rate that in that cohort group for 2016/7 (n=8). Data is presented below as table 7.

Table 7: Percentage of respondents without IT qualifications from Digital History Survey.

No relevant IT Qualifications %

New		Graduating	
201415	20%	**201415***	17%
201516	23%	**201516**	13%
201617	32%	**201617**	0%
201718	31%	**201718**	14%
*2014/15 – Returning students rather than graduating final year students were permitted to respond, so data is not directly comparable.			

The question identified qualifications commonly provided by UK Higher Education institutions, but as this list could not be exhaustive, participants were permitted to identify other qualifications using the "other relevant qualification" option. Participants were permitted to select more than one qualification. Most participants had some formal education relating to digital technology input, however many of the qualifications declared by students did not exceed GCSE level or equivalent. The data shows that at least 40% in most cohorts have a GCSE in Information & Communications Technology (ICT) or other relevant qualification, which is higher than the national uptake of GCSE ICT by school children in 2014 of 14.2% (T. Gill, 2015). It is important to note that there is a time delay typically of 2 years for students to gain a GCSE, so the 2016 data would be most relevant to the 2016/17 cohort, where 48% of new students had a GCSE ICT or equivalent.

The changes in qualification content throughout the years makes it difficult to ascertain which skills these students have because of their qualifications, and assuming a greater level of digital literacy based on formal qualifications is shortsighted, as the level of digital skills, competence or literacy imparted by the qualifications is unclear. However, a base level of familiarity with common technologies for these students can be assumed.

Operating system familiarity

Students were asked to identify which operating system they were most familiar with for a personal computer, a tablet device and a smart phone.

For personal computer, Microsoft was the most selected operating system by a fair margin for every year and student cohort.

For tablet devices, Apple was the most selected operating system for all student groups and cohorts. This is an unexpected result, as returning/graduating student groups would have had familiarity with the existing Superlab Tablets, which were Android devices for the first year of the study, and Microsoft devices for the following years. Although some participants did select these options, it is lower than anticipated. This suggests that students are using tablet devices external to the university with differing operating systems to those present within the Superlab.

For smartphones, students selected that they are familiar with both Apple and Android devices, with the share of the cohorts varying from year to year. Data from 2014/15 is shown as table 8 and data from subsequent years is available as an appendix (appendix 1).

Table 8: Familiar operating systems of students, 2014/15, split by cohort. Digital History Survey 2014/15

Familiar Operating System	2014/15 new	2014/15 returning
n	**155**	**88**

PC	**Microsoft**	128	69
	Apple	12	7
	Linux	1	0
	I don't know	14	12
Tablet	**Microsoft**	22	11
	Apple	74	39
	Android	33	21
	I have never used this device	7	3
	I don't know	17	13
	Other	1	1
Phone	**Microsoft**	12	2
	Apple	88	45
	Android	38	36
	I have never used this device	3	0
	I don't know	12	4
	Other	2	1

Ownership and access to digital technologies

As established earlier in this chapter, access to technology is an important predictor of the digital experiences of students. The Jisc Learner profile tool indicated to survey students for ownership of devices, and that students should tick the item if their mobile phone was capable of that functionality.

A few modifications were made to this question to update technological references. The question was slightly modified to isolate the difference between a smart (internet capable) phone, and a traditional mobile phone. Palmtop / PDA was removed from the technology list due to being a less popular device at the time. “Laptop” as re-termed “laptop or netbook” to encompass the miniature-laptop style netbook devices that were available. Items included in the survey were: smart phone, other mobile phone, iPod or mp3 player, tablet, laptop or netbook, digital camera, digital video camera, webcam, digital audio recorder and assistive technology.

Table 9: Number of items owned, split by cohort. Digital History Survey 2014-2018

		Number of items owned										
Cohort	**n**	**0**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
2014/15 new	155	0	1	8	20	21	29	24	18	12	0	0
2014/15 returning	88	1	1	9	12	24	23	21	15	6	1	0
2015/16 new	77	1	3	14	13	14	14	9	5	3	1	0
2015/16 graduating	8	0	0	1	1	2	2	2	0	0	0	0
2016/17 new	68	0	3	11	12	14	11	6	7	4	2	0
2016/17 graduating	8	0	0	2	3	0	0	1	3	1	0	0

2017/18 new	54	1	4	9	12	10	7	3	3	4	1	0
2017/18 graduating	7	0	0	2	0	2	0	2	1	0	0	0

Over 95% of each cohort owned a smart phone, with very few students identifying that they had a traditional non-internet enabled mobile phone (Table 9, Figure 11). Most students identify that they own between 3 and 6 items of technology, however smart phones in 2014 could run applications allowing many of the functions identified. It is possible that students were unaware of the functions or chose to not use them. The question was developed as a positive selection question, rather than yes/no, so it is not possible to identify if a participant has missed an individual item.

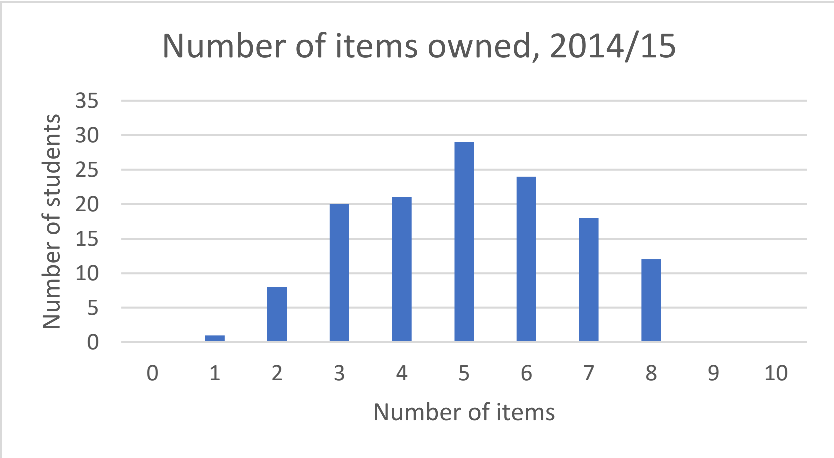

Figure 11: Number of items of technology owned by students 2014/15 DHS.

Self-assessed digital competence measures

Items within the Digital History Survey that allowed students to self-assess competence of a digital technology task were considered against the NTU Digital Framework Items were assigned a score in relation to their level within the framework, as more complex tasks are higher on the framework (tables 10 and 11).

Table 10: Digital History Questions compared to NTU Digital Framework levels.

Digital History – Digital Usage and Competence scored elements

Question		Score assigned	Comments
Customisation	I have customised my computer* to suit my personal preferences (Yes/No)	2 points	ICT / computer literacy and communication level 2
2014/15: In my personal and social life, I do the following: For 2015/16 onwards, students were asked “ how often do you do the following:”	Use social networking sites (e.g., Facebook, Twitter, G+)	2 points	Communication level 2
	Download podcasts	1 point	Media literacy level 1
	Use instant messaging or chat (e.g., Facebook messenger, Skype typed messages)	2 points	Communication level 2
	Use video calls (e.g., Facetime, Skype video chat)	2 points	Communication level 2
	Watch live TV or catchup TV online (e.g., iPlayer, 4OD)	1 point	Communication and media literacy level 1
	Watch on demand video (e.g., YouTube)	1 point	Communication and media literacy level 1
	Upload video or photo content to the internet (e.g., Instagram, YouTube)	3 points	Media literacy level 3
	Participate in discussion groups or online chatrooms	3 points	Communication and collaboration level 3
	Use wikis or blogs	1 point	Media literacy level 1
	Maintain my own blog or website.	4 points	Media literacy level 4
	Take part in an online community through online gaming	2 points	Communication and collaboration level 2

Table 11: Digital History Questions compared to NTU Digital Framework levels.

Question		Score assigned	Comments
Before commencing your university course (or previous year) how frequently did you:	Download, save and open files.	1 point	ICT/ computer literacy level 1
	Put information into a premade form, downloaded from the internet. (A proforma / template)	1 point	ICT/ computer literacy level 1
	Co-create resources or work with a peer online	3 points	Communication and collaboration level 3
	Use formulae to manipulate data a spreadsheet (e.g., Excel)	2 points	ICT/computer literacy level 2
	Produce professional diagrams using drawing packages (e.g., ChemDraw or BioDraw)	3 points	ICT/computer literacy level 3
	Use a Virtual Learning Environment (e.g., NOW, WebCT, Moodle)	1 point	Media literacy and ICT/computer literacy level 1
	Create graphs using a spreadsheet (e.g., Excel)	1 point	ICT/ computer literacy level 1
	Insert images, tables and graphs into word processed files or presentations. (e.g., MS Word, PowerPoint)	1 point	ICT/ computer literacy level 1
	Use cloud storage (e.g., Dropbox.com, NOW MyFilesiCloud, SkyDrive)	2 points	Communication, ICT/ computer literacy level 2
	Interact with staff or students online (e.g., email, discussion boards)	1 point	ICT / computer literacy and communication level 1

The maximum score available is 40 points. The two large matrix questions regarding digital activities were frequency questions and were scored that "never" assigned a score of zero, and any indicated activity (a few times a year to every day) scored the full points value of the item. Not all activities would be of equal likelihood to occur within the laboratory, and the self-assessed digital experience of the students could be unintentionally skewed if frequency was considered by students when answering the questions.

In total, across 4 years of data collection, 464 digital history survey responses were obtained. Of these, only 30 students obtained scores higher than 35, with fewer than 10 students in total achieving higher than 37 points. No students scored fewer than 7 points.

3.1.5 Discussion

The Digital History Survey results show that although students are using technology in their everyday lives, that this does not necessarily extend to the higher scoring, higher order digital literacies. It is of course possible that the students are digitally literate, and this is not being identified due to limitations of the tool. Due to the diversity of devices and activities it is not possible to measure a student's digital experiences exhaustively on this scale and the Digital History Survey is a snapshot of student's usage of common devices and appropriate technologies related to the Superlab environment. If students are not familiar with using the devices, then there is likely to be an impact on student's operation within the Superlab. This should be considered when implementing technologies in any teaching environment, but particularly a complex environment like the teaching laboratory.

3.2 Measuring environments

History of Environment inventories.

Environment inventories are a type of tool for assessing an environment within a known set of parameters, often relative to a user's preference of that environment. Environment inventories were chosen as they are designed to measure large scale cohorts for individual and cohort student experiences of the environment, with successful implementation in a variety of learning environments. Fraser (2014) details the history of environment inventories in great detail, explaining that Walberg and Moos developed early environment inventory is creating the **Learning Environment Inventory (LEI)** (Walberg, 1969) and the **Classroom Environment Scale (CES)** (Moos, 1973) respectively. These tools have been the inspiration for the development of a wide range of environment inventories that have been validated for use in of a wide multitude of contexts including school and higher education in a variety of countries, and even cross-subject studies. Publicly accessible tools such as the SLEI limited at the time research commenced. One proposed tool was the Colorado Learners Attitude to Science Survey (CLASS) (W. K. Adams et al., 2008) however this measures attitudes more broadly rather than specifically in relation to the laboratory so was deemed to be less appropriate for the environment-linked research than the SLEI.

Development of Environment Inventories

The tools selected for modification for use within the Superlab were the Student Laboratory Environment Inventory (SLEI) (Fraser & Wilkinson, 1993) and the appendix sections of the Technology Rich Outcomes-Focused Laboratory Environment Inventory (TROFLEI) (Aldridge et al., 2004). The SLEI was chosen because this project intended to explore the student perception of the SuperLab environment. The TROFLEI was chosen as the questions probed student's perceptions of technology specifically which was not contained within the parameters SLEI. The SLEI has been subsequently modified to form the Chemistry Laboratory Environment Inventory (Wong & Fraser, 1996b) and has been further modified for use in new contexts such as different educational systems in Korea (Fraser & Lee, 2009). The SLEI has also been used extensively in combination with other tools (Wong & Fraser, 1996a) , (Lightburn & Fraser, 2007). Importantly as environment inventories are not intended to fully represent an environment, they should not be used in this manner. Each inventory is contextually developed and may not be able to be generalised as they are only capable of representing an environment within the specific parameters and context of that inventory (Braunsberger & Gates, 2009). A summary of the use of the SLEI prior to the start opening of the Superlab is displayed in table 12.

The SLEI has two forms, the personal and group form of the tool, in the personal form students are asked to reflect on their personal experiences rather than those of their class. The tool takes the form of a set of statements with two Likert scales below that participants indicate their agreement with the statement. The first scale is the actual scale, asking for student's actual experiences, and the second is the preferred, asking for the student's ideal experience.

Table 12: Studies using the SLEI or its derivatives, or the TROFLEI.

Date	Authors	Description
1993	Fraser, B. J. Wilkinson, W. J.	Initial development of SLEI. 5447 students in 53 sites covering 269 classes. International study including England, Canada, Australia, USA and Nigeria.
1994	Wong, A. F. Fraser, B. J.	Usage of the CLEI (Chemistry laboratory environment inventory) which is modified from the SLEI. 1592 participants in 56 classes from 28 schools in Singapore.
1995	Fraser, B. J. Giddings, G. McRobbie, C. J.	Evolution of the personal form of the SLEI. 5447 students in 269 classes in England, Canada, Australia, USA and Nigeria.
1995	Fraser, B. J. McRobbie, C. J.	Development of the personal form of the SLEI, covering 516 students in 31 schools with 56 classes.
1996	Wong, A. F. Fraser, B. J.	Further studies using the Singapore sample, but clarifies that class cross disciplinary boundaries encompassing chemistry and physics
1997	Fisher, D. Henderson, D. Fraser, B. J.	SLEI used in bioscience classes in Tasmania. 489 students in 28 classes.
1998	Henderson, D. Fisher, D. Fraser, B. J.	High school classes in Australia, 100 students in 7 classes in Australia using the Environmental Science Laboratory Environment Inventory ESLEI which was developed from the SLEI.
2000	Henderson, D. Fisher, D. Fraser, B. J.	SLEI in combination with another tool, the Questionnaire on Teacher Interaction. 489 students in 28 biology classes.
2001	Hofstein, A. Nahum, T. L. Shore, R.	SLEI used in combination with qualitative data to investigate inquiry-type laboratories in Israel. 130 students were included in the inquiry group.
2002	Quek, Choon Lang Wong, A. F. Fraser, B. J.	Using the SLEI to investigate gender differences in attitudes to the laboratory in Singapore. 497 students in 18 single sex classes.
2004	Aldridge, J. M. Dorman, J. P. Fraser, B. J.	Validation of the TROFLEI with 1249 high school students from Australia.
2007	Lightburn, M. E. Fraser, B. J.	A modified SLEI using reduced scales in combination with several other tools deployed to 761 students in 25 classrooms to evaluate a specific activity.
2009	Fraser, B. J Lee, S. S. U.	The SLEI modified for use in Korea, 439 students from three subject-specific streams.
2011	Aldridge, J. M. Fraser, B. J.	Validation of the TROFLEI using 2317 students from Australia
2011	Koul, R. B. Fisher, D. L. Shaw, T.	Use of the TROFLEI in New Zealand, with 1027 students from 30 high school classes.
2012	Welch, A. G. Cakir, M. Peterson, C. M. Ray, C. M.	A translated TROFLEI equivalent in Turkey, with 980 Turkish students and 130 students in the USA.

3.2.1 Development of the modified SLEI.

Statistics in this section were undertaken contemporaneously, on the tool as it was after each iteration. As such the number of items in each scale may change as items are discarded. Additionally, the n-number and completeness data will be different to statistical analysis undertaken later in the chapter. It is of note that question labels will vary due to deletion and modification of the tool, and therefore the full text will be identified as appropriate.

3.2.2 Ethical Approval

All tools and amendments within this research underwent review and approval by Nottingham Trent's School of Science and Technology Non-Invasive Ethical Review Panel.

3.2.3 Reliability

Key arguments for this section are from Clark & Watson (1995) which is a guide for development and assessment of construct type psychological tools.

Reviewing the literature in which the SLEI is used, a variety of statistical methods are used to assess the tool and draw conclusions. However, the most commonly used are Cronbach's Alpha – used as a measure of validity, and discriminant validity – used to ensure that the scales within the measures are discrete and measuring separate phenomena. The statistical methods used by researchers using the SLEI vary, but typically use parametric tests including MANOVAs to test for difference between groups.

Cronbach's alpha is a measure of internal consistency, ensuring that all items in a scale are measuring the same phenomenon without excessive overlap. Asking a highly similar question several times would result in a very high value for Cronbach's Alpha while asking unrelated questions should result in a very low Cronbach's Alpha. Acceptable values of Cronbach's Alpha in literature vary (Taber 2018), however Field (2017) provides guidance that Cronbach's Alpha should be used with caution as a measure of reliability. Although popular consensus indicates that Cronbach's Alpha should have a value between 0.6 and 0.8 for a scale to be considered reliable, values of 0.9 and above should be considered to too high, further consideration is required.

If a Cronbach's Alpha value was highlighted as an issue, individual inter-item correlations are to be considered to identify items that are correlating least well with other items. The inter-item correlation is a correlation between two items on a scale, and the value should be more than 0.3 to indicate that the items are related and should not exceed 0.9 (Clark & Watson, 1995). High alpha and high inter-item correlation values can indicate that there is a level of redundancy in the questions of the construct (Tavakol and Dennick 2011).

All tests were undertaken in SPSS. SPSS provides a value of "Cronbach's Alpha if item deleted" which re-calculates the alpha value if the item was discarded from the scale, which can allow identification of items that should be considered for discarding. Additionally, SPSS also provides the corrected item total correlation which needs to be above 0.3 for the scale to be considered reliable (Field, 2017).

As actual and preferred scales are paired, any changes made to one scale must be matched on the other, and therefore actual and preferred scales are considered together. Where modifications were made, re-phrasing a question was preferred to deletion of an item, as scales should not have too few items. Clark & Watson (1995) state that the number of items in a scale is permitted to be as high as 35, if the phenomenon is broad, and as low as 4 for a very narrowly defined construct. All scales originally had 7 statements.

2014/15 completeness revisions.

The Modified SLEI tool was very time consuming to complete, with informal feedback from participants relating to the difficulty in completing repetitive question type. As such measures were taken to improve response rates (Table 13).

Table 13: 2014/15: Number of complete scale responses of contemporaneous scale form.

	Social Cohesiveness		Open-Endedness		Integration		Rule Clarity		Material Environment		Use of Technology		Attitude to Technology
	Actual	Preferred	Actual	Preferred	Actual	Preferred	Actual	Preferred	Actual	Preferred	Actual	Preferred	
Number of entered surveys	112	112	112	112	112	112	112	112	112	112	112	112	112
Number of complete scale participant responses	99	97	85	85	77	81	83	81	86	86	85	85	85
% completion	88%	87%	76%	76%	69%	72%	74%	72%	77%	77%	76%	76%	76%

The SLEI is formatted with one question from each scale per page, as such it is difficult to represent the exact point where a student ceases to answer the questions by scale, however the Use of Technology and Attitude to Tablets scales were placed at the end of the survey. 25 of the 112 surveys completed had no responses for the three final scales, indicating a high degree of non-finishing of the tool (Table 14).

Table 14: 2014/15: Number of questions completed in each contemporaneous scale form.

Number of complete answers	Social Cohesiveness		Open-Endedness		Integration		Rule Clarity		Material Environment		Use of Technology		Attitude to Technology
	Actual	Preferred	Actual	Preferred	Actual	Preferred	Actual	Preferred	Actual	Preferred	Actual	Preferred	
8													85
7	85	82	85	85	77	81	83	81	86	86			2
6	4	6	4	4	6	8	6	8	3	3			0
5	1	2	1	1	6	1	1	1	1	1	85	85	0
4	4	3	4	4	5	4	4	4	4	4	2	2	0
3	3	4	3	3	2	3	3	3	3	3	0	0	0
2	3	3	3	3	11	3	3	3	3	3	0	0	0
1	7	7	7	7	5	7	7	7	7	7	0	0	0
0	5	5	5	5	0	5	5	5	5	5	25	25	25
Total	112	112	112	112	112	112	112	112	112	112	112	112	112
Less than half the scale complete	18	19	18	18	18	18	18	18	18	18	25	25	25

As the impact of technology is of significant interest to the project, this atrophy in response towards the end of the instrument is of concern and it was decided to move the technology related questions to the start of the survey, ahead of the laboratory focussed section. The Material Environment scale was removed, as this was deemed to be of least relevance to the project, since the material environment of the laboratory is a fixed parameter that can be minimally affected by the research, since outcomes of the research would be unable to affect structural change to the environment of the laboratory. Removing the material environment scale removed 7 questions from the whole tool.

This finding is consistent with research by Porter et al. (2004) regarding the phenomenon known as Survey Fatigue. Survey fatigue occurs when an individual is required to complete too many surveys or undertake particularly long surveys. Minimising the length of the survey is therefore a reasonable step to take, as long surveys are likely to have more skipped questions, and result in participants having difficulty in concentrating while responding (Le et al., 2021).

2014/15 reliability and revisions

Table 15: Reliability data for 2014/15 tool using contemporaneous scales.

201415	Actual or Preferred	Cronbach's Alpha
Social Cohesiveness	Actual	0.761
	Preferred	0.734
Open Endedness	Actual	0.556
	Preferred	0.583
Integration	Actual	0.872
	Preferred	0.674
Rule Clarity	Actual	0.625
	Preferred	0.486
Material Environment	Actual	0.771
	Preferred	0.647
Use of Technology	Actual	0.819
	Preferred	0.867
Attitude to Technology	N/A	0.924

Scale reliability values for this academic year are displayed in table 15.

Social Cohesiveness

Social Cohesiveness Scale Questions
Students in this laboratory class get along well as a group
Students have little chance to get to know one another in the laboratory
Students in this laboratory class help one another
Students in this laboratory class get to know each other well
Students are able to depend on each other for help during laboratory activities
It takes too long to get to know everybody by their 1st names in this laboratory class
Students work cooperatively in laboratory sessions

Social cohesiveness Actual scale has 9 question pairs with inter-item correlation matrix values that higher than the threshold, mostly in relation to questions 12 and 32. For question 12, the corrected item total value was only slightly under the acceptable threshold value (0.3), at 0.299 and deleting Question 12 would result in an increase of Cronbach's Alpha to is 0.772. For question 32, the corrected item total value was under the threshold at 0.259 and deleting Question 32 would result in an increase of Cronbach's Alpha to 0.792.

Social Cohesiveness Preferred scale has 11 question pairs with inter-item correlation matrix values that higher than the threshold, mostly in relation to questions 12 and 32, however all corrected item total values are acceptable. Deleting Question 12 would result in an increase of Cronbach's Alpha to 0.762. Question 12 also has a slightly lower than threshold corrected item total value of 0.296.

- Question 12 was re-worded in an attempt to resolve the problems with inter-item correlation. "*Students have little chance to get to know one another in the laboratory*" was re-phrased to "*There is little opportunity for me to get to know other students in the laboratory sessions*". This brought the wording of the question more in line with the personal experience that was being sought from students, rather than a cohort-wide assessment. It is possible that since the laboratory is a large interdisciplinary laboratory, it is possible that students in simultaneously taught but subject-separate sessions may never meet.
- Question 32 "*It takes too long to get to know everybody by their 1st names in this laboratory class*" was re-worded to "*It takes too long for me to get to know people by name in this laboratory class*", by the same reasoning as the re-wording for question 12. Students may well not meet every student within the laboratory as a whole, but may know everyone in their class.

Open-Endedness

Open-Endedness Scale Questions
There is an opportunity for students to pursue their own science interests in this class
In this laboratory we are asked to design our own experiment to solve a given problem
In a laboratory sessions different students collect different data for the same problem
Students are allowed to go beyond the regular laboratory exercise and do some experimenting of their own
In a laboratory different students to different experiments
In our laboratory sessions, the instructor decides the best way to carry out the laboratory experiments
The students decide the best way to proceed during laboratory experiments

Open-endedness Actual scale has a lower than threshold Cronbach's Alpha value (0.556), with many of the inter-item correlation were below the threshold of acceptability. Three items have corrected item total values that are below the acceptable value, questions 13, 18 and 33 are 0.193, 0.181 and 0.100 respectively. Question 33 is the only question where deleting the question would improve Cronbach's Alpha towards the acceptable value, with an increase to 0.579.

Open-endedness Preferred scale has a lower than threshold Cronbach's Alpha value (0.583), and many of the inter-item correlation matrix values were below the threshold of acceptability. Deleting question 8 would improve the Cronbach's Alpha to 0.581 and deleting question 33 would improve the Cronbach's Alpha to 0.615. The corrected item total for questions 8 and 33 are both below the acceptable threshold at 0.191 and 0.103 respectively.

This scale was not performing as would be expected, as there was a low measure of reliability. As such several changes were implemented

- Question 11 "*In this laboratory we are asked to design our own experiment to solve a given problem*" was re-worded to "*In our laboratory sessions we are asked to design our own experiment to explore a topic*". This question was re-worded to remove a possible focus on problem-based learning, as not all teaching laboratory practicals are based on real-life problems and may be targeting a more abstract hypothesis or topic. (Domin, 1999).
- Question 18 "*In a laboratory session, different students collect different data for the same problem*" was re-worded to "*Within a laboratory session, students follow different procedures or use different samples to investigate the same idea*". The intent here was to remove the focus on an individual's data, which may differ due to procedural errors, and focus more on the exploratory collaborative intent of the original scale which may be misunderstood in the personal experience the tool is seeking.
- Question 33 "*In our laboratory sessions, the instructor decides the best way to carry out the laboratory experimen*ts" was re-worded to "*For our laboratory sessions the lecturer provides a method describing how to carry out an experiment.*" The intent here was to remove the emphasis on the decision-making by the academic which may happen external to the laboratory.

Integration

Integration Scale Questions
What we do in our regular lectures/seminars is unrelated to our laboratory work
The laboratory work is unrelated to the topics that we are studying in our lectures/seminars
Our regular lecture/seminar work is integrated with laboratory activities
We use the theory from our lectures/seminars during laboratory activities
The topics covered in lecture/seminar work are quite different from the topics dealt with in laboratory sessions
What we do in the laboratory sessions helps us understand the theory covered in lectures/seminars
Laboratory work and lecture/seminar work are unrelated

Integration Actual scale has a slightly high Cronbach's Alpha value (0.872), acceptable inter-item correlation matrix values, and acceptable corrected item total values. Removal of items to reduce Cronbach's Alpha would be acceptable.

Integration Preferred scale has an acceptable Cronbach's Alpha score (0.674), but several inter-item correlation values that are below the acceptable threshold. The corrected item total for question 34 is slightly too low at 0.273. No items would improve the alpha value if deleted. Removal of question 34 would reduce the Cronbach's Alpha value the least to 0.666 which is still in the acceptable range.

To attempt to improve the inter-item correlation matrix values, two questions were re-worded.

- Question 9 "*What we do in our regular lectures/seminars is unrelated to our laboratory work*" was re-worded to "*The material covered in our regular lectures/seminars is unrelated to our laboratory work*". This was to focus on the content and theory, rather than the actions/activities undertaken in the non-laboratory teaching.

- Question 34 "*What we do in the laboratory sessions helps us understand the theory covered in lectures/seminars*" was re-worded to "*What we do in the laboratory sessions helps us to understand the topics taught in lectures/seminars*". This was to remove the potentially confusing term "theory".

Rule Clarity

Rule Clarity Scale Questions
Our laboratory has clear rules to guide student activities
This laboratory is rather informal and a few rules are imposed
Students are required to follow certain rules in the laboratory
There is a recognised way of doing things safely in this laboratory
There are a few fixed rules for students to follow in laboratory sessions
The instructor outlines safety precautions before the laboratory sessions commence
This laboratory class is run under clearer rules in other classes

Rule Clarity Actual scale has inter-item correlation values that are below the acceptable threshold with question 10 correlating poorly with questions 15, 20 and very poorly with question 30. Question 15 correlates poorly with questions 10, 20, 30 and 40. Question 30 correlates very poorly with all other items in the scale. Question 40 correlates poorly to questions 15, 20, 30, 35 and 40. Question 30 has a very low corrected item total value of 0.063. This question would also increase the Cronbach's Alpha value from 0.625 if it was deleted, to a more acceptable value of 0.743.

Rule Clarity Preferred has a very low Cronbach's Alpha value (0.486) and several poorly correlated inter-item correlation values. Three questions have corrected item totals below the acceptable item total, with question 14 having a value of 0.242, question 30 is 0.122, and question 40 has a value of 0.200. Deleting question 30 would increase the Cronbach's Alpha value to 0.575, however this is still below the target value and would be regarded as low.

- Question 15 "*This laboratory is rather informal, and few rules are impos*ed" was re-worded to "*This laboratory has few rules and is an informal place to work*". This re-wording was an attempt to re-focus the question on the rules, rather than the formal environment, as the laboratory is a professional environment rather than an informal one.
- Question 30 "*There are few fixed rules for students to follow in laboratory sessions*" was removed, justified by increasing both the actual and preferred Cronbach's Alpha value. Re-wording was considered, but it was deemed that this question could not be re-phrased without losing the original intent of the question.
- Question 40 "T*his laboratory class is run under clearer rules than other classes*" was re-phrased as "*This laboratory has clearer rules than other types of classes e.g., lectures/seminars*" in order to avoid comparison between the Superlab environment and other laboratory environments, as not all students had access at the time to non-Superlab laboratory environments.

Material Environment

Material Environment Scale Questions
The laboratory is crowded when we are doing experiments
The equipment and materials that students need for laboratory activities are readily available
Students are ashamed of the appearance of this laboratory
Laboratory equipment is in poor working order
The laboratory is hot and stuffy
The laboratory is an attractive place to work
The laboratory has enough room for individual and group work

Material Environment Actual has an acceptable Cronbach's Alpha value (0.771), however there are 7 pairs of questions with low inter-item correlation values, notably questions 21 and 31 correlate poorly with 2 other questions each. All corrected item totals were acceptable and none of the questions would improve the Cronbach's Alpha value.

Material Environment Preferred has a slightly low Cronbach's Alpha value (0.647), and several poorly correlating pairs in the inter-item correlation matrix.

Questions 16 and 26 have corrected item total values of lower than acceptable, at 0.253 and 0.266 respectively. No items would improve the value of Cronbach's Alpha upon deletion.

Question 16 "The equipment and materials that students need for laboratory activities are readily available" and question 26 "Laboratory equipment is in poor working order" were identified as potential candidates for modification to improve the scale, however as the Material Environment scale was removed to reduce the length of the total tool as previously discussed, the consideration of questions for removal is moot.

Use of Technology (Adapted TROFLEI Computer Usage appendix scale)

Use of Technology Scale Questions
If I face difficulties in the laboratory, I use the tablets to search for an answer
I use tablets in the laboratory to refer to my lecture notes to help me understand my equipment
Whilst in the laboratory access further reading using the tablets to help my understanding
I use the tablets to help me link my laboratory work to "real-world science"
I use the tablets to access information on how to use equipment/procedures safely

Use of Technology Actual scale has an acceptable Cronbach's Alpha score (0.819), and only one poorly correlating question pair with questions 42 and 46 having an inter-item correlation value of 0.275. Deletion of question 46 would increase the alpha score, which would be undesirable, taking it closer to the unacceptable value of 0.9 where items in a scale can be deemed to be too similar. All other items would decrease the Cronbach's Alpha value, if deleted.

Use of Technology Preferred scale has an acceptable Cronbach's Alpha (0.867) and acceptable inter-item correlation values for all items in the construct.

No questions were modified or removed at this stage.

Attitude to technology (Adapted TROFLEI Attitude to Computers appendix scale)

Attitude to Technology Scale Questions
I'm good with tablets
I like working with tablets
Working with tablets inspires me
I am comfortable trying new software on the tablets
Working with tablets is motivating
Working on a tablet makes my work more enjoyable
I do as much work as I can using the tablets
I feel comfortable using a tablet

This is the only scale that does not have an actual and preferred form, which is appropriate given that this is measuring a student's self-conception of attitude which will not have a preferred form. When developing this scale, questions were reworded to be laboratory specific, and the word Computers was replaced with Tablets to make the tool more specific to the Superlab environment, as the presence of the tablets was deemed to be a key aspect of the Superlab.

The alpha value of this construct is too high at 0.924, which indicates that some of the items may be measuring the same phenomena. This is supported by the fact that all inter-item correlation values are high, which is to be expected if the tool is measuring the same phenomena repeatedly. The inter item correlation values are all acceptable, except questions 47 and 47 with a slightly low value of .295, below the acceptable value of 0.3. All corrected item total values are acceptable, and the Cronbach's Alpha value would decrease upon deletion of any of the items, except item 47 where it would increase. Decreasing the Cronbach's Alpha value would be desirable, but deletion of any individual item would result in Cronbach's Alpha still being over 0.9, which is still unacceptable.

At this stage, despite concerns regarding this tool, no questions were re-worded or removed, due to the high degree of non-response for this section of the survey.

2015/16 completeness revisions.

The relocation of the attitude to tablets and use of technology scales, as well as reducing the overall size of the instrument appears to have resolved the issues with completion, with a much greater level of completion (table 16).

Table 16: 2015/16: Number of questions completed in each contemporaneous scale form.

Number of complete answers	Attitude to Tablets	Use of Technology		Social Cohesiveness		Open-Endedness		Integration		Rule Clarity	
		Actual	Preferred	Actual	Preferred	Actual	Preferred	Actual	Preferred	Actual	Preferred
8	111										
7	1			98	96	100	98	100	95		
6	0			2	3	0	1	0	4		
5	0	106	94	1	1	1	1	1	1	99	95
4	0	1	2	0	0	0	0	0	0	1	2
3	0	0	0	1	1	1	1	1	1	1	1
2	0	0	0	1	1	1	1	1	1	1	1
1	0	0	0	1	2	1	2	1	2	1	1
0	1	6	17	9	9	9	9	9	9	10	11
Total	113	113	113	113	113	113	113	113	113	113	111
Less than half the scale complete	1	6	17	12	13	12	13	12	13	12	13

2015/16 reliability and revisions

Table 17: Reliability data for 2014/15 tool using contemporaneous scales.

201415	Actual or Preferred	Cronbach's Alpha
Social Cohesiveness	Actual	0.761
	Preferred	0.734
Open Endedness	Actual	0.556
	Preferred	0.583
Integration	Actual	0.872
	Preferred	0.674
Rule Clarity	Actual	0.625
	Preferred	0.486
Material Environment	Actual	0.771
	Preferred	0.647
Use of Technology	Actual	0.819
	Preferred	0.867
Attitude to Technology	N/A	0.924

Scale reliability values for this academic year are displayed in table 17. Revised question sets are presented in scale sets, with modified questions highlighted in bold.

Attitude to Technology

Attitude to Technology Scale Questions
I'm good with tablets
I like working with tablets
Working with tablets inspires me
I am comfortable trying new software on the tablets
Working with tablets is motivating
Working on a tablet makes my work more enjoyable
I do as much work as I can using the tablets
I feel comfortable using a tablet

The alpha value for this scale is very high still, and the inter-item correlation between questions 11 and 12 may be too similar with value of 0.793. The Cronbach's Alpha if question 12 was removed would reduce to 0.881. The corrected item total for this item was also very high at 0.776.

Question 12 "*Working on a tablet makes my work more enjoyable*" was removed from the scale at this point.

Use of Technology

Use of Technology Scale Questions
If I face difficulties in the laboratory, I use the tablets to search for an answer
I use tablets in the laboratory to refer to my lecture notes to help me understand my equipment
Whilst in the laboratory access further reading using the tablets to help my understanding
I use the tablets to help me link my laboratory work to "real-world science"
I use the tablets to access information on how to use equipment/procedures safely

Use of Technology Actual has an acceptable value for Cronbach's Alpha of 0.672, however 7 inter-item correlation values are very low. Question 16 has a slightly low corrected item total of 0.272, and correlates poorly with all other questions. Question 15 is the only question that deletion would improve the Cronbach's Alpha value to 0.680 which is a minor improvement from 0.672.

Use of Technology Preferred has an acceptable Cronbach's Alpha value of 0.757, however again this has several low inter-item correlation values with 8 low pair values. Question 16 has a low inter-item correlation value against question 18. All corrected item totals are acceptable values, and no items would improve the Cronbach's Alpha value upon deletion.

Since removing question 15 "*If I face difficulties in the laboratory, I use the tablets to search for an answer*" would lower the alpha value in the preferred scale away from the desired value and only has a minor improvement on the actual scale, the item was retained in the scale.

Social Cohesiveness

Questions highlighted in bold are those that were modified in this iteration of the survey.

Social Cohesiveness Scale Questions
Students in this laboratory class get along well as a group
There is little opportunity for me to get to know other students in the laboratory sessions
Students in this laboratory class help one another
Students in this laboratory class get to know each other well
Students are able to depend on each other for help during laboratory activities
It takes too long for me to get to know people by name in this laboratory class
Students work cooperatively in laboratory sessions

Social Cohesiveness Actual scale has an acceptable value for Cronbach's Alpha of 0.763, however there are 8 question pairs with low inter-item correlation values. Most notably the correlation between question 24 and 28, where the correlation value is -0.048. Question 24 also correlates poorly with questions 36 and 45, and Question 24 has a corrected item total lower than the threshold. Removing question 24 would increase the Cronbach's alpha score to 0.793, which is still within the acceptable range.

Social Cohesiveness Preferred scale has a slightly high but still acceptable value for Cronbach's Alpha of 0.803. Question 24 correlates poorly with three other questions,

questions 28, 36 and 43. Question 24 again has a corrected item total of 0.202, below the threshold of acceptance of 0.3, and removing question 2 would increase the Cronbach's Alpha score to 0.825.

Question 24 "*There is little opportunity for me to get to know other students in the laboratory session*" was removed at this stage. This is a question that was re-worded since the previous version of the survey.

Open-Endedness

Open-Endedness Scale Questions

There is an opportunity for students to pursue their own science interests in this class

In our laboratory sessions we asked to design our own experiment to explore a topic

Within a laboratory sessions students follow different procedures or use different samples to investigate same idea

Students are allowed to go beyond the regular laboratory exercise and do some experimenting of their own

In a laboratory different students to different experiments

The students decide the best way to proceed during laboratory experiments

Open-Endedness Actual scale has an acceptable Cronbach's Alpha score (0.673), but has 14 poor inter-item correlation values, with most of these relating to questions 40 and 44. Question 40 also has a low corrected item total value of 0.112, and removal of question 40 would improve the value of Cronbach's Alpha.

Open-Endedness Preferred scale has an acceptable Cronbach's Alpha score (0.589), although a little lower than the target range of 0.6-0.8. This scale had several negative values in the inter-item correlation matrix, and many values below threshold otherwise. Questions 37 and 40 correlate poorly with the most other questions. Question 40 has a corrected item total value of -0.164 and question 44 has a corrected item total value of lower than the acceptable threshold at 0.283. If question 6 was to be deleted for this scale, the Cronbach's alpha value would increase by 0.079 to 0.677, which is within the target range.

Question 40 had already been reworded from Question 33 in the previous edition of the survey and therefore was removed.

Integration

Integration Scale Questions
The material covered in our regular lectures/seminars is unrelated to our laboratory work
The laboratory work is unrelated to the topics that we are studying in our lectures/seminars
Our regular lecture/seminar work is integrated with laboratory activities
We use the theory from our lectures/seminars during laboratory activities
The topics covered in lecture/seminar work are quite different from the topics dealt with in laboratory sessions
What we do in the laboratory sessions helps us to understand the topics taught in lectures/seminars
Laboratory work and lecture/seminar work are unrelated

Integration Actual scale measure has a slightly high value for Cronbach's alpha (0.864). There is only one inter-item correlation pair that is under threshold, correlating between questions 22 and 41, with a value of 0.276 which is slightly below the threshold of 0.3. All corrected item totals are above the threshold of acceptance.

Integration Preferred scale has an acceptable value for Cronbach's alpha (0.708) but has some very mixed inter-item correlations with several very high and low values. To compare the data sets more easily, researchers compared the graphical representations more easily for the data sets produced by SPSS and noted that the positive and negatively worded questions were displaying different distributions.

Positively and negatively worded questions behaving differently could be due to the dimensionality of a question being affected by positive or negative phrasing (Clark & Watson, 1995) (Roszkowski & Soven, 2010). To investigate whether responses to the preferred scale are being affected by positive and negative wording, a pair of new questions were designed that duplicated the questions in the scale with the dimensionality swapped e.g., unrelated became related. These questions were situated in the survey in spaces left by removed questions, but away from their duplicate to avoid confusion on the part of participants (table 18).

Table 18: Pairs of questions with flipped dimensionality introduced in 2016/17 survey.

Original	"Flipped" Dimensionality
27. Our regular lecture/seminar work is integrated with laboratory activities	40. Our regular lecture/seminar work is not integrated with laboratory activities
22. The material covered in our regular lectures/seminars is unrelated to our laboratory work	33. The material covered in a regular lectures/seminars is related to our laboratory work

* Question numbers relate to position in 2016/17 survey

As the Cronbach Alpha value for both Actual and Preferred scales for Integration were acceptable, and there were no values that were significantly outside of the ranges of acceptance other than inter-item correlation values, no items were removed from this scale at this time.

Rule Clarity

Rule Clarity Scale Questions
Our laboratory has clear rules to guide student activities
This laboratory has few rules and is an informal place to work
Students are required to follow certain rules in the laboratory
There is a recognised way of doing things safely in this laboratory
The instructor outlines safety precautions before the laboratory sessions commence
This laboratory has clearer rules that other types of classes e.g. lectures/seminars

Rule Clarity Actual scale has an acceptable Cronbach's Alpha value (0.615) but has several inter-item correlation values below the threshold, mostly relating to questions 27 and 46. The inter-item correlation between question 27 and 42 is -0.122, and between 27 and 46 is -0.002. The corrected item totals for 3 questions are below the acceptable threshold with questions 27, 42 and 46 having values of 0.143, 0.234 and 0.291 respectively.

Rule Clarity Preferred scale has a Cronbach's Alpha value that is slightly lower than the acceptable range (0.560). This scale has 11 values of inter-item correlation that are below the acceptable threshold, particularly relating to questions 27 and 46. The corrected item totals for questions 27, 42, and 46 have values of 0.199, 0.128 and 0.297 respectively, which are all below the acceptable threshold of 0.3. If question 27 were deleted, Cronbach's Alpha would improve to 0.596, and if question 42 were deleted, Cronbach's Alpha would improve to 0.586 but removing neither of these questions increases the value to within the acceptable threshold.

Questions 27 and 46 were identified as candidates for removal, as the questions had already been re-phrased in revisions from 2014/15. It was decided that only one question should be removed at this stage to avoid having too few items in the scale, as scales should not have small item numbers unless the construct is narrow and well defined (Clark & Watson, 1995). Deletion of question 27 would result in the maximum increase to the Cronbach's Alpha value of the preferred scale for Integration and had the most values below-threshold for inter-item correlations, so was identified as the question to be deleted. Question 46 was retained but identified for further investigation.

2016/17 completeness

The number of questions represented in this data set is lower than that of 2015/16 (table 19) with a lower number of partially complete scales (table 20). This question set does not include the questions that were flipped to investigate whether positive or negative phrasing was impacting the reliability of the scale.

Table 19: 2016/17: Number of complete scale responses of contemporaneous scale form

	Attitude to Tablets	Use of Technology		Social Cohesiveness		Open-Endedness		Integration*		Rule Clarity	
		Actual	Preferred	Actual	Preferred	Actual	Preferred	Actual	Preferred	Actual	Preferred
Number of entered surveys	102	102	102	102	102	102	102	102	102	102	102
Number of complete scale participant responses	101	95	92	87	81	87	83	85	82	89	85
% completion	99%	93%	90%	85%	79%	85%	81%	83%	80%	87%	83%

*Excluding the Integration flipped questions, as they were not intended to be included in the actual scale, merely for investigation purposes.

Table 20: 2016/17: Number of questions completed in each contemporaneous scale form.

Number of complete answers	Attitude to Tablets	Use of Technology		Social Cohesiveness		Open-Endedness		Integration*		Rule Clarity	
		Actual	Preferred	Actual	Preferred	Actual	Preferred	Actual	Preferred	Actual	Preferred
8											
7	101							85	82		
6	1			87	81	87	83	4	5		
5	0	95	92	2	7	3	6	1	3		
4	0	3	2	1	2	2	2	2	2	89	85
3	0	0	0	2	2	2	3	2	2	3	7
2	0	1	0	2	2	0	0	0	0	2	2
1	0	0	2	1	1	1	1	1	1	1	1
0	0	3	6	7	7	7	7	7	7	7	7
Total	102	102	102	102	102	102	102	102	102	102	102
Less than half the scale complete	0	4	8	10	10	8	8	10	10	8	8

*Excluding the Integration flipped questions, as they were not intended to be included in the actual scale, merely for investigation purposes.

2016/17 reliability

Table 21: Reliability data for 2016/17 tool using contemporaneous scales.

2016/17	Actual or Preferred	Cronbach alpha
Attitude to Tablets	N/A	0.865
Use of Technology	Actual	0.745
	Preferred	0.768
Social Cohesiveness	Actual	0.772
	Preferred	0.719
Open Endedness	Actual	0.65
	Preferred	0.54
Integration	Actual	0.859
	Preferred	0.709
Rule Clarity	Actual	0.554
	Preferred	0.745

Scale reliability values for this academic year are displayed in table 21.

Attitude to Technology

Attitude to Technology Scale Questions

I'm good with tablets
I like working with tablets
Working with tablets inspires me
I am comfortable trying new software on the tablets
Working with tablets is motivating
Working on a tablet makes my work more enjoyable
I do as much work as I can using the tablets
I feel comfortable using a tablet

The Cronbach's Alpha value for this scale is a little high (0.865), however all items correlate well with one another except for questions 7 and 13, which have an inter-item correlation of 0.209. The corrected item totals of all items are above the acceptable value. No items would reduce the Cronbach's alpha if they were deleted by more than 0.03.

Use of Technology

Use of Technology Scale Questions
If I face difficulties in the laboratory, I use the tablets to search for an answer
I use tablets in the laboratory to refer to my lecture notes to help me understand my equipment
Whilst in the laboratory access further reading using the tablets to help my understanding
I use the tablets to help me link my laboratory work to “real-world science”
I use the tablets to access information on how to use equipment/procedures safely

Use of Technology Actual scale has a Cronbach’s Alpha value which is within the acceptable range(0.745). Questions 14 and 17 have a slightly low inter-item correlation value of 0.234, and questions 14 and 18 have an inter-item correlation value of 0.131, questions 15 and 18 have an inter-item correlation value of 0.171, all of these are below the acceptable threshold of 0.3. The removal of question 18 would increase the value of Cronbach’s Alpha to .760 which is a small increase of 0.015.

Use of Technology Preferred scale has a Cronbach’s within the acceptable range (0.768). Questions 14 and 19 have a lower than acceptable inter-item correlation value of 0.242. All corrected item totals are above the acceptable threshold. Removing question 5 would increase the Cronbach’s Alpha score to 0.797, which is a small increase of 0.021.

The removal of question 18 was considered as it had below-threshold correlation values with another item in both scales however as the improvement of the Cronbach’s Alpha score was minimal, the question was retained.

Social Cohesiveness

Social Cohesiveness Scale Questions
Students in this laboratory class get along well as a group
Students in this laboratory class help one another
Students in this laboratory class get to know each other well
Students are able to depend on each other for help during laboratory activities
It takes too long for me to get to know people by name in this laboratory class
Students work cooperatively in laboratory sessions

Social Cohesiveness Actual scale has an acceptable Cronbach’s Alpha score (0.772), but question 37 correlates poorly with all other items on the scale. The weighting of the question was checked to ensure there were no errors in assigning scores as the correlations were so poor. The corrected item total for question 37 is below threshold at 0.123, and the Cronbach’s alpha if deleted value for question 37 is 0.848, which is at the upper end of tolerance.

Social Cohesiveness Preferred scale has an acceptable Cronbach’s Alpha score (0.719), near the middle of the target range, this value has decreased notably from 2015/16 where the value was 0.803. This may be as a result of the re-wording of one question in the scale. There are still several item pairs on the inter-item correlation matrix that are below the acceptable threshold with question 37 correlating poorly with 3 other items.

The corrected item total for question 37 is 0.203, which is below the threshold, and if deleted, the Cronbach's alpha would increase by a small amount to 0.783.

No action was taken at this point. Question 37 was flagged for review as the Cronbach's Alpha for both the actual and preferred versions is already within acceptable limits, and removing this question would not have a large effect on the overall performance of the scale.

Open-Endedness

Open-Endedness Scale Questions

There is an opportunity for students to pursue their own science interests in this class

In our laboratory sessions we asked to design our own experiment to explore a topic

Within a laboratory sessions students follow different procedures or use different samples to investigate same idea

Students are allowed to go beyond the regular laboratory exercise and do some experimenting of their own

In a laboratory different students to different experiments

The students decide the best way to proceed during laboratory experiments

Open-Endedness Actual has a Cronbach's Alpha value on the lower side of acceptable but has decreased slightly from 0.673 to 0.650. There are several values below threshold on the inter-item correlation matrix with 12 out of 15 pairs correlating poorly. All items correlate poorly with all other items, except for question 30 which has values above the threshold for all items. The corrected item totals are acceptable except for question 23 which is 0.245. The Cronbach's Alpha value if deleted for all items represents only small decreases, which would be undesirable for the scale reliability.

Open-Endedness Preferred has a Cronbach's Alpha value below the acceptable threshold of 0.6, at 0.540. There are several items in the inter-item correlation matrix with 12 out of 15 pairs with correlation values below the acceptable threshold. Question 30 correlates well with 2 other scales, and question 20 and 23 correlate well with one another, but all other values are below threshold. The corrected item total for question 35 is on213, and for question 42 is 0.152. Removal of question 42 would marginally improve the Cronbach's Alpha value to 0.551, but this is below the acceptable threshold still.

When considering revisions for this scale, it was proposed that there may be a challenge with this scale in relation to the wide variety of levels of study that this tool is attempting to cover. The participant pool for this research includes students on a variety of levels of courses from FHEQ levels 4 to 7 (UK Quality Code for Higher Education. Part A: Setting and Maintaining Academic Standards, 2014) and differing courses may have different levels of open-endedness as suggested in Domin (1999). No questions were removed at this stage, as none would improve the reliability of the scale.

Integration

Integration Scale Questions
The material covered in our regular lectures/seminars is unrelated to our laboratory work
The laboratory work is unrelated to the topics that we are studying in our lectures/seminars
Our regular lecture/seminar work is integrated with laboratory activities
we use the theory from our lectures/seminars during laboratory activities
The topics covered in lecture/seminar work are quite different from the topics dealt with in laboratory sessions
What we do in the laboratory sessions helps us to understand the topics taught in lectures/seminars
Laboratory work and lecture/seminar work are unrelated

<u>Flipped questions for the purposes of investigating dimensionality</u>
Our regular lecture/seminar work is not integrated with laboratory activities
The material covered in a regular lectures/seminars is related to our laboratory work

For the reliability analysis of the Integration scale, questions where the dimensionality had been "flipped", henceforth referred to as the "flipped questions" are excluded from this analysis and were considered only within an assessment of whether positive and negative wording influenced the performance of the scale.

Integration Actual scale has a higher than acceptable Cronbach's Alpha value of 0.859, but this is a slight improvement from 2015/16. The inter-item correlation values and corrected item total values are all above the acceptable threshold. The removal of any items would increase the value of Cronbach's Alpha which would be undesirable.

Integration Preferred scale has an acceptable Cronbach's Alpha score, which has remained consistent, at 0.708 for 2015/16, and 0.709 in 2016/17. Question 21 has inter-item correlation values below the acceptable threshold with all other six items in the scale (table 22). This table contains correlation coefficients between each of the question pairs. Unacceptable inter-item correlations are highlighted in coloured boxes. Red boxes show poor correlations that are a positive/negative question pair. Pink boxes show poor correlations that are either positive/positive or negative/negative question pair. The poor correlations were noted to be more commonly with negative/negative question pairs, or positive/negative question pairs, which led to consideration of whether negative phrasing of the scale item could be impacting on the results of the scale (Nielson, 2022).

In total 9 of 21 items have inter-item correlation values below the acceptable threshold. The inter-item correlation value for question 21 is below the acceptable threshold at 0.187, and Cronbach's Alpha value would increase to 0.764 if question 21 was deleted.

Table 22: Inter-item correlation matrix for Integration Preferred scale 2016/17. Flipped dimensionality questions are excluded.

Integration Preferred Scale Inter-Item Correlation Matrix, 2016/17								
No #	+/-	21	24	27	31	36	38	43
+/-		*Negative*	*Negative*	*Positive*	*Positive*	*Negative*	*Positive*	*Negative*
21	*Negative*	1.000	*0.216*	0.050	0.230	*0.067*	0.116	*0.090*
24	*Negative*		1.000	0.398	0.328	*0.261*	0.446	0.489
27	*Positive*			1.000	0.435	0.232	0.428	0.396
31	*Positive*				1.000	0.314	0.480	0.248
36	*Negative*					1.000	0.356	0.306
38	*Positive*						1.000	0.416
43	*Negative*							1.000

Key	Negative correlating with Negative below the acceptance value of 0.300	
	Positive correlating with Positive below the acceptance value of 0.300	
	Negative correlating with Positive below the acceptance value of 0.300	

The poor correlation values are all linked to negatively worded questions, with positively worded questions all correlating in an acceptable manner to one another. This is investigated further as dimensionality is investigated in relation to this scale. Although removal of question 21 would improve the Preferred scale, it would negatively impact on the Actual scale, therefore no items were removed or re-worded from this scale, but the reliability is questionable.

Rule Clarity

Rule Clarity Scale Questions
Our laboratory has clear rules to guide student activities
Students are required to follow certain rules in the laboratory
There is a recognised way of doing things safely in this laboratory
The instructor outlines safety precautions before the laboratory sessions commence

The Rule Clarity scale now has only 4 items, which considered to be very small for an inventory scale. Rule Clarity Actual has a Cronbach's Alpha value has decreased to 0.554 from 0.614 in 2015/16 and is now no longer within the acceptable range for reliability. 3 values of 6 in the inter-item correlation matrix are below the acceptable threshold with questions 28 and 39 correlating poorly with each other and one other item. No item correlates well with all others in this scale. Question 28 and 39 have a particularly low inter-item correlation value of 0.063. The corrected item total for question 28 is lower than the acceptable threshold at 0.299 and deleting question 28 would increase Cronbach's Alpha to 0.561, which is a small increase and still below the acceptable range.

Rule Clarity Preferred scale has an acceptable Cronbach's Alpha value, which is a marked increase from 0.560 in 2015/16 to 0.745 in 2016/17. All inter-item correlation values are above the acceptable threshold.

The scale is behaving in a conflicting manner. The Preferred scale would be deemed reliable, but the Actual scale is not. This may be due to the variety of students, sessions and instructors in the Superlab, as different sessions may have different acceptable thresholds of safety. As an example, if a chemistry student is handling a particularly strong acid, they would be required to undertake the whole experiment in a restricted area, a fume hood, whereas a less hazardous experiment may have more lax rules.

No items were deleted from the scale, as there is a minimum number of items for a scale. Instead, data was still collected for this scale, but it is not deemed to be reliable when used in the "Actual" form.

2017/18 Completeness

No further revisions were undertaken after 2016/17, therefore the tool in 2017/18 is identical and completion data and other statistical investigations can be directly compared. Completeness data for 2017/18 is available in tables 23 and 24. Response numbers were low across all cohorts in this academic year, which is likely because the researchers had less available time to advertise the survey to participants, due to development in research strategy.

Table 23: 2017/18: Number of complete scale responses of contemporaneous scale form.

	Attitude to Tablets	Use of Technology		Social Cohesiveness		Open-Endedness		Integration*		Rule Clarity	
		Actual	Preferred	Actual	Preferred	Actual	Preferred	Actual	Preferred	Actual	Preferred
Number of entered surveys	50	50	50	50	50	50	50	50	50	50	50
Number of complete scale participant responses	47	45	42	36	34	35	34	35	35	36	36
% completion	94%	90%	84%	72%	68%	70%	68%	70%	70%	72%	72%
*Excluding the Integration flipped questions, as they were not intended to be included in the actual scale, merely for investigation purposes.											

Table 24: 2017/18: Number of questions completed in each contemporaneous scale form.

Number of complete answers	Attitude to Tablets	Use of Technology		Social Cohesiveness		Open-Endedness		Integration*		Rule Clarity	
		Actual	Preferred	Actual	Preferred	Actual	Preferred	Actual	Preferred	Actual	Preferred
8											
7	47							35	35		
6	2			36	34	35	34	1	1		
5	0	45	42	0	2	5	6	4	4		
4	0	0	2	4	3	1	1	1	1	36	36
3	0	0	0	1	2	2	2	2	2	5	5
2	0	0	0	2	2	2	2	2	2	2	2
1	0	0	0	2	2	0	0	0	0	2	2
0	1	5	6	5	5	5	5	5	5	5	5
Total	50	50	50	50	50	50	50	50	50	50	50
Less than half the scale complete	1	5	6	10	11	9	9	9	9	9	9
*Excluding the Integration flipped questions, as they were not intended to be included in the actual scale, merely for investigation purposes.											

2017/18 reliability review

Table 25: Reliability data for 2016/17 and 2017/18 tool using contemporaneous scales.

2015/16	Actual or Preferred	Cronbach alpha 2017/18	Cronbach alpha 2016/17
Attitude to Tablets	N/A	0.833	0.865
Use of Technology	Actual	0.679	0.745
	Preferred	0.829	0.768
Social Cohesiveness	Actual	0.817	0.772
	Preferred	0.530	0.719
Open Endedness	Actual	0.643	0.650
	Preferred	0.753	0.540
Integration	Actual	0.900	0.859
	Preferred	0.695	0.709
Rule Clarity	Actual	0.422	0.554
	Preferred	0.511	0.745

Scale reliability values for this academic year are displayed in table 25, including 2016/17 data for comparison. It is unusual that despite the tool remaining consistent, in subsequent academic years the reliability data changes so drastically. This suggests that there are underlying factors that are not being accounted for by the research design at present that is impacting on the reliability of the modified SLEI in the Superlab context.

3.2.2 Impact of changing dimensionality on the Integration scales

2016/17

This scale has questions phrased in both positive and negative manners, which is a feature that can cause differences in responses for Likert-type scales (Braun and Clarke 2006; Roszkowski and Soven 2010; Nielson 2022). To check whether this positive/negative phenomenon was affecting the outcomes of this scale, two additional questions were added into the survey which were cloned from another question, with altered positive/negative dimensionality (table 26).

Table 26: Questions in 2016/17 and 2017/18 Integration scales.

Question	Question text - Integration Scale	Positive or Negative	Comments
21	The material covered in our regular lectures/seminars is unrelated to our laboratory work	Negative	Re-worded question
24	The laboratory work is unrelated to the topics we are studying in lectures/seminars	Negative	From original survey
27	Our regular lecture/seminar work is integrated with laboratory activities	Positive	From original survey
31	We use theory from our lectures/seminars during laboratory activities	Positive	From original survey
33	Our regular lecture/seminar work is not integrated with laboratory activities	Negative	Flipped dimensionality question, from # 27
36	The topics covered in lecture/seminar work are quite different from topics dealt with in laboratory sessions	Negative	From original survey
38	What we do in laboratory sessions helps us to understand the topics taught in lectures/seminars	Positive	Re-worded question
40	The material covered in a regular lectures/seminars is related to our laboratory work	Positive	Flipped dimensionality question, from # 21
43	Laboratory work and lecture/seminar work are unrelated	Negative	From original survey

To compare the behaviour of the scale, the questions were separated out into two sub-scales, one positively phrased and the other negatively phrased.

Table 27: Reliability data for 2016/17 Integration scales.

2016/17 Integration	Cronbach's Alpha
Actual – Positive	0.779
Prefer – Positive	0.815
Actual – Negative	0.853
Prefer - Negative	0.605

Although both the positively and negatively phrased Integration scales are within the reliable range, there is a notable difference between the positively and negatively phrased scales (table 27).

For the positively worded scale, all inter-item correlation values across both Actual and Preferred forms are above the threshold of acceptance, and the corrected item totals are much higher than other scales, with values of up to 0.712.

For the negatively worded scale, all inter-item correlation values on the Actual scale were acceptable, as were the corrected item total values. However, the inter-item correlation matrix for the preferred scale had several items below the acceptable threshold (table 28).

Table 28: Inter-item correlation matrix for Integration Preferred (Negative) scale 2016/17.

2016/17 Integration Preferred, Negative Dimensionality only					
No #	21	24	33	36	43
21	1	0.216	0.004	0.067	0.09
24		1	0.461	0.261	0.489
33			1	0.268	0.427
36				1	0.306
43					1

In addition to this, Question 21 has a corrected item total lower than the acceptable threshold at 0.120. It is possible that the dimensionality of using positively and negatively worded questions in the same scale is having an effect on the outcomes of this survey and this should be investigated further.

2017/18

Data was collected using the same question sets for 2017/18 to allow further comparison of positively and negatively worded items (table 29).

Table 29: Reliability data for 2017/18 Integration scales.

2017/18 Integration	Cronbach's Alpha
Actual – Positive	0.840
Prefer – Positive	0.760
Actual – Negative	0.902
Prefer - Negative	0.704

For the positively worded scale Actual scale, all values in the inter-item correlation matrix, and corrected item totals were above the threshold of acceptance. Deleting any single item would cause Cronbach's Alpha to increase away from the centre of the acceptable range. For the positively worded Preferred scale, question 27 had lower than threshold correlations with questions 38 and 40, 0.275 and 0.160 respectively. Corrected item totals were above the threshold of acceptance. Removal of questions 38 or 40 would decrease the value of Cronbach's Alpha to 0.711or 0.728 respectively however this would not be appropriate as it would decrease reliability for the Actual scale.

For the negatively worded Actual scale, the Cronbach's Alpha value suggests that the items in the scale may be too similar. All values in the inter-item correlation matrix and corrected item totals were above the threshold value for the negatively worded Actual scale. Deletion of any one item in the scale would at most reduce the Cronbach's Alpha to 0.856, which is still high. For the negatively worded Preferred scale has four inter-item correlations below threshold, all related to either questions 21 or 43 (table 30).

Table 30: Inter-item correlation matrix for Integration Preferred (Positive) scale 2017/18.

2017/18 Integration Preferred, Negative Dimensionality only					
No #	**21**	**24**	**33**	**36**	**43**
21	1	0.496	0.165	0.160	0.078
24		1	0.473	0.473	0.294
33			1	0.311	0.296
36				1	0.591
43					1

The corrected item total values for this scale are all above the threshold of acceptance, and the Cronbach's Alpha if any item was deleted would move the value away from the centre of the range of acceptance.

Using exclusively positively or negatively worded items in the scale appears to have broadly increased inter-item correlation and corrected total values for the Actual scale, however the Preferred scale is still not showing as reliable for either the positively or negatively worded scale (table 31). The scale has performed less reliably in the Negative preferred scale than either the equivalent mixed or positive scale. It is possible that the dimensionality is influencing the responses students are giving, and this would an interesting avenue to explore with future studies.

Table 31: Reliability data for all modes of Integration scales 2016/17 and 2017/18.

	number of items	2016/17	2017/18
Mixed - Actual	7	0.859	0.900
Mixed - Preferred	7	0.709	0.695
Positive - Actual	4	0.779	0.840
Positive - Preferred	4	0.815	0.760
Negative - Actual	5	0.853	0.902
Negative - Preferred	5	0.605	0.704

3.2.3 Including and excluding in-fill data values.

Instructions on how to analyse the SLEI are somewhat limited in the literature, and some interpretation was required. For the SLEI-based questions, the scoring method is to sum the weighted score responses (Fraser & Wilkinson, 1993). The TROFLEI attitude scales require the researcher to sum the score values, so this was applied to the Attitude to technology scale (Aldridge & Fraser, 2008, 2011). The Use of Technology scale was developed from an appendix to the TROFLEI tool, which required the researcher to sum the items and subtract 10 (Aldridge & Fraser, 2008).

The instructions for using environment inventories often indicate that the researcher should in-fill missing data values in scales using the mid-point of the scale (Fraser, 1981).

The high amount of non-completed scales caused concern so the impact of the distribution of student data by adding in the mid-value, 3, to incomplete scale responses was investigated. Initially, a threshold was determined that a participant was required to have at least 50% of a scale complete to qualify to have the mid-point scores in-filled.

Prior to undertaking any statistical difference testing, it is important to undertake distribution testing to ensure that the tests used are appropriate for the distribution of the data set. Shapiro Wilks tests were undertaken on the full set of respondent data to assess whether the data was parametric or non-parametric, with Open-endedness and Integration being excluded from 2014/15 analysis due to the changes in the structure of the survey meaning no responses were complete without in-fill values. For this test, a p-value of less than 0.05 indicates that the data is non-parametric.

Tables 33 and 34 show the outcomes of this test, with only 2 scales having their distribution affected by the addition of the in-fill values, Social Cohesiveness preferred and Integration actual in 2017/18. As only two scales are affected, and these scales have very low response numbers in relation to the rest of the data set, it was decided that 3's would be added to the participants who had more than half of their scale completed (table 32).

Table 32: The number of scale responses in the modified SLEI with in-fill values added, split by year.

Survey Edition		2014-15	2015-16	2016-17	2017-18
Social Cohesiveness	Actual	4	2	3	4
	Preferred	7	2	9	5
Open-Endedness	Actual	N/A	1	5	6
	Preferred	N/A	2	8	7
Integration	Actual	N/A	1	7	6
	Preferred	N/A	4	10	6
Rule Clarity	Actual	5	2	3	5
	Preferred	7	2	7	5
Material Environment	Actual	N/A	N/A	N/A	N/A
	Preferred	N/A	N/A	N/A	N/A
Use of Technology	Actual	2	1	3	0
	Preferred	2	2	2	2
Attitude to Tablets		2	0	1	2

This test did highlight that several of the scales are non-parametric, which would typically impact on the choice of statistical test undertaken later in the study. Other published SLEI studies typically use non-parametric tests, but do not always declare the distribution statistics for the data.

Table 33:Shapiro-Wilks test values for each scale of the modified SLEI for 2014/15 and 2015/16 with and without in-fill values. Data in bold is non-parametric with a p-value of less than 0.05. Reproduced with permission from (Rayment, 2023)

	2014/15						2015/16					
	With 3s			No 3s			With 3s			No 3s		
Scale	Statistic	df	p.	Statistic	df	p	Statistic	df	p	Statistic	df	p
Social Cohesiveness Actual	0.962	90	**0.011**	0.964	86	**0.016**	0.974	101	**0.045**	0.975	99	0.055
Social Cohesiveness Preferred	0.944	90	**0.001**	0.937	83	**0.001**	0.931	100	**0**	0.93	98	**0**
Open Endedness Actual	-	-	-	-	-	-	0.97	101	**0.019**	0.97	100	**0.021**
Open Endedness Preferred	-	-	-	-	-	-	0.968	100	**0.016**	0.97	98	**0.026**
Integration Actual	-	-	-	-	-	-	0.98	101	0.127	0.979	100	0.116
Integration Preferred	-	-	-	-	-	-	0.964	100	**0.008**	0.96	96	**0.006**
Rule Clarity Actual	0.919	94	**0**	0.919	89	**0**	0.931	101	**0**	0.928	99	**0**
Rule Clarity Preferred	0.856	94	**0**	0.862	87	**0**	0.908	100	**0**	0.903	98	**0**
Use of Technology Actual	0.973	87	0.069	0.973	85	0.069	0.984	107	0.23	0.984	106	0.215
Use of Technology Preferred	0.964	87	**0.015**	0.963	85	**0.016**	0.951	96	**0.001**	0.944	94	**0.001**
Attitude to Technology	0.978	87	0.145	0.98	85	0.225	0.981	112	0.113	0.981	112	0.113

Table 34: Shapiro-Wilks test values for each scale of the modified SLEI for 2016/17 and 2017/18 with and without in-fill values. Data in bold is non-parametric with a p-value of less than 0.05. Reproduced with permission from (Rayment, 2023)

	2016/17						2017/18					
	With 3s			No 3s			With 3s			No 3s		
	Statistic	df	p	Statistic	df	p	Statistic	df	p	Statistic	df	p
Social Cohesiveness Actual	0.977	90	0.115	0.977	87	0.129	0.966	40	0.274	0.963	36	0.259
Social Cohesiveness Preferred	0.961	90	**0.009**	0.956	81	**0.007**	0.933	39	**0.023**	0.952	34	0.137
Open Endedness Actual	0.981	92	0.189	0.979	87	0.181	0.968	41	0.303	0.969	35	0.421
Open Endedness Preferred	0.979	91	0.155	0.981	83	0.255	0.967	41	0.272	0.964	34	0.319
Integration Actual	0.979	92	0.133	0.979	85	0.171	0.959	41	0.149	0.937	35	**0.045**
Integration Preferred	0.972	92	**0.048**	0.971	82	0.056	0.921	41	**0.007**	0.908	35	**0.006**
Rule Clarity Actual	0.914	92	**0**	0.912	89	**0**	0.906	41	**0.002**	0.892	36	**0.002**
Rule Clarity Preferred	0.875	92	**0**	0.856	85	**0**	0.844	41	**0**	0.838	36	**0**
Use of Technology Actual	0.967	98	**0.013**	0.966	95	**0.015**	0.978	45	0.524	0.978	45	0.524
Use of Technology Preferred	0.979	94	0.134	0.978	92	0.119	0.966	44	0.213	0.966	42	0.239
Attitude to Technology	0.99	102	0.638	0.99	101	0.619	0.965	49	0.154	0.966	47	0.183

3.2.4 Formation of the finalised scales

As the scales have changed throughout the years, it is important to consider whether to include new "re-phrased" scale items in the final scale scores. This is because if a re-phrased question is included in the scale, any survey data collected prior to the inclusion of the question will be incomplete.

Cronbach's Alpha reliability analysis was undertaken on each permutation of questions for each year of data collection, both including and excluding questions that were unavailable at previous stages. An example of this table for one scale, Social Cohesiveness, is shown below as table 35. Each row represents a different set of including or excluding questions. This was an exercise undertaken to identify whether including the revised questions improves the scale, or if they could be excluded entirely from the scale, permitting the use of a greater set of longitudinal data. For example, if Social Cohesiveness question labelled 2015-C5A was included in the final data set, data for Social Cohesiveness for 2014/15 could not be used, as items would be missing from the scale.

Table 35: Example permutation grid for Social Cohesiveness scale, with Cronbach's Alpha values.

Scale	Year	Questions to include							Alpha score
Social Cohesiveness	2014/15	2016-C1A	XX	2016-C2A	2016-C3A	2016-C4A	XX	2016-C6A	.835
		2016-C1P	XX	2016-C2P	2016-C3P	2016-C4P	XX	2016-C6P	.782
	2015/16	2016-C1A	XX	2016-C2A	2016-C3A	2016-C4A	XX	2016-C6A	.846
		2016-C1P	XX	2016-C2P	2016-C3P	2016-C4P	XX	2016-C6P	.857
		2016-C1A	XX	2016-C2A	2016-C3A	2016-C4A	2015-C5A	2016-C6A	.799
		2016-C1P	XX	2016-C2P	2016-C3P	2016-C4P	2015-C5P	2016-C6P	.825
	2016/17	2016-C1A	XX	2016-C2A	2016-C3A	2016-C4A	XX	2016-C6A	.848
		2016-C1P	XX	2016-C2P	2016-C3P	2016-C4P	XX	2016-C6P	.792
		2016-C1A	XX	2016-C2A	2016-C3A	2016-C4A	2015-C5A	2016-C6A	.772
		2016-C1P	XX	2016-C2P	2016-C3P	2016-C4P	2015-C5P	2016-C6P	.719
	2017/18	2016-C1A	XX	2016-C2A	2016-C3A	2016-C4A	XX	2016-C6A	.853
		2016-C1P	XX	2016-C2P	2016-C3P	2016-C4P	XX	2016-C6P	.616
		2016-C1A	XX	2016-C2A	2016-C3A	2016-C4A	2015-C5A	2016-C6A	.817
		2016-C1P	XX	2016-C2P	2016-C3P	2016-C4P	2015-C5P	2016-C6P	.530

Table 35 shows how this process was undertaken, with removed questions being flagged as discarded. Items filled in black are where no data was available, so a question was revised subsequent to data collection. Items highlighted in red are those where a question was removed. Blue boxes signify that the question was included for the reliability analysis in that row, while yellow shoes excluded.

The final version of the Modified SLEI questionnaire used within this study with the questions in order of presentation is available as Appendix 5. The questions that were retained for analysis are listed overleaf, compiled by scale.

Finalised Modified SLEI

Social Cohesiveness

Students in this laboratory class get along well as a group
Students in this laboratory class help one another
Students in this laboratory class get to know each other well
Students are able to depend on each other for help during laboratory activities
It takes too long for me to get to know people by name in this laboratory class
Students work cooperatively in laboratory sessions

Open-Endedness

There is an opportunity for students to pursue their own science interests in this class
In our laboratory sessions we asked to design our own experiment to explore a topic
Within a laboratory sessions students follow different procedures or use different samples to investigate same idea
Students are allowed to go beyond the regular laboratory exercise and do some experimenting of their own
In a laboratory different students to different experiments
The students decide the best way to proceed during laboratory experiments

Integration

The material covered in our regular lectures/seminars is unrelated to our laboratory work
The laboratory work is unrelated to the topics that we are studying in our lectures/seminars
Our regular lecture/seminar work is integrated with laboratory activities
We use the theory from our lectures/seminars during laboratory activities
The topics covered in lecture/seminar work are quite different from the topics dealt with in laboratory sessions
Laboratory work and lecture/seminar work are unrelated
Flipped questions for the purposes of investigating dimensionality
Our regular lecture/seminar work is not integrated with laboratory activities
The material covered in a regular lectures/seminars is related to our laboratory work

Rule Clarity

Our laboratory has clear rules to guide student activities
Students are required to follow certain rules in the laboratory
There is a recognised way of doing things safely in this laboratory
The instructor outlines safety precautions before the laboratory sessions commence

Use of Technology

If I face difficulties in the laboratory, I use the tablets to search for an answer
I use tablets in the laboratory to refer to my lecture notes to help me understand my equipment
Whilst in the laboratory access further reading using the tablets to help my understanding
I use the tablets to help me link my laboratory work to "real-world science"
I use the tablets to access information on how to use equipment/procedures safely

Attitude to Technology

I'm good with tablets
I like working with tablets
Working with tablets inspires me
I am comfortable trying new software on the tablets
Working with tablets is motivating
I do as much work as I can using the tablets
I feel comfortable using a tablet

3.2.5 Reliability and validity of the modified SLEI

To investigate the reliability of the finalised scale, Cronbach Alpha tests were run for each scale. Discriminant validity testing was undertaken to confirm that each of the scales were discrete and there was no redundancy in measuring the same parameter more than once. This uses a multivariate analysis known as correlation matrix analysis which measures that each scale is discrete by comparing the mean correlations between the scales. The analyses were undertaken using GraphPad Prism, and as the data is a mix of parametric and non-parametric data sets, Spearman Rho was used to calculate the discriminant validity (Table 37).

Discriminant validity is a measure of validity, which checks that the scales within a tool are in fact measuring linked but unrelated phenomena. As for Cronbach's alpha, there is no defined value for acceptable discriminant validity values, however there is guidance available (Clark & Watson, 1995) If the discriminant validity value is too high over 0.85, then the phenomena pair considered are likely to be related to one another closely, meaning they should not be used in a construct-based tool such as an environment inventory, where the constructs or scales are designed to be separate parameters relating to a single environment.

The Cronbach Alpha values for the scales range from 0.422 to 0.924, and the mean correlation values range from 0.09 to 0.44. All discriminant validity values are acceptable, with low values indicating that the scales are sufficiently different. However, several scales have Cronbach Alpha values for both actual and preferred scales that are either too high (over 0.9) or too low (below 0.6). This appears to not be uncommon within the use of the SLEI (table 36) with published tools declaring both Cronbach Alpha values or Discriminant Validity ranges that could be deemed unacceptable when considering them in comparison to statistical guidelines.

Table 36: Cronbach Alpha and Discriminant Validity ranges from a variety of SLEI-derived tools and the TROFLEI.

Reference	Tool	Cronbach Alpha Values	Discriminant Validity Range
(Wong & Fraser, 1997)	CLEI (Modified SLEI)	0.41-0.91	0.03-0.542
(Henderson et al., 2000)	SLEI	0.58-0.92	0.10-0.52
(Lightburn & Fraser, 2007)	Modified SLEI (4 scales)	0.67-0.93	Not declared.
(Aldridge & Fraser, 2008)	SLEI	0.85-0.98	0.15-0.48
	TROFLEI	0.09	0.21
This study (Evans, 2025)	Modified SLEI and TROFLEI scales	0.422 to 0.924	0.09 to 0.44

Table 37: Reliability and validity data for the modified-SLEI final form, reproduced with permission from (Rayment, 2023)

scale	**no. items in the scale**	**Year**	**Cronbach- α**		**Mean correlation with other scales**	
			actual	preferred	actual	Preferred
Social Cohesiveness	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
Openendedness	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

3.2.6 Investigation of difference in student attitudes towards the teaching laboratory environment.

A key theme in the literature regarding the teaching laboratory is the development of students throughout their courses (Bertram et al., 2014) , and models of conceptual development indicate that would be an anticipated difference in the ways students of different educational levels approach their studies.

For the purposes of this comparison, responses were categorised as new students (year 1, level 4) or those in graduating years (Year 3, level 6 BSc and Year 4, level 7 MChem) (table 38).

Table 38: Number of students with at least one complete scale response for the modified SLEI, Chemistry and Forensic Science students only.

		2014/15	2015/16	2016/17	2017/18	Total
Forensic Science	New	7	30	12	3	**52**
	Graduating	3	9	6	1	**19**
Chemistry	New	19	19	21	6	**65**
	Graduating	5	9	21	10	**45**
	Total	**34**	**67**	**60**	**20**	

Response rates for MChem (Year 4, level 7) students were very low with a total of just 7 MChem students responding, this is likely caused by the student numbers for this cohort being typically low.

Distribution test of responses from students on Chemistry-based courses.

The tool performing as a cross-discipline tool was important as this project is part of a larger research project, encompassing two departments, Biosciences and Chemistry & Forensic Science. This study focuses exclusively on those in Chemistry-based degrees, and subsequent analysis uses exclusively data from students within the Chemistry and Forensic Science department. As such it was necessary to undertake normality testing of the Chemistry and Forensic Science data. Shapiro Wilks normality test was undertaken of this isolated data (table 38).

Table 39: Normality data for all years of SLEI data combined, Chemistry and Forensic Science students.

Scale	Scale Type	Item mean	Standard Deviation	Shapiro-Wilk p-value	Parametric (Yes/No)	n
Social Cohesiveness	Actual	12.749	3.701	0.015	Yes	167
	Preferred	10.748	3.169	0.000	Yes	163
Open-Endedness	Actual	21.022	3.691	0.027	Yes	136
	Preferred	19.304	4.07	0.392	**No**	135
Integration	Actual	14.382	4.347	0.047	Yes	136
	Preferred	11.63	3.512	0.001	Yes	135
Rule Clarity	Actual	6.935	2.162	0.000	Yes	170
	Preferred	6.213	1.962	0.000	Yes	169
Use of Technology	Actual	6.434	3.827	0.045	Yes	175
	Preferred	5.314	4.505	0.024	Yes	169
Attitude to Tablets		20.75	5.683	0.113	**No**	180

Investigation of difference in student attitudes towards the teaching laboratory environment by student year group.

To assess for difference, a one-way MANOVA was completed on each the actual and preferred data sets to compare the responses from new students and graduating students. For these tests, students were grouped into two groups, new students (Year 1, level 4), and graduating students (years 3 and 4, FHEQ levels 6 and 7). As the MANOVA is usually undertaken on parametric data, and some of the scales in the modified-SLEI data set are non-parametric, a post-hoc Box's M test was undertaken to ensure the validity of any differences found (table 40).

The Attitude scale does not have actual/preferred forms, so was included in the Actual scale set, because the questions ask the students about their current actual attitudes to devices.

Table 40: Outcomes of statistical difference tests for modified-SLEI responses for Chemistry and Forensic Science students, New and Graduating groups, all years.

	MANOVA outcomes		Box's M test	
Scale Group	**Wilks-Lambda F value**	**Wilks-Lambda p value**	**Box's M Value**	**Box's M test p value**
Actual scales including Attitude	0.931	1.554	28.784	0.163
Preferred scales excluding Attitude	0.976	0.598	21.483	0.154

For the Actual scale set, the Wilk's Lambda p value exceeds the F value, and therefore there is a significant difference in the Actual responses from new and graduating students. The Box's M test values indicate that the tests are valid as the distributions of the data sets match, which counteracts any non-parametric effect on the data.

For the Preferred scale set, the Wilk's Lambda p value does not exceed the F value, and therefore there is not a significant difference in the Preferred responses from new and graduating students. The Box's M Test values indicate that the tests are valid as the distributions of the data sets match, which counteracts any non-parametric effect on the data.

To investigate the differences, a set of unpaired t-tests were undertaken on the Actual scale set. As part of the t-test, it is recommended that Levene's Test for Equality of Variances is applied. As most values are in excess of 0.05, the variances of the different scale samples are assumed to be the same (table 41), the notable exception is Rule Clarity, where equal variance is not assumed as $p<0.05$.

Table 41: Results from Levene's Test for Equality of Variances, Modified-SLEI data, new vs graduating students, Chemistry and Forensics students only. Actual Scale set.

	Levene's Test for Equality of Variances	
	F	p
SC_Actual	0.015	0.901
OE_Actual	3.712	0.056
I_Actual	0.293	0.589
RC_Actual	4.830	**0.029**
Tech_Actual	0.805	0.371
Attitiude	1.008	0.317

The t-test results (Table 42) indicates that there is a statistically significant difference in two of the scales from the Actual set - Use of Technology, and Integration, as the two-tailed test p-values are below the significance threshold of 0.05.

To represent the direction of difference Stem-and-Leaf plots were generated using SPSS to visualise the comparative spread of the data (figs. 12 and 13). These plots display that new students are scoring slightly higher on both technology use and integration than graduating students.

Table 42: Outcome for unpaired t-test of the modified SLEI, new vs graduating students, Chemistry and Forensics students only, Actual Scale set.

Independent Samples Test

		t-test for Equality of Means							
				Significance				95% Confidence Interval of the Difference	
		t	df	One-Sided p	Two-Sided p	Mean Difference	Std. Error Difference	Lower	Upper
SC_Actual	Equal variances assumed	0.981	165	0.164	**0.328**	0.592	0.603	-0.599	1.783
OE_Actual	Equal variances assumed	1.495	134	0.069	**0.137**	0.976	0.653	-0.315	2.268
I_Actual	Equal variances assumed	2.033	134	0.022	**0.044**	1.553	0.764	0.042	3.064
RC_Actual	Equal variances not assumed	-1.601	99	0.056	**0.113**	-0.592	0.370	-1.326	0.142
Tech_Actual	Equal variances assumed	2.505	173	0.007	**0.013**	1.497	0.598	0.317	2.676
Attitiude	Equal variances assumed	1.619	178	0.054	**0.107**	1.430	0.883	-0.313	3.174

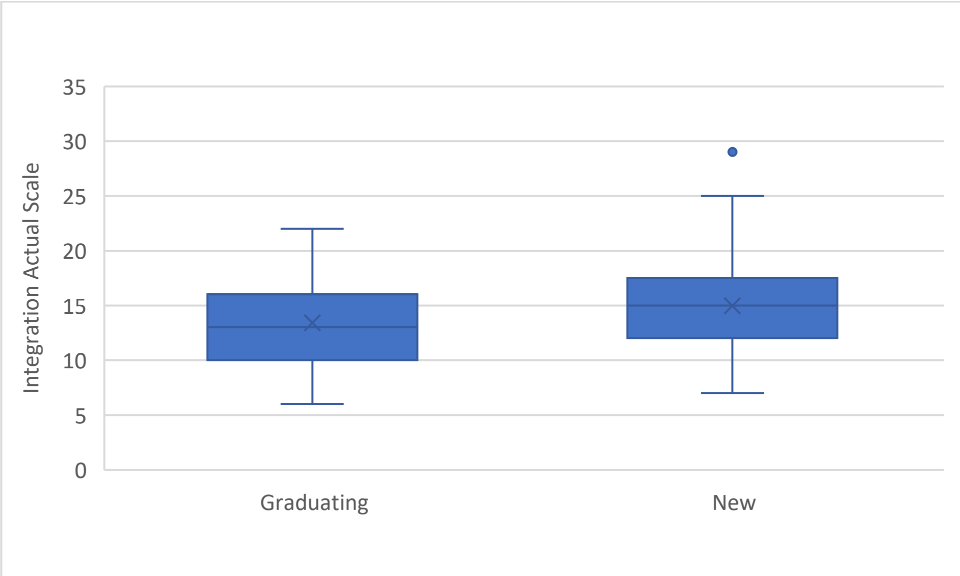

Figure 12: Stem and Leaf plot of Integration Actual Scale responses for modified SLEI, Chemistry and Forensic Science students, split by Graduating and new students.

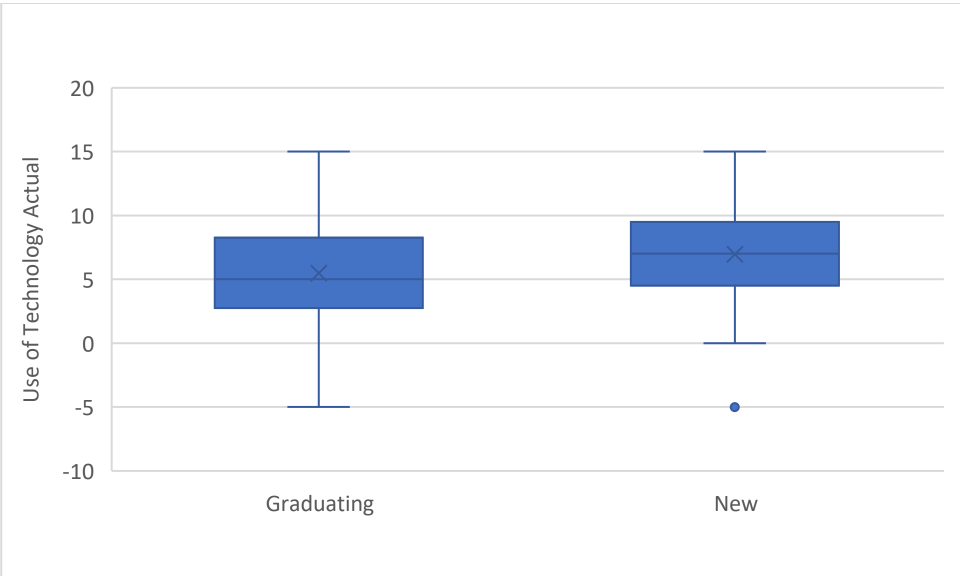

Figure 13: Stem and Leaf plot of Use of Technology Actual Scale responses for modified SLEI, Chemistry and Forensic Science students, split by Graduating and new students.

Figures 12 and 13 indicate that there is a difference between new and graduating students' perceptions of the teaching laboratory, with graduating students perceiving lower levels of integration between their taught content and their teaching laboratory environment, and also lower levels of technology usage.

3.2.7 Discussion

The outcomes of the difference testing for the modified SLEI data indicates that there is a significant difference in the student-perceived actual experiences for the scales of integration and use of technology between of the different level student groups. The purpose of the environment inventory is not to identify the cause of that perceived difference, and therefore this requires further exploration. Interestingly, the preferred student-perceived experiences of these participants do not differ in any area, indicating that they have similar preferences for their teaching-laboratory experiences regardless of level.

The reliability data for the modified SLEI been concerning during the development process, requiring with a considerable degree of modification from the original tool. As such, the modified SLEI would require re-validation when the final structure of the tool was finalised. The results of this validation test are at best varied, with 11 scales out of 44 producing unacceptable values for Cronbach's alpha, with Rule Clarity being of most concern.

Employing the modified SLEI in this context did not produce consistent and reliable results as would be anticipated for such a highly validated tool, with concerns relating to the of reliability survey outcomes even when the tool was had a consistent format and content in the final two years of data collection. There were consistent issues with the responsiveness of students, with low response numbers from the cohort making this study much smaller than any of the other studies published using SLEI-derived tools, which could account for the lack of reliability. Similarly, it is unclear if other SLEI-derived tool studies using multiple cohorts of students employed a method to control for variances in delivery in a longitudinal or varying cohort sample. This raises the question of whether the modified SLEI is indeed suitable for researching the Superlab environment where a wide variety of courses are studied.

A possible contributing factor to this variability in student responses when using an environment inventory style tool within the context of this study is the non-homogeneity of the Superlab environment. Each year the researchers were faced with a variety of challenges causing uncontrollable change in the Superlab environment, making comparison between years challenging. Examples are listed below:

- Changes in course content
- Changes in teaching laboratory activities
- Changes in student's prior experiences, such as changes to A-level structures (ofqual, 2018)
- Changes in staffing
- Changes in the hardware and software in the Superlab environment, notably a complete device and operating system change in 2017 from Android tablets to Windows Surface tablets.

These changes are beyond the control of the researchers and often happen in such a way that the researchers are unable to account for them in the data collection or tool design process but may explain why the modified-SLEI did not behave as expected. Environment inventories have been used successfully in a longitudinal manner to monitor changes in an environment (Aldridge and Fraser 2011), but not to monitor an environment in spite of variation. In studies where data is collected from multiple cohorts, it is not immediately clear if data was collected concurrently from those cohorts, and whether these cohorts were employing similar course structures or curricula (Wong and Fraser 1996a).

An additional challenge in relation to the use of environment inventories, as discussed in section 3.2.3, is ensuring the scoring of the modified SLEI is consistent with other SLEI-derived tools. Scoring systems for the SLEI-derived tools were challenging to ascertain, as the SLEI has been modified many times in a variety of contexts (Section 3.2) and the scoring methods are not always included in publications of the subsequent iterations of the SLEI, and they are assumed to adhere to previous iteration. Due to the age of the original tool, the original papers are difficult to obtain to verify this adherence. The tools and reliability and validity data of each modification are readily published; however, the scoring rubrics for each iteration of the tool are not always easily available for researchers to implement and as such, scoring rubrics were derived from the SLEI and TOSRA. This resulted in a bespoke scoring scale of the modified SLEI reduces the capacity of this study to be readily compared to other SLEI-based studies. It is essential that before a tool is deployed in research, a clear and robust analysis mechanism is in place, which would have allowed some comparison between this study and other studies where the SLEI has been modified.

The unusual reliability values produced by this study does however reinforce how critical it is to re-validate any tool when it is imported into a new context, even if the context seems related or familiar, as the impact on the data from any variation in the new environment is unknown until it is tested. This is however challenging in many STEM faculties in Higher Education settings in the UK, due to the lower cohort numbers per institution, the varied curricula and teaching methods between institutions. Additionally, there are the low uptake of students and survey fatigue of using such large survey tools which were both factors within this study.

The quantitative elements of this study on their own have been unable to adequately explain the student experience within the teaching laboratory or provide a deep understanding of how students are using the technology-rich teaching laboratory environment. As such, a more qualitative and exploratory methodology was developed, exploring the research questions using a mixed methods context.

A variety of approaches were considered, with identified strengths and weaknesses tabulated as table 43.

Table 43: Data collection methods considered for qualitative data collection.

Data Collection Method	Strengths	Weaknesses
Open ended surveys (Bradburn et al. 2004)	Able to collect data from a larger number of participants and can allow more accurate representation of less socially desirable behaviour in comparison to closed question surveys. Allows for unique responses to be collected, not just common ones.	High volume of textual analysis, and the possibility of researcher influence is high, as there is no opportunity to ask additional questions or explore topics raised further, unless paired with further data collection.
Interviews (Kvale 2007; Rowley 2012; Segal et al. 2006)	Participants can express their own opinions and experiences without peer influence. Open ended questions in interviews have similar strengths as for surveys, with researchers able to represent unique responses as well as common ones.	Time consuming to transcribe. Possible impact of interviewer on responses introducing bias (Kvale 2006).
Focus Groups (Morgan 1996; Gill et al. 2008)	Discussion of experiences with peers can highlight commonality and difference in experiences.	Group dynamics require careful management by the interviewer to avoid peer influence bias.
Observational Research (Cohen et al. 2017; Opie et al. 2004)	Allows accurate observation of student activities within the Superlab, which is not skewed by self-reporting.	Structured data collection required, to avoid data overwhelm Analysis is very time consuming and requires iterative review. It is possible that observation affects the behaviour of participants. Given the scale of the Superlab, this was not chosen as observing in a highly populated environment is challenging.

Qualitative interviews with stakeholders within the teaching laboratory, both students and staff, were developed to further explore the variation in experience of students of different levels that was identified in the modified SLEI. The themes are designed to explore areas that were not well explored by the qualitative studies such as student approaches and perception of purpose of the teaching laboratory, as well as questions relating to decision making within the teaching laboratory which aimed to probe how students are using the teaching laboratory. The final year of data collection for the quantitative study overlaps with the start of the development for the interview protocols for the qualitative study, with the staff interviews and first set of student interviews happening in the same academic year as the final year of data collection for the SLEI.

4. Qualitative investigation of teaching laboratory experiences

As the quantitative phase of this study raised a lot of questions and provided few clear answers, a decision was made to embrace the more exploratory methods of qualitative research, by combining the existing quantitative studies with a qualitative element, namely interviews of both staff and students who operate within the Superlab environment.

4.1.1 Methodology

4.1.2 Mixed methods research.

Mixed methods research relies on the collection of both qualitative and quantitative data (Tashakkori & Creswell, 2007), and the complementary analysis of these to produce an integrated conclusion. Johnson & Onwuegbuzie (2004) suggest that mixed methods research attempts to combine the strengths of both qualitative and quantitative methods, while attempting to mitigate the weaknesses. In the context of this project, it is intended that mixed methods will be employed to avoid the over-generalisation of qualitative research resulting in a homogenous perception of a richly varied environment, while also not over-focussing on details relating to individual students. The combination of qualitative and quantitative research undertaken within this project aims to provide guidance to practitioners regarding best practice for operation within the teaching laboratory, while exploring the experiences of students and staff within the teaching laboratory.

4.1.3 Phenomenography

Phenomenography (Bowden & Walsh, 2000) is a qualitative methodology that is well suited to exploring educational environments and experiences (Orgill, 2007) and has been used extensively within chemistry educational research to investigate educational phenomena (Tullberg, 1997). Initially developed by Marton (1986), phenomenography differs from its more well-known relative phenomenology (Cibangu & Hepworth, 2016), (Bowden & Green, 2005), (Bowden & Walsh, 2000), in that phenomenography is designed to collect data from participants on the varieties experience of the individuals that the researcher then interprets to gain perspective on the phenomenon, with the focus being on perception and experience rather than the essence of the phenomenon. This is highly important within educational environments as students are not homogenous and may react differently given the same environment (Marton, 1986), (Marton, 1992). Marton (2014) suggests that phenomenographic research can be combined with quantitative data to provide a rich picture of perceptions of a phenomenon. The capacity to represent differing perceptions of a phenomena is ideal to overcome the preconceptions relating to an environment that one is very familiar with.

4.1.4 Data collection and development

Focus groups and Interviews

Phenomenographic investigation of an environment requires collection of rich personal data (Bowden & Walsh, 2000), therefore qualitative, open data collection is needed. A variety of methods can be used to collect data for this purpose, but the two most common methods are interviews and focus groups.

A focus group is a group interview format, where six to ten participants discuss a topic, facilitated by a moderator (Kvale, 2007). Focus group moderation is a skilled role (Boddy,

2005) that requires extensive training to produce a constructive and supportive atmosphere where participants feel free to discuss even sensitive topics (Chrzanowska, 2002).

An interview is a one-on-one data collection method between the participant and the interviewer, where the participant is directly asked questions by the interviewer (Kvale, 2007). Chrzanowska (2002) indicates that without the structure of the focus group, the interviewer-participant relationship can be impactful on the data collected within one-on-one interviews, and interviewer training is important.

Although focus groups can offer insights resulting from the discussion between participants, focus groups are not intended to reach consensus (Kvale, 2007), and are likely to be impacted by moderator experience levels and bias so can be more limited in their outcomes. Interviews were selected over focus groups as they allow for greater personal experience with reduced pressure of peer opinion (P. Gill et al., 2008),.

Interview formats

Interview structures exist on a continuum from structured to unstructured, with advantages and disadvantages of each approach (Brinkmann, 2020).

Structured interviews follow a pre-defined set of questions, with restrictions on allowance of the interviewer asking probing or elaboration questions (Brinkmann, 2020). Segal et al. (2006) describe the strengths of the structured interview extensively including that as the same questions are asked of all participants, direct comparison between participants is possible. Additionally, Segal suggests that as there are restrictions on the input of the interviewer, it is possible for the interviewers to vary between participants with minimal impact on the content of the interview. Brinkmann (2020) indicates that fully structured interviews are more analogous to surveys than less structured interviews, with little room for participants to narrate their own experiences, so they are less suitable for exploratory studies on poorly understood phenomena.

Unstructured interviews have a defined topic or theme, but few restrictions on the questions asked during the interview with few pre-defined questions, as such the interviewer is primarily a listener and asking for clarification where required (Brinkmann, 2020). When researching an unknown or poorly understood phenomenon Brinkmann (2020) suggests that it is not possible to prepare questions in advance in a thorough way, and the space within the semi-structured interview allows the interviewer to be responsive to the participant's experiences and promotes the facilitation of a participant's narration of their lived experience. Unstructured interviews also allow the interviewer to rephrase or re-word questions to facilitate the participant's responses, which can be advantageous when researching with participants who may struggle to understand questions, such as the young or cognitively impaired (Edelstein et al., 2006).

In an unstructured interview, the interviewer's control over the content and direction of the interview is intended to be minimal (Zhang & Wildemuth, 2017), so the direct comparison between different participants is challenging, Segal et al. (2006) explain that unstructured interviews are influenced by the needs of the participant, and that topics may not be covered by one participant, not because they are unimportant to the context or phenomena, but because they were simply omitted by the participant. This is particularly true with interviews that may have a broad scope, and extensive planning is required to prevent unfocussed, over-broad data collection that does not answer the research question (Zhang & Wildemuth, 2017).

Semi-structured interviews are perhaps the most widely used form of interviews within qualitative research and are found along a spectrum between structured and unstructured (Brinkmann, 2020). Johnson & Christensen (2008) illustrate the range of possible variety in semi-structured interviews by exemplifying either end of the spectrum, with *informal conversational interviews* and the *interview guide approach*. Informal conversational interviews are at the less-structured end of the spectrum, with topics of interest defined prior to the interview, and the interviewer forming questions based on the participant's responses. The interviewer as guide approach has several specific open-ended questions that are designed to prompt the participant to explore a given topic in detail, however there is no obligation for the interviewer to explore every avenue proposed by the participant which allows the interview to remain on a narrowly defined topic.

Semi-structured interviews were chosen as the teaching laboratory is linked to the learning experience of the students, and it could be possible for participants to discuss their incredibly broad experiences at university. Semi-structured interviews with the interviewer a guide approach was employed to keep the participants focussed on the Superlab environment, while having the freedom of expression to explore their perceptions of the environment. A semi-structured interview (de la Croix et al., 2018) rubric was developed, related to the teaching laboratory environment broadly, and specifically technology within the teaching laboratory.

As the interviews and the associated transcription and analysis are time-consuming, a limit was placed on the number of participants that could be invited for interview, with a maximum of 12 participants to be selected from any one year-group.

The researcher undertaking these interviews was a novice interviewer, as such it was decided to undertake the interviews with staff members first as pilot interviews to develop interview technique. The interviewer researched good practice for interviews prior to interviewing participants (Rowley, 2012).

Additionally, it is necessary to review possible sources of bias (Delgado-Rodriguez, 2004b) when undertaking research, but particularly with research involving qualitative data collected face to face.

It is possible that student participants who volunteered for the interviews were previously taught by the interviewer, as such students may represent views that they feel the researcher understands more readily or phrase their experiences more positively. Similarly, the researcher's affiliation with Nottingham Trent University by employment and studies could cause participants to suppress negative comments regarding the university environments or teaching (Kvale, 2006). This is particularly true for in-person student interviews where it was staff members wear different protective equipment to identify them, marking the interviewer as a staff member.

The researcher, as a teacher in the laboratory but also previously a student, held their own personal biases. A method of managing the impact of this is known as researcher reflexivity. Researcher reflexivity requires a researcher to acknowledge their own personal biases prior to undertaking analyses and ensure that phenomena as represented within research are based on clear observations within the participants(J. L. Johnson et al., 2020).

Selection survey

A participant selection survey was developed to allow for purposive selection of participants with varying demographic details, this intended to represent the widest variety of experiences possible. This survey was offered to participants in-person before their teaching laboratory classes to allow them to ask questions about the process and reassure them regarding time commitment and withdrawal rights. The survey was showcased as part of a "market stall" style stand, with the researcher present to answer any queries. Prospective participants were offered an incentive of food for engaging with the stall and were informed of their right to withdraw participation at any time. Participants who completed an interview were provided with a £10 amazon voucher in thanks to compensate them for their time.

Ethical approval

All selection surveys, interview themes and processes were approved as appropriate by the NTU school of science and technology non-invasive ethical panel.

Interview themes

Themes and guide questions identified for interviews.

Purpose of laboratory sessions – e.g., what do you think purposes of lab sessions are?

Learning associated with laboratory sessions – e.g., What do you think you learn in a lab session? [generally, not asked to staff]

Student aims of laboratory sessions – e.g., What are your aims for a typical laboratory session?

Strategies implemented by students to achieve aims – e.g., What do you do to achieve these aims?

Decision making associated with laboratory sessions – e.g., Why do you do these activities?

Recognition of achievement of aims – e.g., What does a successful lab session look like to you?

Staff aims of laboratory sessions– e.g., What aims do you think staff members have for you during laboratory sessions?

Comparison of Superlab – e.g., Considering the Superlab and other labs, what impact do you think using technology in the lab has on your learning?

Educational, experiential, teaching and family history of staff and students may be discussed, in reference to the themes above. E.g., prior experience of laboratory work, familiarity through family experiences etc.

Figure 14: Interview themes and guide questions for in-person interviews with staff and students.

4.1.5 Interview timeline

Staff interviews (2017)

- Interviews with staff participants
- In-situ in the Superlab
- Focusing on staff practice and staff perception of student behaviours
- 5 participants
- Manual verbatim transcription of audio recordings.

Student interviews (2018)

- Interviews with student participants
- In-situ in the Superlab
- Focussing on student perceptions of the laboratory
- First and final year students were offered two interviews, to check for in-year variation.
- 8 participants, 3 with second interviews.
- Manual verbatim transcription of sections of audio recordings, with MS Stream transcription being utilised for later stages of complete transcription.

Student interviews (2021)

- Interviews with student participants
- Online interviews via MS teams
- Focussing on student perceptions of the laboratory
- Single interviews offered due to logistical challenges of second interviews.
- Additional questions on technology added to themes.
- 7 participants
- Automatic transcription of MS Teams recordings using MS Stream, which are manually reviewed to allow for verbatim amendments and for accuracy.

4.1.6 Data Analysis

All interviews, both with staff and student participants were recorded. In person interviews were recorded on two digital audio recorders, with lapel microphones to allow for possible equipment failure and to counteract possible background noise in the teaching laboratory setting. Microsoft Teams interviews as used in the second set of student interviews were recorded using Microsoft Teams. All interviews were transcribed by the researcher verbatim. Interviews were initially analysed using using QSR NVivo (2018), however the researcher found this very challenging to manage with a large volume of data, and instead the researcher used post-it notes to group key themes and rearrange them physically. This process was undertaken question by question, in a structured approach to allow the researcher to manage data more effectively and prevent overwhelm (Saldana 2021).

Inductive coding (Azungah 2018) was used for all interviews in this study. Inductive coding principles require researchers to review the transcript without preconceptions of the anticipated content of the responses and assigning a label or “code” to participant statements to allow them to be grouped for commonality or difference (Deterding and Waters 2021). Codes can be grouped together to create higher levels of code or linked for association or theoretical importance without being the identical statements or ideas, as coding should move beyond the merely descriptive and aim to provide a deeper theoretical understanding of the material (Gibbs 2012). By way of contrast, deductive coding is an alternative coding method (Fife and Gossner 2024), where a researcher has a set of expected codes and screens the transcript for those phenomena rather than openly exploring the data set. Inductive coding is regarded as an effective way to minimise the effect of the researcher’s preconceptions on the outcomes of the interview analysis allowing new themes to emerge, rather than analysing transcripts in the context of existing research (McGowan et al. 2020), in line with phenomenographic methods (Bowden & Green, 2005). This General Inductive Approach (Thomas 2006) allows a large amount raw data such as a transcript to be condensed into a more manageable format for comparison between participants.

An example of the coding process is shown as table 44 for the first question asked to staff members, with key elements identified from the interview text, these grouped into codes, and then the codes being grouped into themes. A full coding table for this question is available as appendix 6.

Table 44: An example of the coding process, showing quotes from participant responses, keywords highlighted and coding. Narrow codes were grouped into larger thematic codes.

ID	Quotes	Keywords/phrases identified	Narrow Code	Broad code / Theme
2	"It's to apply theoretical knowledge in a practical sense and to build up their practical skills"	apply theoretical knowledge	Apply Theory	Learning Chemistry
		build up practical skills	practical skills	Practical/ Manipulative Skills
	"it helps in their understanding of what's being taught theoretically, so they have a kinaesthetic approach to umm.. to actual learning as well but also they need those physical skills to be able to operate in a lab environment safely basically"	understanding what's being taught theoretically	Understanding	Learning Chemistry
		operate in a lab environment safely	Safety	Practical/ Manipulative Skills
	I: ok so, in an ideal world, would you always have students coming in with some theoretical knowledge? P: not always. It's sometimes that doesn't occur because… the order in which they have lectures, so a lot of the practicals encompass usually a whole wide range of knowledge across that particular module and of course that module is being taught throughout the year. So at the start of the year we tend to try to give them the basic skills that they would need in the lab, but some of the more in-depth knowledge of say, instrumentation they don't learn until later on.	Lecture / lab link - does not always need to be chronological - linking theory	Chronology of learning	Other comments
		basic skills that they would need in the lab	practical skills	Practical/ Manipulative Skills
		in-depth knowledge instrumentation in the context of use	Understanding (Instrumentation)	Practical/ Manipulative Skills
	P: But, saying at the same time they are working in the lab and they are using those basic skills but, umm… they're not … they possibly don't understand how the instruments work quite so much, so you're trying to explain that as you go as well. So it is not just a session where they are engaging in an activity that they follow on a piece of paper like a recipe. It should be more an activity where they are actually learning as they go, umm… and possibly asking the demonstrator and supervisor questions of things they don't understand. I: ok, so there's like a knowledge seeking aspect during the lab as well? P: yes, there should be , yeah	explain as you go… actually learning as they go asking … questions knowledge-seeking, engagement	Active learning	Learning Chemistry

4.2. In person staff interviews

The first interviews undertaken were those with staff members. This was intended to be a pilot for the interview themes which had paired questions between staff and students.

Demographics of respondents

Seven staff members responded to the selection survey, two were unable to schedule interviews at compatible times with the researcher. Demographic information is shown in table 45, with some values generalised or removed to avoid identification of participants within ethical requirements. As there are far fewer staff, it is necessary to include less demographic information than is feasible for students to prevent identification. All staff members had taught at Nottingham Trent University for at least a year and were eligible to teach both within the Superlab and externally in other labs at Nottingham Trent University.

Table 45: Anonymised demographic information of staff interview participants (2017)

ID	Age	Gender	Teaching Area	Years of teaching experience
S2	36 & over	Male	Analytical chemistry	Over 15 years
S4	26 – 35	Female	More than one area of chemistry	5-10 years
S5	26 – 35	Male	Inorganic chemistry	5-10 years
S6	26 – 35	Female	Inorganic chemistry	Less than 5 years
S7	36 & over	Male	Organic chemistry	5-10 years

Staff Interview outcomes

Results are presented separated by question and collated by thematic group. The topic question is presented at the start of each section. Themes will be discussed at the end of each theme or question group to align staff perspectives to current literature.

Due to the semi-structured nature of the interviews, not all questions were asked in the same order to all participants, and if the participants had already covered the topic of a question, it may have been omitted.

Themes from staff interviews will be reflected upon in comparison with the student interviews that took place in subsequent years.

4.2.1 Purpose of the teaching laboratory

In this section, the staff members were responding to the question "What do you think the purpose of the teaching lab sessions are?"

Staff identified multiple purposes of the teaching laboratory, with purposes covered by staff including learning theory, learning practical chemistry skills, transferrable skills and increasing familiarity with the laboratory environment, which are grouped by theme.

Learning chemistry theory

All staff participants referenced theoretical learning as a purpose of the teaching laboratory, with several referring application of theory learnt elsewhere in the course.

Participant S2 indicated that the teaching laboratory is an environment in which students should be applying theoretical knowledge. They agreed that the teaching laboratory should be an environment in which students are actively seeking knowledge and identified methods to promote this knowledge-seeking behaviour. The participant indicated that they ask questions of the students throughout the sessions and avoid recipe-style laboratory experiments where students can follow instructions without thinking. This participant indicated that the teaching laboratory is an environment where students should be able to ask questions.

Participant S5 agreed that the purpose of the teaching laboratory is for application of theory, indicating that the purpose of the teaching laboratory is to fit within a teaching model of introduction, apply, context. Theory should be introduced in the lectures, applied by students to questions in seminars, and then applied to real life problems in the teaching laboratory.

I: What do you think the purpose of teaching lab sessions are:
P: To show there's a real use for the theory in the lectures. It's kind of like a three stage thing, where you get first stage is introduction to the material, so that's your lectures. This is where you're showing what you're supposed to know. And then a lot of the times, you show them what you know, you don't know it, that's the point, new stuff. And then stuff like tutorials , and kinda l… question based things, can you logically apply those theories…
I: yeah..
P: to a problem, and then the lab is that final thing where you apply it to a real life situation trying to make something.
I: ok, so it's sort of about… revisiting the same information in lots of different ways?
P: yeah

Figure 15: Excerpt from interview with participant S5 on the topic of the purpose of the teaching laboratory.

Participant S7 indicated that the purpose of the teaching laboratory is to demonstrate theory. Chemistry is a field that must be actively participated in, and they agreed that "doing chemistry" involved the application of chemistry theory.

P: I think another one is to demonstrate the theory of chemistry, so chemistry is a meaningless subject, to me, unless you actually do something
I: yeah
P: so sitting in a lecture theatre isn't actually doing... doing chemistry. So you have to put it into practice, and so, yeah that's all part of... part of the subject.
I: ok, so it's like a, for you it's a sort of it's the intrinsic "doing Chemistry" bit?
P: yes,. It doesn't have to be in a lab…
I: yeah?
P: it can be computationally or, or, or whatever... but yeah...
I: but it's the applying that matters...
P: that's
I: rather than the passive learning?
P: yes, yeah. yeah

Figure 16: Excerpt from interview with participant S7 on the topic of the purpose of the teaching laboratory.

Participant S6 indicated that theoretical learning is present in the best teaching laboratory sessions, but that this is not necessarily present in all sessions. Learning is described as an incremental process by this staff member, with students piecing together theory from within and outside the teaching laboratory in a longitudinal process. This participant refers to the teaching laboratory reinforcing the theory taught elsewhere in the course.

P: And also, I think for students who are more practical-minded, it's a good link to the theory to see it actually happening in practice. I think it's one of the great things about Chemistry is that most… things you learn about you could do in practice. Even in a teaching lab. Umm… So it's sort of another way of learning.

I: Ok. So you use it sort of as a… a reinforcement for the theory?

P: That… Ideally… In an ideal world that is how it would happen.

I: Ok, in the actual world, how do you think it happens?

P: I think they piece it together bit by bit. And occasionally you'll get somebody in a lab who goes "Oh, like how we learned back in the lecture!" or you'll get somebody in a lecture who goes "Oh, we did that in a lab!" because you don't always manage to get the timing right because of timetabling and lecturer constraints of who's teaching what when, but I think the best designed experiments are ones where there's practical learning and also some theory reinforcement. And not just feeling comfortable with chemicals and having an idea of timescales and what… the fact that things don't always work the first time. That kind of thing is equally as valuable, learning to plan an experiment

I: yep

P: Umm… so I'm definitely of the school of thought that you shouldn't just always let them run off a script because then the come to do their first research project or job, and they just don't know where to begin!

Figure 17: Excerpt from interview with participant S6 on the topic of the purpose of the teaching laboratory.

Participant S4 indicates that the teaching laboratory promotes students' ability to recall concepts.

The comments from participants S6 and S4 are consistent and relate to spaced repetition theory (Kang, 2016) which suggests that repeated encounters the same concept spaced out in time aids effective learning, with this paper determining that effective learning is long-lasting learning. Staff participants were asked "What their students learn in a laboratory session" and "what a successful laboratory session is" in a subsequent question to try and resolve the complex nature and often unclear definition of "effective laboratory teaching". The application of theory described by participants S2 and S5 could also be encompassed by spaced repetition theory, as this method of teaching encompasses various teaching methods, including problem solving, which can account for some of the application of theory as described above.

Participants S2 and S6 suggest that the teaching laboratory may be more effective for students who prefer a more hands-on model of learning, with S6 identifying that the teaching laboratory is beneficial for students who are practically minded, and S2 identifying that the teaching laboratory uses a kinaesthetic approach.

The phrase "kinaesthetic approach" may be linked to the visual, auditory, kinaesthetic learning styles model (Fallace, 2023), a popular and widely used learning styles model that indicates that students have a preference for learning via different types of tasks. This model has been criticized for a lack of validity and overly limited approach to learning styles (Y. Li et al., 2016).

Practical skills

Four participants indicated that the purpose of the teaching laboratory is to fosters the development of practical skills used within experiments.

Participant S2 indicated that the purpose of the teaching laboratory is to build up to enable safe operation within a laboratory environment. Practical skills were not defined by this participant, other than the link to safety.

I: what do you think the purpose of teaching lab sessions are?
P: It's to apply their theoretical knowledge
I: Mmm hmm
P: in a practical sense and to build up their practical skills
I: mmm hmm
P: So that umm… one – it helps in their understanding of what's being taught theoretically, so they have a kinaesthetic approach to umm.. to actual learning as well but also they need those physical skills to be able to operate in a lab environment safely basically

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P: So at the start of the year we tend to try to give them the basic skills that they would need in the lab, but some of the more in-depth knowledge of say, instrumentation they don't learn until later on. But, saying at the same time they are working in the lab and they are using those basic skills but, umm… they're not … they possibly don't understand how the instruments work quite so much, so you're trying to explain that as you go as well.

Figure 18: Excerpts from interview with participant S2 on the topic of the purpose of the teaching laboratory and practical skills.

Participant S4 indicated that the main purpose of the teaching laboratory is to develop practical and experimental skills, which they defined to be a wide range of skills that may vary between different sessions associated with different module content. The participant identified that practical skills encompassed health and safety within the laboratory too.

I: when you talk about practical skills and experimental skills,
P: Mmm hmm.
I: do you mean manipulative skills? or do you mean sort of data handling skills that go with the lab?
P: I think it's both, you can't really distinct [sic. distinguish] from one of them, so it depends obviously on which approach you're talking about, or which modules you're talking about or which type of chemistry, effectively.
I: ok
P: But I think it's both of them because I many kind of ways you'll have to have the lab setting where you actually do the experiment and you know how to handle the glassware, the uhh… health and safety of it as well.

Figure 19: Excerpt from interview with participant S4 on the topic of the purpose of the teaching laboratory and practical skills.

Participant S6 indicated that chemistry is a largely practical subject, so practical skills are important and are linked to future successful careers in chemistry-related fields. This participant listed a variety of techniques that are common within chemistry laboratory experiments and identified that repetition of these leads to effective skills learning.

P: (indistinct) Well… Chemistry, especially, is just a largely practical subject. A lot of the skills you want to get out of it are practical ones, if you are going to have a career in chemistry, at least to start off with… the skills you need, about half of them are probably practical-based. And there's no other way, really, to learn those skills other than to practice them. Not just once, but preferably repeatedly for the skills like weighing, pipetting, measuring, titrating, refluxing – all of those things you would need to do on a daily basis as a chemist.

Figure 20: Excerpt from interview with participant S6 on the topic of the purpose of the teaching laboratory and practical skills.

Participant S7 indicated that development of practical skills was the key aim within the laboratory. Later in the interview, when discussing their aims for students in the teaching laboratory, the participant indicated that this would be a range of techniques appropriate for the student's educational level, however producing an exhaustive list of these would be challenging.

I: What do you think the purpose of teaching labs sessions is?
P: ooh… that could be a very long answer. So one... one of the key things is to train students to have the practical skills…
I: mmm hmm
P: umm... (pause) that they may need in employment or further study or whatever…

Figure 21: Excerpt from interview with participant S7 on the topic of the purpose of the teaching laboratory and practical skills.

The meaning of practical skills seems to vary between participants and is ill defined. Where possible, the interviewer asked for more depth in these answers to avoid conflation of unrelated ideas. Although one participant, S5, included skills within this category that are not linked to apparatus or instrumentation within the teaching laboratory, these comments otherwise broadly relate to the use of apparatus or instrumentation within the teaching laboratory in an effective and safe manner.

Laboratory skills

For the purposes of this study, the following definition of laboratory skills has been adopted. **A laboratory skill is a skill that is necessary to operation within a laboratory setting, that is not a practical or physical manipulative skill. These skills may be able to be developed in environments other than the teaching laboratory, and include examples such as data handling, observation and critical thinking.** Laboratory skills are separate from practical skills which are physical manipulative skills that involve the use of equipment or instrumentation. When participants mentioned "laboratory skills", the interviewer did typically attempt to clarify whether they meant practical skills or laboratory skills such as observation.

Two participants identified laboratory specific skills that may be transferable external to the laboratory that are developed within the teaching laboratory within the broader purpose of the teaching laboratory.

Participant S4 emphasises that understanding observation is an important skill developed within the laboratory. They also emphasise the importance of the teaching laboratory for developing data handling skills. This participant indicated that it is not possible to clearly separate laboratory-related skills such as data handling from practical skills of using equipment, as they are all skills developed during the teaching laboratory sessions.

Participant S6 indicated that the purpose of the laboratory is to develop students' skills to allow effective operation in the laboratory and identified a range of transferable skills that can be employed within the laboratory such as planning an experiment, decision making and working with others in groups.

Familiarity within the laboratory

Participant S6 states that although a purpose of the teaching laboratory is for the students to feel comfortable with chemicals and timescales, that should not be the sole purpose. This participant also indicates that a purpose of the teaching laboratory is to develop a student's idea of "how to use the lab" which indicates a degree of familiarity.

Participant S4 echoed similar ideas as S6, with references to getting used to the teaching laboratory and gaining confidence with instrumentation within the teaching laboratory.

Other comments

In response to this question, participants did discuss some ideas that do not fit within the broad themes above, these are included in the section below to allow full representation of participants' responses.

Participant S2 was discussing the way students apply theory within the teaching laboratory and indicated that due to timetabling constraints, students do not always encounter the theory first external to the teaching laboratory. The participant said that it is not always necessary for this theory-first model to happen for effective learning, but with new students the teaching laboratory course is designed such that the first few sessions are very skills-focussed, and theory is included at a later date.

Participant S6 agrees with S2 in identifying that the timing of the teaching laboratory sessions in relation to the theory content is not always ideal.

Participant S6 indicates that the purpose of the teaching laboratory develops over time, with a greater level of scaffolding in earlier years. This participant described a model of reducing scaffolding to allow students at higher levels to have greater levels of decision making or ownership embedded within their teaching laboratory sessions. This participant indicated that earlier levels of the teaching laboratory should have greater levels of demonstration, step-by-step instruction and peer support where students are all undertaking the same experiment. At higher levels the participant indicated a more outline style procedure and a project-type approach with minimal guidance from staff.

Participant S6 indicates that the primary purpose of the laboratory is to develop students towards a chemistry-based career, encompassing both the practical skills and theory elements as well as the more transferable skills identified earlier within this section.

Discussion

Staff members indicate a wide variety of purposes of the teaching laboratory environment, with different staff members putting emphasis on different elements of those purposes. Although most of the participants emphasised both the practical and theoretical purposes of the teaching laboratory environment, the degree to which each purpose was emphasised by each participant varies. There is a range of opinions on the purpose of the teaching laboratory, with some participants heavily focussed on the theoretical purpose of the teaching laboratory, such as Participant S5, who indicates that the primary purpose of the teaching laboratory is to apply theory in context and only briefly noted that there are practical/manipulative aspects related to safety. Meanwhile other participants more extensively acknowledged a mixture of purpose, with Participant S2 suggesting that there is a level-ness to the purpose of the teaching laboratory which develops over the duration of a year. Participants S6 and S7 both put heavy emphasis on the practical element of “doing chemistry”. “Doing science” is described extensively by Hodson (2014) as part of the nature of science and is distinct to “learning science”. Doing science as described by Hodson tends to be most easily identified in inquiry type laboratories (Domin 1999) where although the theory is important, but not necessarily centralised within the laboratory environment and is described to be linked to the authentic investigative process.

4.2.2 Aims for students in the teaching laboratory.

Participants were asked to identify their aims for their students within the teaching laboratory. Aims are grouped thematically, with participants identifying several conceptual, behavioural, and skill-based aims for their students.

Participant S7 indicated that their aims for the students are not isolated within the teaching laboratory, with the participant indicating that students’ learning in the teaching laboratory is linked to activities undertaken by students both before and after the timetabled session and that these activities external to the teaching laboratory would be included within their aims for the students too.

Different aims for different sessions

Four participants indicated that their aims for students may vary between different levels or modules.

Participant S7 aims for the students to develop practical skills commensurate with level of study, which suggests differing aims at different levels, or a difference in complexity or breadth of the same aim.

Participant S6 indicated differences in levels early in their interview and in this question details their different aims for students at different levels. Participant S6 indicates aims of lower levels of complexity for first years with a high degree of emphasis on safety, building to a more complex set of aims with a different style of laboratory learning in higher levels. The participant indicated that there is a greater degree of choice for the student at higher levels and linked this to the students having a greater range of techniques to draw upon within the teaching laboratory. The participant reiterates this point in their response to the subsequent question theme regarding student actions, where they indicate their personal priorities as a teacher for their students’ development in different sessions does indeed vary, sometimes focusing on the theory, sometimes the write-up and sometimes on recording data.

Participant S4 indicated that different areas of chemistry have emphasis on different aims. They specified that some aims are important across all laboratory work, such as confident working, but some areas of chemistry may use different techniques or processes.

Participant S2 discussed a similar variety in aims when discussing student actions to achieve aims, for ease of comparison, this information is presented out of question sequence. Participant S2 indicated that they have different aims for students at different levels, with first year students having a higher degree of focus on basic practical skills, working accurately and precisely and appropriate data recording procedures known as good laboratory practice (GLP) that are in place to retain the accuracy and traceability of data. At higher levels the participant indicated they would require a greater degree of analysis, different processing methods and ideally for students to move up to the higher levels of cognitive skill in Bloom's taxonomy (Krathwohl, 2002).

Understanding chemistry theory

Three participants indicated that students developing understanding within the teaching laboratory was an aim for their students, in particular understanding the purpose of actions within the teaching laboratory within the experimental context.

Participant S5 aim for their students to produce a good practical outcome (product) and understand the process they took to get there. However, this participant also identified that not obtaining a good practical outcome is effective for learning too, as they can review the steps and understand the process they've taken still. The theory is described as the foundation by this participant, and the problem solving within the lab is built upon that.

Participant S2 also indicates that they aim for students to understand the purpose of their actions in the lab by reflecting on them throughout the teaching laboratory. This participant aims to promote inquiry into the purpose of actions by questioning students during the laboratory to prompt reflection within the session.

Participant S4 aims for students to understand what they're doing in all teaching laboratory sessions, however particularly for technique-focussed sessions, they aim for the students to understand the technique they are learning.

Scientific method

Two participants referenced a cycle of operation within the laboratory, indicating a cycle of design, experiment, observation, and interpretation which is consistent with the scientific method as described by Carey (2011). Participant S7 terms this "how to do science" and indicates that this includes also investigating and tackling problems and understanding what to do when the experiment appears to go wrong.

Participant S2 details a similar idea of the experimental process within analysis of sample preparation, standardisation, calibration, analysis and reporting data which they aim to develop with their first-year students. This description misses out the design phase however with first year students this is consistent with S2's description of different aims for earlier stage sessions.

Practical skills

Three staff members identified aims of developing practical skills throughout the duration of studies within the teaching laboratory.

Participant S7 indicated they aim for students to develop practical skills commensurate with their level of study, and that if a student reached a certain level of study without some common techniques that they would be surprised, however they indicated that producing a definitive list of required practical skills or techniques would be very challenging.

Participant S4 indicated that an aim is for students to get practice with the techniques that are presented to them in the teaching laboratory and be able to handle any data produced appropriately.

Participant S6 identified that their aim for students in the first year is to learn a range of basic techniques, and typically each experiment will focus on a specific technique. At higher levels, students are still learning new techniques, but they are perhaps more specialist. Higher level students should still practice basic techniques to improve their execution, as the participant identifies that they have seen higher level students making mistakes in basic techniques. This participant also included an example of a laboratory-related calculation in this discussion, so it is possible that they are including data handling in the laboratory skills.

As noted in earlier discussions, the concept of practical skills is poorly defined, and here participants appear to be mostly focused on practical techniques, however data handling skills are mentioned by two participants in this section.

On a similar theme of practical skills, participant S5 emphasised the importance of obtaining a correct practical outcome (product) in first year experiments as they are designed to always work. This would indicate a degree of practical competence in executing these experiments is required to reach the correct outcome. The emphasis on correct product is lower in later years as the experiments may be less optimal, but first year experiments are identified by the participant as designed to always work to foster confidence in the students.

Two participants identified safety as an aim within the teaching laboratory, which is included in this section as participants S2 and S4 have already commented that safety skills can be included in practical skills. Participant S2 indicated that students should operate safely within the laboratory and understand the rules of the teaching laboratory environment. Participant S6 indicated that safety was a key aim for first year students within the teaching laboratory, suggesting that they are stricter in first year with students on the topic of safety.

Behaviour development

Participants detailed the development of a variety of behaviours as aims for their students within teaching laboratory sessions.

Participant S6 detailed that an aim for their first-year students is to develop an understanding of appropriate behaviours or actions within the teaching laboratory session. They identified that they want students to build on these behaviours with more layers of complexity. This is fostered by a less scaffolded approach to the experiment with a greater degree of choice for higher level students, linked to a greater selection of available techniques.

I: what would you aim your first year students to have learnt in a lab session?
P: So I think first year is about learning how to be in the lab and how to do a lab session rather than learning anything beyond that, if you see what I mean
I: OK
P: Umm… I want them to learn how to make a good lab book entry and how to then turn that into a report that contains all of the information . Umm… And I want them to learn to work safely in the lab

Figure 22: Excerpt from interview with participant S6 on the topic of aims for students within the teaching laboratory.

Participant S4 indicated that they aimed for their students do develop confidence through working in teaching laboratory and that the students should develop good laboratory practice. This participant did not define the concept of good laboratory practice.

Participant S4 identified that they aim for students to be able to apply techniques that they had learned to an unknown problem, effectively developing problem solving schema within the laboratory.

Participant S5 indicates a similar aim for students as S4, with the students applying theory to solve a problem and develop a rule that they can then apply to other situations. This was discussed later in the interview, as part of the question regarding actions to achieve aims.

P: yep, yeah, I think the lab is that last kind of… part of the jigsaw puzzle where they can really apply this theory that they've been shown, use as a problem set to apply to what they're actually doing where it might not be overly obvious when you look at the experiment say it's making… paracetamol.
I: yeah
P: but you just think, I'm just making this drug, you add A and B, it reacts together and then you get your product. But what's actually happened? What reaction are you carrying out, what's the theory behind it? What are then the applicable rules you can get from it?

Figure 23: Excerpt from interview with participant S5 on the topic of applying theory and problem solving within the teaching laboratory.

Participant S2 identified an extra aim later in the interview when discussing student actions to achieve aims. This participant aims for their students to be able to reproduce the experimental technique that they have learned in the teaching laboratory and apply it to new contexts if required, with a degree of independence.

P: down to them to actually reproduce those experiments themselves.
I: So you're trying to scaffold them towards the ultimate aim of being independent analysts where they could design their…
P: yes
I: own experiments?
P: yes

Figure 24: Excerpt from interview with participant S2 on the topic of the aim of student independence in the teaching laboratory.

Discussion

As each staff member will typically be involved in teaching multiple levels of teaching within the laboratory, potentially encompassing students of differing ability and engagement, a variety of aims and purposes are to be expected. The wide variety of aims is consistent with the wide variety of aims of the teaching laboratory identified in the literature.

It is interesting to note that despite every participant indicating that the purpose of the teaching laboratory is for learning chemistry theory, only three of five participants cited developing understanding of the theory as an aim for their students.

Development of skills related to the laboratory, either practical or data handling skills, or behaviours that relate to the laboratory such as safety is a very prevalent theme arising from discussion with these students. This is consistent with the aims of experimental competence and safety in accreditation guidelines for chemistry-based courses (Royal Society of Chemistry, 2022) (QAA, 2022). This skill development is described in different ways, with staff members describing both basic skills such as fundamental practical skills or data recording, and advanced skills such as experimental design.

4.2.3 Actions taken to achieve aims in the teaching laboratory.

Participants were asked to identify actions that they undertake, or they ask their students to undertake to achieve the aims they have for them within the teaching laboratory. Staff identified different practices they undertake within the teaching laboratory to influence student experience, often focused on interacting with students. Communicating with students was discussed by every participant in some way, with a strong tendency towards verbal communication in the teaching laboratory.

Communicating aims

Participant S7 indicates that they set specific aims for each experiment detailed in both the laboratory manual provided to students and an introduction for each teaching laboratory session. This participant indicated they would explicitly state the aim of each session to the students, explaining that the focus was learning a technique or solving a problem, including why the students are undertaking the experiment and whether it was new to them or not.

Participant S2 also indicates that they provide an introduction at the start of each laboratory session with verbal guidance on the purpose and process of the sessions.

Discussion with students

Participant S2 says that discussion with the students in the laboratory is a good opportunity to provide perspective on their experiment and prompt reflection. This discussion allows the participant to get feedback directly from them that they are understanding the content covered. The participant mentioned that ideally this questioning should not occur at the end of the session, as students tend to disengage due to the length of the sessions.

Participant S2 also undertakes a process of signing off data before allowing students to leave, which prevents students leaving without having a discussion. This participant indicated that students can be engaged to a greater or lesser extent in this discussion process with engaged students asking questions that can promote understanding for the staff member, while less engaged students can feel like the discussion is a test or exam, so the participant tries to be gentle with these students. The participant indicates that it is important that the students understand what they have done within the teaching laboratory to be able to write it up after the session independently.

Participant S4 indicates they ask questions during the teaching laboratory session, as well as discussing with the students at the end of the session to promote review of what the students have done, this is also an opportunity to check over any data produced.

Participant S5 indicates that they do question students to promote reflection and understanding, but that the timing of these questions is important. If the student is working on an intricate process, then they do not distract the students.

Participant S6 indicated that rather than asking their students questions, they answer questions from students, mostly to reassure students and trouble-shoot experiments when they are not proceeding as anticipated. This participant aims to promote independence in their students with minimal intervention by using this method.

Course design

Three participants identified elements of course design that are intended to promote success within the teaching laboratory.

Participant S6 indicated that the course is designed such that the students have a pre-laboratory session and have access to pre-laboratory information. This pre-laboratory content will typically require the students to review some information relating to the safety of the experiment they will be undertaking.

Participant S4 also identifies a pre-laboratory session where the staff member will discuss the broader context of the experiment being undertaken, as well as any steps or techniques to be careful of. This is an opportunity for staff members to ensure that the students have read and understood the experimental script.

Participant S7 indicated that they select experiments that ensure a variety of techniques are presented to the students throughout the course avoiding too much repetition with differing emphasis in each week of a teaching laboratory course.

Other comments

In response to this question, participants did discuss some ideas that do not fit within the broad themes above, these are included in the section below to allow full representation of participants’ responses.

Participant S6 indicated that the students follow a procedure provided by staff, collect data and draw a conclusion supported by theory at the simplest level which will enable them to achieve aims set out for them in the teaching laboratory. At higher levels the students will not be provided with a method and the students develop a procedure to solve a problem, which will allow them to achieve the staff aims.

Participants S5 and S7 indicated that the teaching laboratory should not be focussed on practical outcomes. Participant S5 indicated that the aim of the teaching laboratory should be generating applicable rules, and participant S7 indicated that the aim should be meeting the defined aims of the activities, as specified in the laboratory manual.

Discussion

A variety of actions linked to educational design and pedagogy have been identified by staff to ensure that students achieve their aims within the teaching laboratory. Many of the actions are rooted within the principles of active learning, prompting students to think during their learning experiences within the teaching laboratory. Effective communication from lecturer to students is emphasised by the participants, with emphasis on communicating aims, demonstrating concepts and communicating ideas within the teaching laboratory environment, as well as discussions and questioning as a method to prompt students to reflect on their work and think critically.

4.2.4 Student experiences in the teaching laboratory

The questions relating to this theme was posed quite differently to each staff member within the context of the interview at the time:

- Participant 2: But what do you think your students think the purpose of a lab is? And a second question of - So what do you think your students are learning in the lab?
- Participant 4: But what do you think your students think the purpose of labs are? Why do they think they're here?
- Participant 6: What do you think students think the purpose of the teaching lab is?
- Participant 5: What do you think your students learn in the lab?
- Participant 7: What do you think your students learn in lab sessions? The participant indicated that this was a challenging and speculative question, so the researcher stated that a paired question would be posed to the students.

As these represent two very different questions, the responses have been separated into two sub-sections for analysis.

4.2.4a Student-perceived purpose of the teaching laboratory.

Participants were asked to reflect on their student's perceived purpose of the teaching laboratory. "What do you think your students think the purpose of a lab is?" Staff identified several different purposes relating to operation within the laboratory and production of a practical outcome, with some broader skills-based purposes identified. This question was only asked to three participants, S2, S4 and S6.

Practical outcome focus

Two participants, S2 and S6, indicated a high degree of focus on practical outcomes within the teaching laboratory. S2 indicated that students view the experiment as a cooking exercise, following instructions to produce a product and avoiding thinking about theory.

Participant S6 indicated that students' main aim is to finish the experiment, with a range of student approaches within that aim. Students are identified as very task or outcome focussed, with some wanting good quality results, and some students wishing to leave as quickly as possible. Students were described as following instructions in the teaching laboratory manual as a recipe with little consideration of the underlying theory of the step. To overcome this recipe-style experimentation, the participant advocates students learning to plan experiments and prompting students in these student-designed experiments to reflect on why a particular step is being undertaken.

P: What I really struggle with is getting them to zoom out from their very specific task and see it in a wider context, so if an experiment is about a particular piece of theory
I: Mmm hmm,
P: I want them to think, as they do each step, "This step is the deprotonation", or whatever, but that's not what they're thinking. They're thinking "now I'm adding some base".
I: yeah
P: so they're not
I: "now I'm adding some ammonia" y'know
P: so they're sort of following the instructions almost like a, more like a recipe rather than actually a practical…
P: That's, that is what often happens if you just give them instructions. Which is why I think it's very important that they learn to plan experiments. Umm…
I: so if they've planned the experiment, do you think they connect that theory more readily?
P: Yeah, if they've planned the experiment there's more of that. They still often have just gone and looked up a procedure for the experiment that you've asked them to do and in the world of internet that's unfortunately difficult to get around. You can't force them, if it's something you're gonna do - a fairly common experiment, you can't force them to come up with it themselves. Umm.. what you can do is ask them questions during the lab

Figure 25: Excerpt from interview with participant S6 on the topic of students thinking about processes undertaken within the teaching laboratory.

Skills developed within the teaching laboratory.

Two participants indicate that their students believe the purpose of the teaching laboratory is to develop practical skills. Participant S6 indicates that students perceive the aim of the teaching laboratory to be developing practical skills.

P: I think on the most part they think it's so that they can get practical skills, if you were to ask them, that's probably what they'd say. But in the lab, their main aim is to finish the lab.
I: Is that finish the lab as quickly as possible or finish the lab with as good results as possible, or something else?
P: I think it's a kind of hybrid of those two things. They know that they are going to get a grade for it and some of them will try very hard, at the expense of time, and you will wish that they were a little bit more…
I: (laughs)
P: rapid… and some of them will just be trying to get out as quick as possible, and most of them it's somewhere in the middle. They want to finish on time, preferably a bit early, but they do want to do a good job. What I really struggle with is getting them to zoom out from their very specific task and see it in a wider context…

Figure 26: Excerpt from interview with participant S6 on the topic of student's aims in the teaching laboratory.

Participant S4 indicated that they hoped students realised that they are doing science, which is based on experimentation and that they needed to develop the necessary scientific skills of designing, observing, and reporting within the context of an experiment.

Other student perceived purposes

Participant S6 indicates that they think students don't think about the purpose of their teaching laboratory sessions, merely that attendance is required and therefore they are required to complete the session and associated work.

Participant S4 indicates that students like learning in the teaching laboratory, and that students can get more from a practical session than a lecture.

Discussion

A striking difference between the staff identified purpose of the teaching laboratory and the staff-suggested student held purpose of the teaching laboratory is the low frequency of references to understanding in the latter. Staff indicate a much higher level of emphasis by the students on the purposes of skills development in the teaching laboratory than the staff themselves identified, with a more restricted range of skills identified by staff when considering the teaching laboratory from the point of view of students. This is consistent with the literature representation of the teaching laboratory having an emphasis on practical skill development (Carnduff & Reid, 2003).

4.2.4b Student learning in the teaching laboratory

In this section, staff are responding to the question "What do you think your students learn in lab sessions?" Responses are grouped by broad theme for ease of comparison. Staff indicated a variety of outcomes relating to conceptual learning, operation within the teaching laboratory and the nature of undertaking scientific investigation. Only three participants were asked this question, S2, S5 and S7.

Participant S7 indicated that students can have very different outcomes within the teaching laboratory, depending on their motivation or approach to the teaching laboratory. This participant indicated that some students struggle within the teaching laboratory and that they as a staff member aimed to create an atmosphere that is conducive to guiding the students to approaching the teaching laboratory in a more appropriate manner.

P: I think it … one the reason why it's difficult actually is 'cause lots of students have very different outcomes in how, what they get out of a lab session.

I: yeah

P: so, so there'll be yeah, students that are very… you can see that they're a scientist and they get the whole thing and then there are students which… who maybe, yeah, struggle in one... one aspect of something and they're, but they're… one thing that you'd… one thing you'd definitely get out of a lab course, teaching a lab course, is you do see the students develop from the start

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[on the topic of prompting students to ask questions]

P: I think you can try and create an atmosphere

I: mmm

P: that's conducive to them… yeah. So for example if you I try not to have lab sessions which are really tight for time and really rushed, because that doesn't give any time for anyone to think or to discuss anything,

I: yeah

P: whereas if you make the time a bit more… yeah, you should finish, you should have lots of time left, then there's more time to discuss things and for the students to think about what they're doing, but also just to think, yeah, about other stuff

Figure 27: Excerpts from interview with participant S7 on the topic of student's outcomes from the teaching laboratory.

Particpant S7 did indicate that regardless of approach, it is possible to see students developing during the length of a teaching laboratory course.

Understanding

Participant S5 indicated that participants learn why things should happen within the laboratory. This was described as how to apply theory and identifying that theory typically does work in practice. Real world circumstances were identified as a factor that may contribute to theoretical practices not working in the lab.

P: so what I think they learn is an appreciation for how theory can show you something in a couple of seconds, but in practice and application, it's a much longer process.
I: yeah
P: so they get an idea for it's mentally easy, but maybe practically difficult.
I: ok, yeah. So it's about the kind of resolution between the nice tidy theoretical chemistry and the much more messy practical chemistry
P: yep. 'cause one thing I like to do is try get them to realise that research and "proper chemistry" as I'd call it doesn't always work, and that's why we all still have jobs.

Figure 28: Excerpt from participant S5 on the topic of students learning an appreciation for the difference between theory and practice.

Participant S5 cites this appreciation of the challenges of practical work as preparing the students for the workforce, as often the role of a chemist in research is to problem solve an experiment that is not proceeding as expected. Experimental design was cited as an important component of this, and student-led laboratories were a way of fostering this capacity. This participant emphasises that with this format of teaching experiment, critical reflection is important. Students who do not critically reflect within the teaching laboratory often fail to produce the correct practical outcome and are required to reflect after the session and rationalise their practical outcomes. Students still get the same learning outcomes of understanding, but perhaps not in the same way.

Participant S7 made a reference to students learning the "science bits" which the researcher queried further as shown in figure 29. This question may be leading however this participant had already referenced conceptual learning in the teaching laboratory in earlier responses within the context of demonstration and practical implementation of science, so this was an attempt at extrapolating "science bits" by the interviewer. This participant noted later in the interview that the students learn from experiments going wrong, possibly learning more than they would have done from an experiment that proceeds as anticipated.

P: hopefully they do get the sort of, science… science bits as well, the sort of yeah…
I: do you think they learn any theory in the lab?
P: oh yes, definitely
I: yeah?
P: yeah, yeah. Yeah, yeah.
I: Do they learn anything new in the lab or does it tend to reinforce something they've learnt before?
P: mostly reinforces things they've learned before, I think. But yeah, so we often… often I find the lab is a good chance to talk to students in a less formal setting about the theory behind what they're doing

Figure 29: Excerpt from interview with participant S7 on the topic of student learning in the teaching laboratory.

Practical skills and laboratory behaviours

Participant S2 indicated that students learn confidence in their practical operation within the teaching laboratory. This participant indicates confidence allows students to progress onto the next stage of learning within the teaching laboratory.

P: Umm… confidence in being able to carry out physical activities. I think that confidence is very important umm… to progress, because if you haven't got enough confidence with what you already know, you can't move on to the next level because you're still doubting what you've already done.

Figure 30: Excerpt from interview with participant S2 on the topic of students developing confidence within the teaching laboratory.

Participant S7 indicates that the students learn techniques relating to reactions and the use of glassware, as well as organisational and time management skills within the context of the laboratory, which improve throughout the duration of their course.

Participant S2 indicated that students also learn a repository of basic practical skills such as sample preparation and measuring, as well as the more transferable skills of data recording and time management. Safety is also emphasised by participant S2, who indicates that some students are less willing than others to learn this, but it is very important that students can work safely.

Participant S5 mentioned that students do learn practical skills within the laboratory, however this was mentioned almost in passing, with little emphasis by the staff member.

I: what do you think your students learn in the lab?
P: I think besides kind of the standard, you know, how to do different procedures. I do think they get… a good feel for why things should happen…

Figure 31: Excerpt from interview with participant S5 referencing practical skills developed within the teaching laboratory.

How to do science

Participant S7 indicated that some participants, but not all, learn "this is how we do science" indicating the scientific process of hypothesis, analysis, and conclusion.

Participant S2 indicated a similar element learnt by students in the teaching laboratory, identifying that students learn the generic message of "how to do quantitative analysis". The participant had earlier identified steps of this method in their list of aims for students and indicates that a good way to check understanding of this process is by using a student designed experiment. This student-designed project style laboratory exercise was identified as a method that forces students into engaging with the distinct stages of the process, as the students are unable to either simply follow instructions or have a peer undertake the research for them.

Discussion

Participants were explicitly asked about learning in this section, which may be the cause of the higher prevalence of comments regarding development of understanding, however comments relating to practical and operational skills remain prevalent. The phrasing of the question includes learning which could predispose participants to indicating theoretical learning, however the prevalence of practical skills in responses suggests this is not the case.

In both the student purpose and student learning questions, the staff participates indicated a high degree of emphasis on the part of the students on practical or manipulative skills, as the main purpose and learning within the teaching laboratory, with suggestions that students may not all have the same perspective on the teaching laboratory.

4.2.5 Student aims in the teaching laboratory.

Participants were asked what they thought their students' aims were in the teaching laboratory. As some participants had previously addressed students' aims earlier in the interview, not all participants were asked this question. Responses drawn from other thematic questions presented as summaries and are labelled as such within this question. Participant S4 was not asked this question. Responses in this section are collated by thematic group.

Staff members indicated that their students mostly held endpoint associated aims, related to either the practical outcome (product or data) of an experiment or assessment-linked aims.

Outcomes focused.

Participant S2 and S6 had both discussed their perceived aims of students earlier in the interview when discussing the student perceived purpose of the teaching laboratory. Students were deemed to have aims related to recipe-style or "cookbook" approaches to the teaching laboratory. This style of approach is characterised by a strong focus on the endpoint of an experiment with little consideration or critical reflection during the process of the experiment.

Assessment focused

Participant S5 indicated that the students' aims were to obtain as high a mark as possible with the least amount of work. The participant indicated that the students' engagement varies throughout the years depending on the enthusiasm, workload and interest levels of students which fluctuates throughout the course. The teaching laboratory is deemed to be an effort-reward system, with students needing to put in effort to obtain the highest grades. The participant also mentioned that some students are less motivated and therefore have different aims to the more motivated students, typically having aims of finishing the experiment and obtaining a mark at the end of the activity. The participant deemed this an incorrect approach to the teaching laboratory, as the teaching laboratory is intended for the application of theory.

P: And some students you're still in that mindset of get in there, get it done and get out, trying to get as good a mark for as little work. And I think it's my job then to help stamp out that attitude to realise that you're only going to get a good mark if you put in the effort, it's an effort-reward system

Figure 32: Excerpt from interview with participant S5 on the topic of student mindsets within the teaching laboratory.

Participant S7 indicated several possible aims for students, including getting the best mark possible, leaving as quickly as possible and students who were inquisitive who asked a lot of questions. The first two aims were identified as more prevalent, with students who are mark or assessment focused are typically aiming to pick up tips on best practice to improve the quality of their product. When asked the participant identified that some of the credit or mark for their assessments is tied to the quality of the product, but it is not the ultimate component of the mark. This is intended to incentivise careful precise working within the teaching laboratory, while not incentivising product-focused attitudes.

I: so what would the student who wanted the best mark possible be doing in the lab?
P: mmm, (pause) so rather than thinking about the science they're too focussed on the process, and like you say, said earlier about making, making this compound, they're trying to do this the best that they, the best that they can, so they're trying to pick up tips on how to do that
I: yeah
P: rather than… I'm more interested in… I don't really care if you get to the end and make this compound or not. What I'm really interested in is yeah, what have you learnt that you didn't know before you came into the lab session?

Figure 33: Excerpt from interview with participant S7 on students who have the aim of the best mark possible.

Participant S7 also discussed the students who want to leave quickly, and these students were characterised by a lack of care within their activities in the teaching laboratory.

The final group of students classified by their aims as identified by participant S7 was students that are interested in the laboratory. These students were deemed to be less common than the assessment or speed groups, however the participant did suggest this may be because the students were underconfident in asking questions or lacked the time to ask.

Discussion

There is clear disparity between the outcomes-focussed purposes and learning perceived of the students by the staff and the wide variety of purposes and learning identified by the staff. Staff perceive students as motivated by product, grade and outcome, while staff would prefer the students to be motivated by learning, understanding and development. This conflict in perception could potentially be overcome by increased transparency or highlighting of the staff-perceived purpose and aims of teaching laboratory sessions or courses, although the metacognitive stance of the students will greatly impact on the way a student approaches a learning environment (John B Biggs and Moore 1993; John B. Biggs and Moore 1993).

4.2.6 Student motivations in the teaching laboratory

Staff members were asked to describe their students' motivations while in the teaching laboratory. Often this question was linked to discussion already taking place in the previous question and phrasing therefore varied between participants. However, the question was often phrased asking what would motivate the students to commit more time or effort to in the teaching laboratory, for example re-doing a step or sample. For example, the phrasing below was used when posing this question to participant S4:

"So it's about the decisions your students make in labs… …so it might be about whether they choose to repeat a sample, or the critical decisions they make about their data and their experiment. What do you think motivates your students when they are making those decisions?"

Participants identified both positive and negative motivating factors in response to this question theme, and results have been grouped into themes for this section, split into broadly positive and negative motivations.

Positive motivations

High quality results or perfectionism

Participant S2 indicated that highly motivated students often aim for perfectionism looking for a correct and high-quality practical outcome.

Participant S6 indicated that some students are committed to high quality practical outcomes while others are not. The students who are motivated to make the right think are characterised by being conscientious within the teaching laboratory and not cutting corners during the experimental process.

Participant S4 identifies that there are students who want the "right" product in comparison to their peers and they may choose to redo a section of an experiment if their results do not match those of their peers. The participant indicates this is because students have previously been taught "right and wrong" outcomes, however the participant identifies that as every result is a result, no experimental results can be wrong. Participant S6 tries to challenge this perfectionism by asking for students to justify their need to redo elements of the experiment.

P: So if they want to repeat samples they can do it. But, I don't want them to repeat it because someone else got the same data, and so they should have this, because that's not how it works.
I: Do you often gets students doing that? Going "My data doesn't look like so-and-so's"?
P: yeah
I: And what do you think is going on in their minds when that's happening?
P: I think the problem is, with most students, uhh… is that prior to arriving here they've just been taught about right and wrong
I: yeah
P: and not what's in front of them. And therefore they, they don't understand that any result is a result.
I: ok, yeah, so it's a bit different in university science to sort of school science?
P: yeah

Figure 34: Excerpt from interview with participant S4 on the topic of the "right" result in the teaching laboratory.

Assessment

Participant S2 indicates that some students are motivated by completion, wanting to finish the experiment and obtain a good result, but the main focus of these students is the mark or grade at the end of the activity.

Participant S5 indicated that some students have an element of self-interest to achieve within the teaching laboratory, as they are credit bearing and the students will do that little bit extra to get a bit better grade. The grades at higher levels contribute towards the students' overall degree aggregate, and at lower levels will contribute towards the students' module grade.

Subject interest

Participant S5 indicates that some students in the lab who are highly motivated may be interested in the subject matter being studied. This participant indicates that they highly value subject interest in their students as these the students who put in effort to figure out what is happening, with the solving of the problem being the motivating factor. If students are not interested in the subject matter, this participant indicates that it may be necessary to revisit the material to see how to make it more interesting to the students.

P: and I think interests, I'll always take a student who is much more interested than just purely academically inclined
I: yeah
P: 'cause any time there's a road bump or speedbump or a wall you hit in research in theory or any part of that, interest gets you through that. Pure academics ability doesn't always.

Figure 35: Excerpt from interview with participant S5 on the topic of interest as a motivating factor.

Participant S7 also indicates that interest is important, but perhaps less present in their students than they would wish in the teaching laboratory. The participant identifies that the often-repetitive tasks within the laboratory may lead to lack of interest. Scientists are interested in the results of the experiments, and this is an attitude that the participant wishes to foster in their students.

P: and if you just think about the things that you do in the lab, they can be repetitive and dull and tedious. But as a scientist you're interested in the results you get from the lab…
I: yeah
P: whereas the students are often interested in… they're interested in what they're doing.

Figure 36: Excerpt from interview with participant S7 on the topic of interest as motivation.

Negative influences

Dislike of the subject or teaching laboratory

Two participants identified dislike of the subject or teaching laboratory environment as a factor that can demotivate a student or prevent engagement.

Participant S6 indicates that some students like the teaching laboratory, while others may not. A suggested factor in this is that the teaching laboratory sessions are very long, and students may find this a feat of endurance. [Author's note: Teaching laboratory sessions at Nottingham Trent University can be all day lasting up to 7 hours.]

Participant S7 indicated that some students may not enjoy the teaching laboratory environment or experiments, suggesting that the activities in the teaching laboratory can be repetitive or dull, and that sessions can be very long. This participant also indicated that some students may develop a dislike for a certain subject area within chemistry, and this can impact on their engagement within the teaching laboratory. The participant suggests that spending time with these students and talking in an informal non-challenging way can help to break down these subject-specific barriers.

P: yeah. Yeah so maybe lack of endure… some... I mean, sometimes students put themselves in boxes as well, and this can be hard to break down and they say "I don't like organic chemistry"
I: (laughs)
P: You say "Why?" and they say "I've never got it…"
I: I'm saying nothing!! (laughs)
P: (laughs) and yeah, you can try and break those barriers that the student puts around them down

Figure 37: Excerpt from interview with S7 on the topic of students who disengage from a particular subject within chemistry.

Participant S5 indicates that some students have a negative attitude towards chemistry as a subject and perhaps have not chosen the degree route out of interest or desire, but perhaps due to external pressures. These students are harder to motivate as they are not interested in the theory and will not apply themselves in tutorials. As the teaching laboratory sessions are compulsory for students to attend, these unmotivated students will attend the sessions but struggle to engage with the application of theory in the teaching laboratory.

P: and I've come across lots of students like that and they're a lot harder to motivate but I think labs help that motivation because I think you can have a student who is not interested in the theory, and that's fine, and you have a student who won't then apply themselves in a tutorial setting, but you can have students who then come into the lab and 'cause they're here for 3 hours, 6 hours depending on the lab, they have to do something.

I: yeah

P: 'cause we don't let them just leave after an hour, they have to come in and do the experiment, so it's another way of coming back through that kind of tri-fold system of theory, problem solving, application but they do it all in the lab

Figure 38: Excerpt from interview with participant S5 on the topic of less motivated students in the teaching laboratory.

Peer influences

Two participants identified three different influences in the teaching laboratory related to the influence of the peer group.

Participant S4 indicated that students often compare themselves to their peers, although this was not cited as a motivating factor explicitly, it is the reason given for the students wishing to repeat elements in some instances. It seems that the participant is indicating that peer comparison instils doubt in the student's perception of the quality of their own work.

Participant S6 suggests that the students who are rushing with the laboratory may be doing so because they are behind their peers, which induces a feeling of panic. The participant suggests that student designed experiments are an opportunity to overcome this, as the students will be unable to compare progress if they are all undertaking different experiments.

Participant S6 indicated that a lot of students do not make decisions in the teaching laboratory and will instead defer to their peers any time they are unsure of what they are doing.

I: what do you think motivates students' decisions when they're in the lab?

P: Definitely a lot of them don't make their own decisions in the lab.

I: OK

P: This is a problem. A lot of them… do just… See what everybody else has done

I: ok

P: and do it that way. So they abdicate the decision. Wherever there is an ambiguity in the script umm.. they'll all just sort of… either confer or… somebody who did it first, they'll copy it. So many times I've seen one group of students do an experiment, and all get the same result. And then the next group will do something and they'll be nominally following the same instructions, and they'll all get a different result and it's because they've all done the same "different thing".

Figure 39: Excerpt from interview with participant S6 on the topic of students not making decisions within the teaching laboratory.

Negative emotions within the teaching laboratory.

Two participants related how negative emotions such as panic, fear or under-confidence can affect a student's behaviours within the teaching laboratory.

Participant S6 mentioned that students can feel panic within the teaching laboratory in relation to feeling behind their peers, which can cause them to rush.

> **P: sometimes if you see somebody is behind you want to go and give them a bit of help, help them over a couple of the questions a bit more quickly so that they, it's important to keep everybody going along otherwise umm… they panic when they start to feel like they're running out of time.**

Figure 40: Excerpt from interview with participant S6 on the topic of panic in the teaching laboratory.

Participant S6 indicated a feeling of under confidence in approaching staff with questions may prevent students from engaging with staff members in the teaching laboratory. This participant tries to allay this fear by setting a standard that there is no such thing as a "stupid question", and that the first few teaching laboratory sessions serve the purpose of acclimatising the students to the environment.

Participant S5 discussed a difficulty in understanding less motivated students, as they relate to them less well on a personal level, however they suggested that low engagement could be linked to fear related to achievement or attainment. This participant tries to allay this fear by showing that attainment within the teaching laboratory requires effort.

> I: and what about those students who just want to get out as quickly as possible with a reasonable grade?
> **P: with a reasonable grade.. I think… what motivates them probably is… see it's hard to know 'cause I wasn't one of those students.**
> I: (laughs)
> **P: I was a super nerd.**
> I: but you've definitely taught those?
> **P: but I've definitely taught those students yeah, yeah. I think everyone has. But it's a case of I think you have to allay the fear of kinda doing really well or doing really poorly.**
> I: hmm
> **P: 'cause that.. some students are "ah that person will do really well, it's fine" it's not always the case. We have to get them to realise that it is an effort to do well**

Figure 41: Excerpt from interview with participant S5 on the topic of sudent fear in the teaching laboratory.

Self-conceptions in the lab

Two participants detailed how a student's self-conception of skill level or potential careers can impact on their behaviours within the teaching laboratory.

Participant S6 indicated that students struggling in the teaching laboratory can be a vicious cycle. A student might make a mistake in the teaching laboratory and then consequently believe that they are "bad at labs", which can be further complicated by factors that can impede on manual dexterity or a student's ability to follow instructions. These factors are identified as leading to more mistakes, and the students tend to focus less on why they are undertaking actions within the teaching laboratory, which impedes on their learning.

I: You've just suggested that you get wildly varying perceptions of labs from different students … do you think there's any reasoning behind that? Or…
P: Umm, there's a measure of sort of… umm… vicious circle I think, in that once you're already slower at the lab than other people or have made a few bad mistakes in the first few labs you do, you become nervous of it, you see it as something you're bad at… umm… if you're not a very practical or dextrous person, it can be challenging and there's definitely people who are very good at the theory aspect and find the practical aspect much more difficult. On the other hand you might be somebody who is good with your hands and you find the practicals are your favourite bits or they help you a lot with the learning because that's something that comes easily to you.
I: Mmm hmm.
P: Umm… There's also a "how good are you at following instructions?" so you've got students who will not listen to the explanation, not read, they'll rush into it at the beginning
I: Mmm hmm.
P: Umm… and they will often have a more negative experience of labs because they will feel like… they've… just… they get bogged down half way through where they haven't figured out what they're supposed to be doing or why.

Figure 42: Excerpt from interview with participant S6 on the topic of students struggling in the teaching laboratory.

Participant S5 suggests that students struggle to see how they can progress from their current stage of development to a career in a chemistry-related field. This conversation followed on from the topic of effort within the teaching laboratory, and the requirement for effort contributing to a student's development.

P:We have to get them to realise that it is an effort to do well
I: yeah
P: that no one just does well. Everyone even if it seems like that, if it seems effortless, it more than probably isn't.
I: yeah, so… (overtalking)
P: that's the point in effort.
I: almost like perhaps they don't see how they can get from where they are to where you'd like them to be (overtalking)
P: I don't think they see a natural progression, yeah
I: ok
P: I don't think they see where the progression lies

Figure 43: Excerpt from interview with participant S5 on the topic of effort and progression in the teaching laboratory.

Other motivations

Participant S2 said that they would hope students would be motivated to learn from their mistakes, however students often want to be told what to do rather than self-evaluate to progress.

Participant S6 noted that educational laboratories are very different to research laboratories. Research laboratories are more likely to have a long-term project that a researcher will revisit over time, while students in teaching laboratories tend to have a different experiment each week and they may be less related to each other. The teaching laboratory is described by this participant as a training environment with a heavy skills focus. The participant was asked about project laboratories and indicated that, allowing for the self-selecting nature of student-chosen projects, the students do approach project laboratory sessions different, perhaps due to a higher degree of ownership. In project laboratories, students are more likely to reflect on why they are undertaking actions.

Discussion

Staff have indicated a wide variety of motivations for students within the teaching laboratory, which is consistent with the varied metacognitive approaches one would expect in a large group of students (John B Biggs and Moore 1993). There is however, a heavy emphasis on obtaining a practical outcome and completion which is consistent with literature indicating students approaching the teaching laboratory as an outcomes-focused recipe activity (Gallet 1998; Boyd-Kimball and Miller 2018; Venkatachelam and Rudolph 1974; Bertram et al. 2014).

4.2.7 Successful teaching laboratory session

Staff members were asked to describe a successful teaching laboratory session. Measures of success identified by staff members are presented grouped by broad theme. Some staff members reflected on their own feelings of success, while others reflected on the success of their students. All responses are included as the success of the teaching laboratory session can be measured from both points of view. Conceptual learning, confidence and successful production of an appropriate practical outcome were identified as measures of a successful teaching laboratory session, as well as the happiness of the students undertaking the session.

Understanding

Four participants mentioned that a successful teaching laboratory session would contain understanding or learning on the part of the students.

Participant S4 indicated that in a successful teaching laboratory session, the students would understand what they were doing and that they have the capacity to evaluate their own data towards the end of the teaching laboratory course.

P: They know which experiment they're doing, they've already read the scripts and they basically are able to understand what they are doing, and just doing it. And if they're not sure, they just ask us questions and we can help them through.

P: When, when especially when the students come to you and show you the results and go "Well, this went well because I've got this and this and that." And actually towards the end of the lab, they were all doing their calculation in the lab, and coming back with "Oh, I've got 97% accuracy, oh, that's really good!"

Figure 44: Excerpts from participant S4 on the topic of a successful teaching laboratory session.

Participant S5 indicated that they view a successful teaching laboratory session as one where students have been able to apply their knowledge and verify their outcomes. When asked how they would know students had achieved this point, the participant indicated discussion with the students regarding reasons for discrepancies or differences from anticipated values. The staff member aims for the students to be able to rationalise their data in relation to the theory that they should have encountered already in the course.

P: and then I think the next part of that is realising how you can verify it is exactly matches what you've told what you should make
I: yeah
P: I think that's where the last part then comes in of applying all your knowledge, so like melting points, IR, NMR that kind of thing
I: yeah
P: can you pull out all these topics you've now learnt to successfully apply them to verify what you've made is what you've made. I think that's the final aspect of being able to come full circle. To go yeah, you can do a reaction but now can you tell me with complete certainty and proof that you've made what you wanted to make.
I: yeah
P: I think that's the end of the lab, once they're able to completely and unambiguously verify what they've made and are happy with their product, that's the end point for me for the lab.

Figure 45: Excerpt from interview with participant S5 on the topic of a successful teaching laboratory session.

Participant S6 indicates that a successful teaching laboratory session is one where they have had at least one conversation with a student that displays they've learned something. This participant aims to talk to as many students as possible during the teaching laboratory session to check their understanding of the theory related to the current experiment.

Participant S7 identifies self-set aims that they want the students to achieve to have a successful laboratory. It is not clear if these aims are the same as the aims earlier detailed to the students, but the exemplars from the staff member related to learning, using "realising" "knowing about". This participant indicated that a really good teaching laboratory session would be one where unanticipated learning takes place. This unanticipated learning may be that a student has discovered a concept in a way that was not anticipated, and this staff member likes this surprising learning.

P: well for a really good lab session, I guess there'll be things that when I've come in at the start of the session I'll have thought "I hope everyone goes out of the session, yeah, realising this, or having done this or knowing about this…"
I: yeah
P: but then for a really good one, I guess, it's probably one where people have learnt stuff that you didn't really think… you didn't… you didn't… I hadn't anticipated they'd learn from that session,
I: yeah
P: so labs are a good place actually, for students to learn things that you, yeah, they're a bit of a, might be a side avenue or… or a different line of thinking…
I: yeah
P: from what you'd thought.

Figure 46: Excerpt from interview with participant S7 on the topic of unanticipated learning.

Practical outcome

Participant 6 indicated a successful teaching laboratory session is one where all the students finish the experiment, and nothing goes wrong. This would mean every student would produce the appropriate practical outcome for the experiments scheduled.

Participant S5 would measure a successful teaching laboratory session against an expectation that all students would have achieved the appropriate and high-quality product by the end of the laboratory. This "right" product was linked to a sense of achievement by the staff member, and it was noted that chemistry is quite unique in the sciences in that the pay-off of the production of an outcome is very immediate, unlike for example the biosciences. This participant indicated that ideally the students would be able to verify that their product is the appropriate product by the end of the session too.

P: To me, they get a nice product within what you'd call "spec" so you know if it's a purple crystals they're making, they get nice purple crystals
I: yeah
P: there's a sense of achievement and I think chemistry is unique in some of those things because biology you've got to wait for stuff to happen, things grow, things die, but in chemistry you're not dealing with stuff that's been alive or dead, you're dealing with inanimate things that you can react together, and I think you get a sense of achievement because you've put in some hard graft for a 3 or 6 hour session and at the end of it you have a malleable tangible product
I: yeah
P: and if it's described in the manual as you know shiny purple crystals, and you get shiny purple crystals, there's that sense of achievement "I've done something proper".

Figure 47: Excerpt from interview with participant S5 on the topic of successful teaching laboratory sessions.

Confidence and student-led

Participant S2 indicated that a successful teaching laboratory session was characterised by student confidence in their actions, the students have confidence in the actions they are taking and there would be minimal questions for the staff member present. The students' confidence leads them to be more self-sufficient, with the staff effectively at a loose end when students are on-task and independent.

In a similar manner, participant S4 indicated that a degree of independence and confidence marks a successful teaching laboratory session. The students have read the experimental scripts and the students are focused on the task, knowing what they are doing. The participant indicated that the students could ask questions if they are unsure, but the students become more independent throughout the course. The participant identified a specific example of a problem-based project laboratory where the students clearly display their development throughout the course to that point.

Other measures of success

Participant S4 identified other measures of success, including the timeliness of students arriving to the teaching laboratory, and the evidence of student development throughout the course. This participant describes teaching a laboratory course that extends over more than 2 months, and the tangible development in the students is a measure of the success of the teaching laboratory course.

Participants S4 and S6 both reference student happiness as a measure of the success of the teaching laboratory.

Participant S4:
P:it's really nice to see them happy. They're like "I've done it!!" and you're like "Yeah, I knew you would!" it's kind of.. so I think that's probably the best kind of labs.

Participant S6:
P:And so I'll feel good if I feel like that's worked in that particular session, and they've learnt something, they haven't broken anything, nobody's burnt themselves and everybody's gone home smiling. (chuckles)
I: (laughs) You want all of them leaving smiling?
P: Well, that's never happened!

Figure 48: Excerpts from interviews with participants S4 and S6 on student happiness as a measure of success within the teaching laboratory.

Discussion

The measures of success broadly correlate with the purpose of the teaching laboratory as identified by staff members with understanding taking precedence over practical skills. The prevalence of the practical outcome category could be linked to the application of practical skills, as students will only be able to obtain a correct product if they use the apparatus correctly. Staff discuss the importance of preparation and reflection in this section, which re-emphasises that the teaching laboratory is not a stand-alone environment and exists within the broader context of the course curriculum, as well as more locally with linked teaching materials such as pre-laboratory exercises or post-laboratory assessments (Agustian and Seery 2017).

4.2.8 Students' recognising success

Staff members were asked to identify the ways in which students may recognise that they had achieved the aims the staff members had for them. Methods of recognising aims that were identified by staff members are presented grouped by broad theme. Staff members indicated that a significant amount of this recognition of aims is facilitated by staff feedback, with multiple models of feedback identified by staff. Staff members also identified self-evaluation and peer comparison as methods of recognising achieved aims.

In this section, when discussing the peer support system within their taught laboratory sessions, the topic of designing the teaching laboratory sessions arose, and staff participant S4 did indicate that they would love to spend more time designing their taught laboratory sessions but has to be satisfied with smaller tweaks over time as it would be impossible for them to redesign everything at once. This statement was loosely related to the discussion represented below on peer influence but does not fit within the broad themes as it is less related to the root question, however it is reflective of this participant's high level of refinement within their teaching practice, with them often citing examples of having modified or developed elements of their practice.

Staff feedback during the session

All participants indicated that they provide feedback to their students during the teaching laboratory session.

Participant S2 indicates that they provide feedback to their students with the aim of prompting self-evaluation in the students. This participant indicated that they also provide feedback on best practice with apparatus or instrumentation during the scheduled sessions.

Participant S5 indicated that they provide positive feedback, or at worst constructive criticism to students within the teaching laboratory. A particular example of feedback cited was reviewing actions taken by a student if their experimental outcome was not as anticipated and identifying issues in their skills that may have contributed to the problem, such as soft skills including comprehension and care taken within the teaching laboratory. The participant identified that these “soft skills” are important and are built up through the teaching laboratory course, however they often focus on the student’s understanding of the theory and don’t make the soft skills an explicit aim of the teaching laboratory. These soft skills are assessed within the assessment scheme for this participant’s taught laboratories, and that the higher grades for this component are often only awarded to the students with very high attention to detail within the teaching laboratory, with high quality presentation skills, behaviours in the laboratory environment and a strong grasp of the theory.

Participant S4 directly tells students when they have achieved their aims. They informally approach students who appear to be struggling and guide them in the right direction, re-explaining concepts if required. The participant values one-on-one time in the teaching laboratory where this can be done, and notes it is a challenge in larger group teaching. Each student is also provided with specific feedback on work submitted to improve their performance in subsequent sessions.

Participant S7 indicated that they provide feedback to the students in the teaching laboratory, discussing what they have done well during the teaching laboratory session, and pointing out what they have learned. This feedback is typically provided face-to-face during the teaching laboratory sessions.

Two participants specifically mentioned feedback mechanisms linked to the end of the teaching laboratory, or leaving the teaching laboratory, which are slightly different in theme to the continuous feedback opportunities indicated above.

Participant S6 indicated that they try to mark students’ work within the teaching laboratory session and likes the opportunity that it provides to discuss with the student to check their understanding, provide support if they haven’t understood and provide guidance on improvement of their grade. The students however are characterised as disliking the discussion portion of the marking process, which the participant suggests is possibly linked to feeling that their lack of knowledge may be exposed and a dislike of being asked questions. The participant identifies that despite the students’ unwillingness to discuss, once the conversation is over the student has achieved another increment towards their final coursework mark so they should feel like they have achieved something. Participant S6 also indicated that students often under-estimate their achievement within the teaching laboratory and assume that their experiment has gone worse than it did.

I: How do they know they've completed a lab successfully?
P: I quite like marking, you can't always do this, I quite like marking their lab book at the end of that lab,
I: ok
P: Because you can have a talk with them, often it hasn't gone as badly as they think it's gone?

Figure 49: Excerpt from interview with participant S6 on the topic of student self-conceptions of achievement within the teaching laboratory.

Participant S2 also specifies that they have a procedure for students who are leaving the teaching laboratory that is designed to facilitate the provision of feedback. Every student is required to have their data signed off by a staff member before leaving the teaching laboratory. This provides an opportunity to review the data for good laboratory practice recording techniques, signs of confusion or errors such as crossings-out within the data set and reviewing whether the student has met the aims of the teaching laboratory session.

Assessment based feedback.

Three participants mentioned that at least some of the feedback for the teaching laboratory is linked to assessments.

Participant S6 undertakes in-laboratory marking wherever they can. They indicated that a large proportion of the mark associated with their teaching laboratory sessions is for taking part in the teaching laboratory session. Feedback given in the teaching laboratory encompasses how to improve this mark for future sessions.

P: You can give them a grade, generally because a large part of the grade is for turning up and getting to the end of the lab, you can give them an ok grade.

Figure 50: Excerpt from interview with participant S6 on the topic of teaching laboratory-based assessment.

Participant S2 indicated that students will receive additional feedback and a grade on their work submitted after the laboratory.

Participant S4 does reference grading to their students' work, however they indicate that the feedback is more valuable.

Participant S7 indicates that practical outputs (products) are graded by quality, and feedback is provided on that.

Peer influences

Participant S4 indicated that the partners that students are working in lab pairs with can have an influence on their work, and this participant plans to switch lab pairs throughout the teaching laboratory sessions. In later sessions this participant aims to pair up high and low achievers to attempt to have a positive influence on the lower achiever.

Participant S2 indicated that students often seek information from students who had previously undertaken an experiment, however this is not deemed to be negative as it is a learning opportunity for the student providing the explanation.

P: perhaps they would, there is also an element of peer-interaction as well. "Well, you did this experiment last week, how did you do this?" so they're discussing amongst themselves how to do laboratory work as well, so that's an opportunity for them to do that. Hopefully it's the correct information that's getting passed. Uhh.. but that is encouraging as well, because that somebody else has to explain
I: mmm hmm
P: what they did, and how they did it , so that's a good way to learn as well.

Figure 51: Excerpt from interview with participant S2 on the topic of peer tutoring related to the teaching laboratory.

Participant S6 mentions that peer comparison can have a negative effect on students' emotions, the participant was discussing sources of stress within the teaching laboratory environment and indicated that the presence of peers can be a contributor to the stress within the teaching laboratory, compounding the fact that the teaching laboratory can already be a stressful environment as the sessions are typically long in duration, and require a high degree of attention throughout with few opportunities for a break which is described as physically exhausting.

P: and there's also the peer aspect, what I said earlier about it was feeling a bit like a competition,
I: yeah?
P: and because you can interact with your peers and see how theirs is doing, like in an exam or something, you can't do that so although it's very stressful and intense, you feel at least like you're just measuring yourself against the exam, whereas in labs, I think it can get umm… they… anger can flare because there's that more interactive
I: yeah
P: sort of aspect of it

Figure 52: Excerpt from interview with participant S6, on the topic of emotions within the teaching laboratory.

Participant S7 indicated that the peer element of the teaching laboratory made it an unusual laboratory environment, as in industry it would be very rare to have large numbers of people in the same laboratory undertaking the same experiment. This participant uses this large volume of data to assist students in learning by implementing the product-critique method described earlier in this section. Additionally, if a student finishes the experiment with no observable product, you can use products from their peers to illustrate what should have happened.

Self-evaluation

Three participants indicated that they aim for students to be able to self-evaluate their progress or attainment in the teaching laboratory, but this is more challenging at lower levels.

Participant S2 indicated that the feedback they provide has the aim of promoting students to be self-evaluating in the long term.

Participant S5 gave an example of a student exhibiting self-evaluating behaviour by identifying that they had made an error in their experiment due to a different morphology of their product. This participant then discussed with the student the operational steps they had taken that changed the morphology of their product.

Participant S7 was directly asked if students can recognise learning gains on their own, and the participant indicated that sometimes students are able to recognise this, and sometimes they can't. In particular, the staff member noted that students often do not have an appreciation for how difficult a technique or experiment is and that their outcome is better than they assess. This participant has a model for overcoming this where students self-assess their products and the outcomes are discussed as a group.

P: something like that… so I put them… I mark a grid up on the bench, which says like number one, two, three… so I try to get them to rank the top three…

I: yeah

P: and then good, average, poor. And I ask the students to place them in the right box.

I: Oh, that's cool…

P: and I moderate it afterwards…

I: yeah

P: but most of the students don't put their sample in number one, two or three, and will put it in average instead of good

I: yeah

P: so I don't know if they are just being a bit humble, or whether they don't think as much of their ability as they…

I: yeah

P: as whether they underestimate their own ability.

Figure 53: Excerpt from interview with participant S7 on the topic of marking products within the teaching laboratory.

Discussion

Staff feedback is the predominant theme arising from this question, with staff providing feedback in multiple formats to students throughout and after the teaching laboratory session. Some staff did suggest that they aim for students to develop self-evaluation through their studies in the teaching laboratory, and if this is a skill that is developed over time, it is understandable that it isn't mentioned by all participants, as not all participants teach at all levels. This feedback however takes many forms, with in-situ feedback during the teaching laboratory session, as well as cyclical feedback where students are expected to act on prior feedback in subsequent sessions.

4.2.9 Technology enhanced learning in the teaching laboratory.

Participants were asked to consider the impact of the presence of the tablets in the Superlab on student's learning. This was often framed in a compare/contrast phrasing with other teaching laboratories where tablets are not present either within Nottingham Trent University or elsewhere in their teaching practice.

Participants demonstrated a range of attitudes towards the tablets within the Superlab, ranging from mixed to positive, with some criticism of the limitations of or the implementation of the tablet technology.

Responses have been categorised into negative and positive aspects and grouped by theme for discussion below. Positive aspects identified include accessibility to and retrieval of data and specific tablet functions that facilitate student operation in the teaching laboratory. Negative comments encompass technological issues, compromises with data recording and the impact on student observation.

Positive comments

Retrieval of data

Participants S2 references that using digital recording systems can be a positive for students, as it allows remote retrieval of data. However, this participant did suggest that a purpose-built laboratory information management system (LIMS) would be more suitable for the teaching laboratory. This participant noted that typed data is already presented to students by the instrumentation, so that may be familiar.

Participant S7 suggested that being able to easily retrieve data within the teaching laboratory and store data over time, however this could be improved with the implementation of an electronic laboratory notebook (ELN) system within the teaching laboratory which would allow a continuous record replicating the traditional laboratory notebook model.

Participant S5 indicated that documentation is easier with the tablets present as students can document physical changes with photos and it is quite easy to lose paper copies of data.

Specific tablet functions

Participant S4 indicated that they can link videos of techniques for students to review within the teaching laboratory.

Participants S7, S4 and S6 all cited the camera as a useful feature of the tablets within the Superlab. Participant S4 indicated that photos can prompt recall and help students in learning the theory associated with the teaching laboratory. Participant S6 indicated that students should employ restraint when taking photos of their experiments, and that photos are only useful to the experimental record if they have context or appropriate commentary.

Participants S7 and S4 both indicated that students could use the internet capabilities of the tablets to undertake research within the teaching laboratory. Participant S4 indicated that they often direct students to research answers to their own questions using the tablets. Participant S7 did cite that research was possible prior to the tablets being present, however it would have been paper-based research using printed tables or a textbook.

Other positive comments

Participant S6 noted that students who are "tech able" can save time while using the tablets in the teaching laboratory.

Negative comments

Technological issues

Participant S5 indicated that technological issues hamper the usefulness of the tablets. The technological issues can cause students to fail to record time-sensitive observations such as colour changes.

Participant S2 indicated that technological issues with the instrumentation present within the teaching laboratory and technological issues with the tablets were different from a teaching perspective, as the issues with the instrumentation can prompt a learning opportunity. The issues with the tablets were deemed to be more random. This participant has a positive attitude towards analogue instrumentation within teaching and indicates that although older analogue devices may be less attractive to students, the physical interaction with the dials on the machine may promote understanding.

> **P: Sometimes in changing with the times, we can see that there's disadvantages and partic… the analytical instruments umm… some of the old instruments looked old, they weren't so y'know attractive to the students, but you could take them apart. You could get the students to twiddle knobs and to… and actually, in that process, twiddling knobs, understand what they're doing.**
>
> I: yeah
>
> **P: the electronic, sort of controls, tends to remove some of that fundamental understanding**

Figure 54: Excerpt from interview with participant S2 on the use of analogue instrumentation to aid learning.

Data recording and observation

Participant S7 suggested that the main function of the tablets within the Superlab is for recording data and without an effective electronic laboratory notebook (ELN) that the tablets are not necessarily fit for purpose at present.

Participant S7 indicated that the tablets are not always ready for students to write or draw on, unlike a paper laboratory book, which is readily available for students to record observations. This participant indicated that students who have only used tablets may not be familiar with appropriate recording methods.

Participant S4 said that the practice of writing a laboratory book entry is being lost due to students using the tablets.

Participant S2 indicated a specific issue with the tablets where data is continually editable in a non-traceable manner, which would be regarded as poor laboratory practice under the Good Laboratory Practice guidance, impacting on data authenticity and traceability.

Participant S6 indicated that students are less likely to record observations, which is poor practice within the teaching laboratory.

Participant S5 states that observing chemistry within the teaching laboratory should always be more important than operating the technology, however students can miss crucial observations in an experiment if they are operating the tablets.

Negative impact on learning

Participant S2 indicates that the tablets are an impediment to learning in their current form. The participant prefers learning to be as pure as possible to allow students to clearly see the point in a teaching session, and the tablets can be a distraction in the teaching laboratory setting. Participant S2 also suggested that using the tablets as a method to accommodate paperless teaching impacts on the efficiency of the teaching within the laboratory.

Participant S6 indicates that students tend to search for answers using search engines on the tablet rather than thinking for themselves, which they cite as a trend for people more generally, not just students in the teaching laboratory. One benefit of the non-technology-enhanced laboratory is that students are required to think and remember within the session, and if they are still unsure, they can ask questions. The lack of questions directed to staff members can cause misconceptions to propagate that could have been challenged if a student approached a staff member.

Participant S6 indicates that teaching laboratories should be designed to foster higher order thinking skills not just produce effective operational chemists, and that anything that impedes on learning is not ideal within the teaching laboratory.

Participant S4 indicated that the tablets have increased the teaching burden on the staff and the learning burden on the students.

P: I think we are trying to achieve too much because of it, and especially the beginning with the first year
I: yeah
P: you are losing a lot of time on technology.. because…
I: because you have to teach them how to use..
P: because you have to teach them how to use it, and the way yeah… so that can be tricky

Figure 55: Excerpt from interview with participant S4 on the topic of teaching students to use technology (tablets) within the teaching laboratory.

Other negative comments

Participant S7 indicates that if the students are using the tablets effectively, then they can be functional, however if they are using them less effectively, then the tablets are not automatically as capable as a traditional paper laboratory book. Participant S7 indicates that poorer use of the tablets within the teaching laboratory may be linked to a lack of confidence.

Operational comments relating to the Superlab.

Participant S4 indicates that the current model of use of the tablets within the Superlab is a missed opportunity, however the development of a more effective process would require a lot of work. This participant advocates a hybrid approach of using technology within the teaching laboratory, suggesting that traditional laboratory books and tablets can coexist.

Participant S2 suggests a progressive model of implementing technology within the teaching laboratory, suggesting paper-based sessions for first year students to allow them to develop basic skills without the distraction of the tablets.

As previously noted, both participants S2 and S7 indicated that the operation of the tablets within the teaching laboratory could be improved by appropriate data management systems.

Comments relating to the Superlab environment.

Despite the question being technology-focussed, two participants indicated that the challenge in the Superlab environment is not one of technology, and rather the issue is the environment itself.

Participant S6 indicated that the Superlab is a large warehouse-like environment with much less immediate supervision than students are used to, and unfamiliarity is increased with the presence of novel equipment such as fume hoods. The Superlab was intimidating to this participant as a staff member, so they suggest it must be intimidating for students.

Participant S4 indicates a logistical difference between the Superlab and other teaching laboratory sessions on campus. In the Superlab, typically technicians provide a tray with the required equipment prepared for students and the students do not put away their own equipment at the end of the session. The participant suggests that this fosters a lack of care within the students, and they are less likely to check their own equipment and clear up after themselves. As a response to this change in logistical approach to the teaching laboratory, this participant is putting a higher degree of emphasis on ensuring that the students have cleaned up after themselves and cared for the teaching laboratory environment.

Discussion

Based on this author's observations from teaching in the Superlab environment, the day-to-day workflow of the Superlab and what forms of software are used within sessions can vary dependant on the level and content of the session and the approach of the staff members involved in the teaching. This was not a question that was included as part of the interview, because many staff members may teach over a variety of modules with which could have different approaches, which would be time consuming to discuss. As such it is challenging to identify the approach that each staff member uses from their responses in this section, as most staff members have not detailed precisely how they expect students to use the hardware and software available in the teaching laboratory, however their comments do allow the identification of strengths and weaknesses in the Superlab environment.

Although the tablets in the teaching laboratory provide some opportunities to students, the method in which the students are using the tablets is causing concern within the staff members. Staff members are concerned that important skill sets are being lost such as the ability to record data appropriately, and that the use of the technology can take priority over the learning happening within the teaching laboratory. Despite this concern, staff members do identify some benefits to the tablets being present within the laboratory and suggest possible developments for the future.

This suggestion that the technology is taking precedence may relate to the pedagogy-technology dichotomy, where technology can be seen to impose upon learning design in a negative way and force change, rather than facilitate change and allow for innovation (Fawns 2022). Fawns proposes that rather than technology and pedagogy being in competition with each other, they should be used collaboratively in order to achieve the true purpose of learning activities. As such, with the wide-ranging purposes of the teaching laboratory already identified earlier in the interviews, the technological solutions will inevitably be complex and require iteration and refinement over time, with some such solutions being suggested by the staff member participants in this study.

A concerning point raised by the staff members is that students may not be using the tablets effectively. This that could potentially impact particularly on the already complex learning environment of the teaching laboratory moreso than on other less cognitively demanding learning environments. If students are required to learn how to use the tablets or technology as an additional cognitive burden, or undertake problem-solving steps when technology fails, then that would be further cognitive load (Sweller 1988) which could be an impediment to learning.

This would particularly affect students who are less confident with technology or have lower levels of digital literacy as alternative pathways of resolving technological issues may not be immediately obvious or accessible to them. As such, it is vitally important that when introducing technology into a cognitively complex environment, that it is robust and reliable, that students and staff members are adequately trained, and that there is resource available to support the development of less digitally literate members of the environment to help bridge the gap (Claro et al. 2018).

Another group that may need more support with this increased cognitive load is students with reduced cognitive load capacity or working memory, however the factors that impact on working memory (Daneman and Carpenter 1980; Anggraini 2023) and cognitive load capacity (Anggraini 2023; Miller 1956) are wide-ranging and would be difficult to address each and every one in an academic context. The best way to facilitate this group may be to reduce the cognitive load on them during the session by decentralising the learning, for example by introducing a pre-laboratory exercise (Carnduff and Reid 2003; Reid and Shah 2007; Rayment et al. 2022). Pre-laboratory exercises are discussed in more depth in section 5.1.3.

4.3 In person student interviews

Demographics of respondents

74 students responded to the selection survey shown in table 45. All respondents to the recruitment survey were listed, and were grouped according to common attributes, such as disability status, age group and prior qualifications, and purposively sampled (Etikan, 2016) to ensure a broad demographic representation. A random number generator was used to select participants in groups of demographically similar students.

Students in their first and final year were offered the opportunity to undertake a second interview, in an attempt to investigate in-year variation of responses, however very few responding participants were eligible for a second interview with a total of three students undertaking a second interview, and as such it is not possible to investigate these differences rigorously.

Table 46: Total responses, selections, and recruitment for phase 1 of the interviews (2018).

Year Group	Number Responded	Number Selected	Number Interviewed
1 (FHEQ lv 4)	28	12	1
2 (FHEQ lv 5)	19	12	4
3 (FHEQ lv 6) BSc	23	12	2
3 (FHEQ lv 6) MChem	No respondents		
4 (FHEQ lv 7)	4	4	1

A significant challenge in gathering data was the timing of these interviews. To be able to assess the student's perceptions of the Superlab, it was important that the interviews should take place after participants had at least some teaching within the Superlab. As such, the interviews were planned for March-April 2018, with second interviews taking place for some respondents later in the term in May/June 2018. Second interviews were available for first and final year students to assess changes in perceptions across the start and end of their course. This is a very busy time of year for university students and possibly because of the demands on the students, there was a high degree of non-response to interview invite, and failed scheduled interviews meant that far fewer participants were interviewed than initially planned (Table 43).

8 different participants were interviewed, with a variety of demographic backgrounds, the majority fall into the typical age range for higher education of 18-21, and all recruited participants had previously studied A-Levels. Demographic information is displayed in table 46 has been generalised where required to prevent the identification of individuals.

Table 47: Demographic information of interview participants (2018)

ID	Gender	2nd interview	Age	English as first language	Disability	Year of study	Course pathway
1_12	Female	Yes	18-21	No	No	1	MChem Chemistry
2_01	Female	Not offered	18-21	Yes	Yes (which impacts on lab experience)	2	FdSc Chemistry
2_02	Female	Not offered	18-21	Yes	No	2	BSc Chemistry
2_07	Male	Not offered	18-21	Yes	No	2	MChem Chemistry
2_11	Male	Not offered	18-21	Yes	No	2	BSc Chemistry
3_19	Male	No	18-21	Yes	No	3	BSc Chemistry
3_21	Male	Yes	22-25	Yes	No	3	BSc Chemistry
4_01	Female	Yes	18-21	Yes	No	4	MChem Chemistry

Participants were allocated a category label according to their current year of study, and then each respondent in that category had subsequent identifying numbers. For example, student 1_12 is the 12th chronological respondent to the recruitment survey in the "first year" category. These participant ID's were assigned before purposive sampling, which accounts for the gaps in the sequence.

In person student interview outcomes

Results are presented separated by question and collated by thematic group. The topic question is presented at the start of each section, although it was not always posed verbatim to students. Themes will be discussed at the end of each data set to compare student perspectives to current literature.

Due to the semi-structured nature of the interviews, not all questions were asked in the same order to all students, and if the students had already covered the topic of a question, it may have been omitted.

4.3.1 Purpose of the teaching laboratory

In this section, the students were responding to the question "What do you think the purpose of the teaching lab sessions are?". Several topics were covered by the students including learning chemistry theory, developing practical skills and career prospects, developing transferable skills, becoming familiar with the laboratory and the variety in the purpose of the teaching laboratory.

Learning Chemistry Theory

Six student participants identified several different elements relating to conceptual learning of Chemistry within the teaching laboratory. Three participants identified purposes linked to reinforcing or augmenting learning undertaken elsewhere in their learning experiences.

Participant 2_07 indicated that their laboratory learning is linked to their lectures and reinforce the learning that they have undertaken elsewhere.

In both of their interview participant 1_12 indicated that observing a physical phenomenon, such as a colour change can make a concept more memorable, aiding their understanding of concepts initially encountered in lecture content by increasing how memorable the idea is, and illustrating theory in practice.

Interview 1:

P: to show us how to theory works in practice an for us also to see how reactions work, or even not reactions, just anything based because if we learn that I dunno, something changes colour work whilst is titrated

Interview 2:

P: it's good to learn it in the in the lecture, but it's also good to do it in the lab and actually see it. It stays in your mind a lot longer. I think as well.

Figure 56: Excerpts from interviews with participant 1_12

Participant 2_02 highlighted the capacity for the laboratory to show the abstract in action and linked the theory they'd learnt in lectures to a technique undertaken later in the laboratory. Abstract concepts are common in Chemistry and are difficult for learners to understand (Taber 2013), and it is encouraging that this student is identifying the teaching laboratory as an environment where this is supported through their experimental learning.

Application of theory was identified as a purpose of the laboratory by two participants with the teaching laboratory identified as allowing them an opportunity to apply theory learnt elsewhere in their learning experiences.

In their second interview Participant 3_21 indicated that they apply theory learnt in lectures within the teaching laboratory, however struggled to explain this. The participant provided an example that identified that an experiment which could have two possible outcomes, and the theory indicated one was much more likely than the other, but in the laboratory both outcomes were observed in their cohort. This helped them appreciate that variable outcomes were possible from the same experimental method and that though something may be unlikely, it can still occur. The student suggested that there are experiments used within the teaching laboratory to demonstrate theory that otherwise have no real-world application, as their products are not commercially useful.

Participant 3_19 provided an example that project laboratory sessions require students to apply theory, by using theory to identify incompatible reagents, however they suggested that at lower levels of their study, they needed to be prompted to think about the theory related to the experiment they were undertaking.

Participant 4_01 indicated in both their interviews that the teaching laboratory is an environment where a student can demonstrate their ability to apply theory learned in lectures, or independently.

The varying descriptions of learning in the teaching laboratory does substantiate that there is a link between the activities undertaken within the teaching laboratory and those in other studies, however there is an emphasis on learning happening first and the laboratory reinforcing that learning or being a place to apply, which implies that the order of sessions may be important to these activities.

Participant 2_02 was asked specifically about the order of sessions and indicated a clear preference for theory to be presented first, as the "correct" manner of undertaking teaching laboratories.

I: so does it normally happen that way around where you have some theory in the lecture and you know something then the lab... Illustrates it or makes you think...
P: no (interrupts)
I: … about again or does it happen the other way 'round or... (overtalking)
P: sometimes. It happens. You learn it in lecture, then do it in lab. But then sometimes you've done the lab and then it comes up in the lecture afterwards.
I: ok
P: So it's not always like scheduled correctly.

Figure 57: Excerpt from interview with participant 2_02.

Participant 2_01 identified that the way information is presented and processed within the laboratory is easier for them to understand, due to their declared disability which impacts on the way they can process text-heavy content in other environments like lecture theatres.

Manipulative or practical skills

Throughout the interviews, students often referred to "practical skills" or "good laboratory practice" without expanding on or defining the terms, so wherever possible the researcher asked for more detail. To avoid misrepresentation of student's experiences, comments relating to practical skills or manipulative skills will be substantiated by quotes wherever possible.

Every participant referred to practical technique or manipulative skills as a purpose of the teaching laboratory sessions, with explicit references to possible future careers in chemistry-based roles, linking the experience or competence with practical techniques to employability within the chemistry industry. This is consistent with the suggestion by Gunstone (1990) that a high degree of emphasis on practical technique on "manipulative skills" or practical skills can cause students to focus heavily on that area.

Participant 3_21 focussed extensively on listing techniques they'd learned within the laboratory in both of their interviews, with little reference to other purposes of the laboratory.

P: to get us familiar with. Just certain techniques, basically. Err, use...
I: ok, so what kind of techniques?
P: Umm... well, this is a very simple one. There's the titrations, there's filtrations and crystallizations.

Figure 58: Excerpt from interview 1 with participant 3_21

Six different participants identified that practical skills, or manipulative skills were specifically linked to future career prospects. Participants 1_12 and 2_02 and 2_07 indicated that developing practical skills would prepare them for a chemistry-based career.

Participant 2_01 indicated that employers require employees to be familiar with physical operation within the laboratory.

When queried further, participant 2_01 indicated that knowing how to behave in the laboratory environment was an important thing they had learned as they highlighted a significant difference with their prior educational experiences, as their chemistry education was mostly theoretical with little laboratory work, so much of what seemed 'common sense' to them now, was simply unknown when they started their degree programme.

Participant 2_11 said that the teaching laboratory provides real life experience of techniques required for future careers in chemistry, particularly that the teaching laboratory teaches small techniques that can build into larger experimental design.

P: I'd say they're to give us real life experience and erm in labs.. …so we're qualified in the future for any jobs involving lab work etc. And to understand the basic fundamental techniques that we can then transfer into other areas.

P: I think it was fundamentally getting the skills correct and good lab practice, so we kind of know our way around the lab and understands feel comfortable in the environment… …and then it builds too, like using these skills that we've learned in small… in smaller reactions also to actually build up actual, more realistic real world examples of different practicals that take place.

Figure 59: Excerpts from interview with participant 2_11.

Participant 3_19 identified differing purposes of the academic-designed and project sessions. They suggested that students obtain laboratory skills and comfort in the laboratory environment in academic-designed teaching laboratory sessions, while their project sessions focussed on more limited techniques and fostered independence and responsibility in the laboratory.

P: So the purpose of teaching labs, in my opinion, was teach good lab skills and just to make you feel comfortable in a lab, rather than thinking.. 'Oh my goodness, there's a big box of chemicals here'

Figure 60: Excerpt from interview with participant 3_19.

Participant 3_19 also indicated that the technique skills obtained in their project are more specialised and are likely to be held by fewer students, but the amount that the skills were repeated gave a degree of competence.

Participant 4_01 identified that the teaching laboratory is an environment for evidencing skills, specifically showing that they could follow theory. Additionally, this participant indicated that the laboratory prepares students for future careers by fostering practical experience of equipment mostly for people wanting to pursue chemistry-based careers.

P: I think that's a way to get practical experience to show that you can follow what's in the lecture and apply it

---

P: also a way to prepare yourself for jobs umm.. further on… …'cause we've heard quite a few times that we get to use more machines in analytical chemistry here

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P: I think just the general learning how to use equipment that you might come across

Figure 61: Excerpts from interview with participant 4_01.

Transferable skills

On the theme of careers and employability, three participants explicitly identified purposes relating to transferable skills, either listing specific skills or identifying that skills learned in the teaching laboratory can have wider applications than chemistry-based industries.

In their first interview Participant 1_12 when asked about practical skills identified that teamwork, communication, and time management would count as skills that may be needed in industry. This was supported in their second interview where they identified that career-focussed skills such as organisational skills and time management would be important to their future career. They identified that these "general skills" could be applicable to careers outside of chemistry-related fields.

Participant 2_01 identified that the teaching laboratory allowed them to develop skills that are useful outside of the laboratory, however, did not identify specific skills.

Participant 2_02 identified that the teaching laboratory assists in learning to work with other people, working independently, time management and organisation as skills that were not limited to chemistry-based careers. Participant 2_02 also mentioned professionalism within the context of the laboratory, which could be a transferable skill, but as it is linked to the laboratory may also be regarded as laboratory specific.

Familiarity or comfort

Two students mentioned developing students' familiarity or comfort with the laboratory environment as a purpose of the teaching laboratory.

Participant 2_11 indicated that the sessions fostered comfort which would allow them to be able to undertake more complex experiments in the future.

P: so we kind of know our way around the lab and understands feel comfortable in the environment…

Figure 62: Excerpt from interview with participant 2_11.

Participant 3_19 agreed with this comment, suggesting that initially they were somewhat overwhelmed or daunted by the teaching laboratory environment, but developed a degree of comfort throughout their studies.

On taught labs:
P: to make you feel comfortable in a lab, rather than thinking.. 'Oh my goodness, there's a big box of chemicals here'
On project labs:
P: Much more freedom purposes. I mean, it makes you extends the comfortable feeling 'cause you're now responsible. I mean it's scary for the first week or two, 'cause you're like "Eek!" But it helps with the overall comfort in our lab.

Figure 63: Excerpt from interview with participant 3_19.

Differences in purpose at different levels.

Three participants identified differences in purpose or approach in different stages of their laboratory career.

Participant 2_11 indicated that the first year of their degree was focussed on the development of standalone skills, while their second year took the individual skills and techniques learnt in previous years and built these into full experiments.

Participant 3_19 identified a difference between taught and project laboratory sessions. Project laboratory sessions were identified as having a greater degree of independence with more reliance on the student to make decisions relating to the experimental process. The taught laboratory sessions were thought to have more scaffolding, designed to foster appropriate behaviour within the teaching laboratory and comfort within the laboratory environment. The project laboratory sessions were identified to be closer to problem solving than following a script.

Participant 4_01 indicates that theory is more ingrained at higher levels, and that at lower levels the teaching laboratory content was more consistently or obviously linked to the lecture material. At higher levels there is a higher requirement for independent learning, and there are concepts met in the teaching laboratory that may not be met elsewhere in lecture content at all. This participant indicated that their final year required them to be able to design experiments and research more extensively than previous years.

Discussion

The purposes of the teaching laboratory identified by students are very similar to the staff purposes of the teaching laboratory, encompassing learning chemistry theory, practical skills and familiarity, however student participants discussed the practical skills more than the staff participants did, and linked those and transferable skills to their desired career goals.

The student's high degree of focus on practical skills is anticipated by the literature (Russell and Weaver 2008), however Russell and Weaver indicate that students do not readily link the theory in their course to the theory learnt elsewhere. In this study, this is not the case, with 7 of 8 students indicating that they do learn chemistry theory, even if it is not the main aim of the teaching laboratory. There remains however a strong emphasis on practical or manipulative skills, with all students stating this as a purpose and several students indicating that they are valuable for their future careers. The link between careers and practical skills gained in a course has been previously documented (Galloway 2017) and is clearly important to the students interviewed in this instance.

Transferrable skills were also linked to future careers in Galloway (2017) and indicated by three students in this study as being developed within the teaching laboratory. Students can struggle to articulate and evidence their transferable skills (Morris et al. 2013), so having students recognising that they are developing transferable skills within the laboratory is a desirable graduate outcome desirable. Mello and Wattret (2021) suggest that this can be emphasised within science curricula in higher education by embedding reflection which is an element highly emphasised in the earlier staff interviews, and Tomasson Goodwin et al. (2019) suggest that teaching interventions may support students in articulating these skills gained.

The changes in the perceived purposes of the teaching laboratory at different levels could be indicative of a change in learning outcomes at different levels. As participants were asked about their teaching laboratory experiences more generally, and not about experiences at a specific level, this was not explored thoroughly as part of these interviews, and it would not be expected that all participants would cover this topic. This could be an avenue for further research, as either longitudinal present-focus interviews or end-stage reflective interviews could explore this topic more thoroughly. Staff participants have also referred to this development in outcome over time and it is indicative of cognitive development through taxonomic levels (Krathwohl 2002), with a possible indication of metacognitive awareness (Schraw and Dennison 1994) in the students who were able to identify this development throughout their course. The students who were able to articulate this development were in their second and final year of their courses.

4.3.2 Learning in the teaching laboratory

In this section, the students are responding to the question “What do you think you learn in a lab session?” As some participants undertook both structured “taught” sessions, and less-structured “project” sessions, they were permitted to discuss these separately if they preferred. Students indicated that they learn chemistry theory through repetition and application, develop practical skills, develop transferrable skills and identified behavioural outcomes learnt within the teaching laboratory setting.

Learning chemistry theory

Three participants emphasised that their learning may not always occur within the teaching laboratory, either due to their focus on their current operation, or the requirement of the structure of the assessment to require post-laboratory work.

Participant 2_02 did not mention theory throughout their discussion of learning in their response, so the researcher asked a direct question, which was regretfully phrased as a closed question. The participant elaborated unprompted to explain that they often focus on what they are doing in the experiment during the teaching laboratory session rather than thinking about it, unless prompted by an external source such as a staff member.

Participant 3_21 identified that how much theory they focus on within the teaching laboratory is time-dependent, and that they tend to focus on operation during the experiment to prioritise finishing their experiment. They identified that they typically focus on learning the theory either before the teaching laboratory session as preparation, or after the teaching laboratory session as a review or reflection. This attitude is consistent with their first interview, where they linked poor understanding of theory within the laboratory to poor preparation on their own part.

Two participants indicated that they learn theory within the laboratory by application of theory learnt in lectures to their experiments. This was mentioned by participant 3_21 in their first interview, and participant 3_19 who indicated that experiments tend to be memorable, and that surface or shallow learning gained within the laboratory can be expanded upon and deepened through exposure to greater context within the teaching laboratory.

Participant 2_11 indicates that they learn more effectively via active methods, and that they can implement knowledge learned within their lectures, which is very similar to applying.

P: I think depending on the module of the course, or whatever I feel like it's very good for implementing knowledge that you learn in lectures
I: OK
P: or something. So I find there's often times where in lectures something will be explained and you don't fully understand how it's need… why it's needed or.
I: mm hmm
P: How to understand the topic generally or something like that? But then when you come to the lab Um Like it kind of backs up that knowledge
I: yeah
P: and provides an example in which this information is actually used.

Figure 64: Excerpt from interview with participant 2_11,

Participant 2_01 indicated that they do learn theory within the teaching laboratory, often through reinforcement or repetition of concepts initially introduced through lectures. They also indicated that the teaching laboratory allows them to understand "how stuff comes together" which could indicate a similar phenomenon as that expressed by participant 2_11, understanding the purpose of isolated concepts within Chemistry as a whole.

In their second interviews participants 1_12 and 4_01 indicated that the teaching laboratory helps them visualise or understand abstract items taught within the lectures, indicating that seeing a phenomenon in the laboratory can aid their learning.

"And yeah, for some of them where it's in the lecture notes it does help. Sometimes if you can see, say for a different, you know doing different things give you different colours. It's a bit easier to see."

Figure 65: Excerpt from interview with participant 4_01, second interview.

The teaching laboratory appears to be treated as a joined-up learning experience by these students, indicating that they are drawing on their lecture content within the teaching laboratory and using the teaching laboratory to further their theoretical understanding.

Participant 2_07 identified that there is a difference in the way different labs required them to learn, suggesting that the structure of Physical Chemistry experiments and assessment led them to focus more on theory after the teaching laboratory session, as that was deemed to be important, whereas other areas of chemistry required more emphasis on in-laboratory operation and skill. This indicates that this student's operation and experience within the laboratory is influenced by the design of the teaching laboratory session, which is consistent with the literature suggesting that design impacts on student outcomes (Domin, 1999).

Manipulative or practical skills

When asked “What do you think you learn in laboratory sessions?” participants often focussed on manipulative or practical skills, however these were presented in a variety of ways from being able to use the equipment, including familiarity and competence, to a broad concept of best practice and good laboratory skills.

Participant 3_21 indicated that they learned familiarity with both equipment in the teaching laboratory and the teaching laboratory environment itself. The interviewer asked if the equipment and environment were inseparable or not, and the participant indicated “yes, they are separable”. The interviewer therefore asked a clarifying question, and the participant indicated that the environment and techniques were not separable.

I: Do you mean becoming familiar with the techniques or being familiar with the lab, are they inseparable?
P: they are separable (sic) yeah
I: yeah OK. So so by becoming used to the techniques you become used to how you operate within the lab?
P: yes

Figure 66: Excerpt from the first interview with participant 3_21

In their second interview participant 3_21 listed practical techniques e.g., extractions or separations in response to the question “what do you learn in the laboratory?”.

In their second interview Participant 4_01 stated that in the teaching laboratory they learn how to use different equipment and machines, however in contrast their first interview did not include reference to practical techniques at all in response to this question.

Participant 2_02 indicated that in the teaching laboratory they learn how to behave in the laboratory, and how to use equipment, as some students do not have much experience of the teaching laboratory environment prior to coming to university, and the school science environment is very different.

In their first interview, participant 1_12 extensively related their operational learning within the laboratory indicated that they learned “to be careful” within the laboratory, to obtain the best results or product. This indicates that the “careful” links more to accuracy or precision than exclusively a safety aspect. This participant also indicated that in the analytical teaching laboratory, they had increased their understanding in relation to the theory instrumentation by experiencing use of them first hand. The participant specified that they “know how to use” the instrumentation, which helps their theory, and when asked, the participant agreed these encompassed operational practical skills. By contrast, in their second interview, Participant 1_12 did not mention practical skills or techniques until asked about professional chemistry skills in the laboratory, with most of their initial response focussing on theory. The participant identified a variety of transferable skills useful within the teaching laboratory and when asked about the behavioural expectations of the teaching laboratory in relation to professional chemistry skills, the participant re-focused their response to practical techniques. This questioning thread may be leading, as the concept of the "professional chemist" is one introduced by the interviewer, however the student's link to practical skills was unprompted.

I: so you're saying things like communication or organization, those kind of things they… … they're sort of tied up in… or at least I think they're tied up in what it means to be a chemist in the lab?
P: Yeah,
I: or what I term kind of "professional chemists",
P: yes
I: So what do you think those are?
P: Any kind of practical skills like again yeah titration (inaudible) and that just actual practical experiments
I: mmm hmm
P: and. Teamwork is really important in the lab.

Figure 67: Excerpt from second interview with participant 1_12.

Participant 3_19 indicated that academic-planned teaching laboratory sessions taught them a reservoir of basic skills that can be built together to solve problems. This student indicates that the teaching laboratory develops problem-solving schema as well as practical techniques that they can apply to experiments later.

Participant 2_07 indicates that in the teaching laboratory environment they "get used to machinery" as this is a broad phrase, the interviewer asked a clarifying question. This participant indicated that the techniques being experienced within the teaching laboratory may be ones they encounter in the "real world.".

I: So when you say getting used to them Umm… do you mean gaining skills in them or gaining confidence or something like that?
P: Probably both at the same time I'd say.

Figure 68: Excerpt from interview with participant 2_07.

Three participants referred to learning best practice within the laboratory, in relation to practical or operational skills.
Participant 2_01 indicated that demonstrations within the laboratory by staff teach them best practice, which they identified as "what to do" and "what to not do" in relation to apparatus or instrumentation, which the participant agreed could be categorised as best practice. The example they provided, separating funnels, links to both ideas of safety and appropriate effective use of the apparatus.

I: Also, learning what not to do you mentioned, so that's a bit about. Best practice, but I think that might be more. More about practical things?
P: Yeah, it's more about sometimes what I'm doing. Sometimes what I see other people doing,
I: yeah
P: it's OK. This is not what you should do, and sometimes depending on who gives you demonstration that they'll show you, this is not how you do things,
I: yeah
P: which I think comes in very helpful.
I: Yeah, so. Umm.. An example of that would probably be things like titrations,
P: Yeah, and umm… other day we had. Two separating funnels. And we were told " this is not how you hold the separating funnel"

Figure 69: Excerpt from interview with participant 2_01.

Two students mentioned "good laboratory practice" in their interviews. Good laboratory practice is an accredited term with a specific meaning relating to an accreditable practice covering the appropriate and secure recording and storage of data in scientific industries (OECD, 2021).

Participant 2_11 identified that the teaching laboratory is a place that they learn practical skills and good laboratory practice, as well as familiarity with the laboratory environment.

In their second interview with participant 3_21, it is noted that the interviewer used the phrase "good lab practice" in relation to safety prior to the student's explanation, however the student's explanation of the term is different than the OECD definition, with the focus being on professional behaviour while in the proximity of others.

I: What do you think you learn in the lab?
P: Uhh… Good lab practice,
I: mm hmm
P: you know, just safety around the lab. In general how to interact with others while in a lab. So 'cause most of the… In the area that we're in right now, we've lots of fume hoods
I: (overtalking) we're in the fume hood bays yep
P: and so usually these fume hoods are shared by two people at a time,
I: yep
P: and so you learn to share space, work together, even if you. When you're doing the same thing, usually it's better just to. Make it more efficient by working together

Figure 70: Excerpt from interview with participant 3_21, focussing on the concept of good laboratory practice.

The students may be conflating the concept of "good laboratory practice" good practice within the teaching laboratory, which in this Author's experience at NTU is typically used to encompass appropriate handling of the equipment safely and professional behaviour and clear, accurate recording of data.

Transferable skills

Four participants discussed transferable skills learnt within the teaching laboratory, typically in a brief manner with little in-depth discussion.

Participant 1_12 listed some transferable skills developed within the teaching laboratory in their second interview including time management and organisation.

Participant 3_21 mentioned collaboration and time management in relation to efficiency within the teaching laboratory in their second interview.

Participant 2_01 indicated that they had learned how to work with others in a collaborative manner, which they had previously found to be a challenge. They also mentioned communication skills, specifically being able to ask for help or support when required rather than struggling alone.

Participant 4_01 discussed organisation and time management in relation to productivity within the laboratory and extensively discussed the requirement for compromise and professionalism within the laboratory when working in an environment where others are also working.

The concept of "practical skills" or "laboratory practice" is a very broad one with students exhibiting a variety of understandings of the terms. These terms would be more useful in a research context if they were more clearly defined. It is possible that due to the perceived familiarity of the researcher with the teaching laboratory environment, as an employee within that context, students felt it unnecessary to explain a perceived simple concept, however even when pushed to expand upon the concepts, some participants struggled to explain them.

Behavioural outcomes of the teaching laboratory

Two participants indicated that the teaching laboratory fostered independence.

In their first interview, participant 4_01 contrasted their 1st year experience with their current experience, indicating a greater degree of independence, particularly in that they are more regularly working on their own rather than with a laboratory partner.

Participant 3_19 indicated that their earlier year experiences developed independence to allow them to succeed in their project laboratory sessions, particularly identifying independence in relation to decision making.

Participant 4_01 put great emphasis on the requirement for preparation prior to entering the teaching laboratory, which they link to their capacity to understand and operate within the teaching laboratory.

I: So what do you think you learn in labs then?
P: Well umm… I think I learn. I learned that I need to prepare myself a lot more beforehand, 'cause? In the first couple years, it wasn't too much. You know, if you didn't really prepare it wasn't too bad 'cause it was like a 5 minute thing at the start, but
I: ok
P: I mean we had a [REDACTED] lab this erm… Just before Christmas and it was like if you didn't prepare, you just couldn't do it.

Figure 71: Excerpt from the first interview with participant 4_01, on the topic of preparation for the laboratory.

Participant 3_21 indicated that they had learned that things don't always work from the teaching laboratory, indicating that practical work can have unexpected outcomes, and that experiments can have multiple outcomes depending on environment and context.

I: So what do you think you learn in a lab session?
P: Do I learn? (laughs) Err.. That nothing goes as planned, (laughs)
I: (laughs) OK? So what do you mean by that?
P: Well, everyone could be doing the same thing at the same time with the same stuff and get completely different results.

Figure 72: Excerpt from first interview with participant 3_21 on the topic of unexpected outcomes to experiments.

Participant 3_21 provided further information by identifying a specific experiment where in the same teaching laboratory session, with the same reagents, a group of students undertook an experiment involving a ligand substitution. Depending on how the experiment proceeded, some students obtained a different colour product, indicating a different structure or method of substitution. The student suggested that this was an experiment specifically designed to show the variability of experimental work and the student indicates that it helped them appreciate that there will always be a degree of variability to experimental outcomes.

Discussion

The learning identified by students and staff are similar, mostly focusing on either theoretical chemistry understanding or learning practical skills, however students have identified learning how to be independent, while staff members identified that students should learn how to do science, indicating following a systematic scientific inquiry style procedure.

The responses to this question are very similar to the previous question regarding purpose, covering the same broad themes in slightly different proportions, with students focussing a little less on learning chemistry theory and more on applying knowledge. Practical skills, comfort and transferable skills are still a prevailing theme, suggesting a level of redundancy in this question.

4.3.3 Student aims in the teaching laboratory.

In this section, students are responding to the question "what those aims are for a typical lab session?" The researcher usually suggested that the participant may have several aims, encouraging the students to think deeply about their responses rather than only provide their main aim. Students identified aims including practical outcomes, assessment, management of stress or anxiety and time efficiency. Responses from this question are grouped by theme, with substantiating quotes where necessary.

Differing aims

Three students indicated that the aims that they have within the teaching laboratory may change vary depending on their level of comfort or the content or design of the module associated to the session.

Participant 4_01 was asked about their motivations regarding time management within the laboratory, and they indicated that their willingness to remain in the teaching laboratory for longer to obtain a high-quality product varies depending on how they feel. It is noted that this question was phrased poorly and in a possibly leading manner.

Participant 3_19 also noted a difference in their aims once they became comfortable with the laboratory environment.

Participant 2_11 indicated a variation in a different manner, with aims varying by module, but they did not elaborate how this variation is present.

Practical outcomes

In a typical teaching laboratory session, students are required to complete a procedure to obtain data. The data may be a dataset for an analytical procedure, or product-related data such as yields, purity data or instrumental analysis of a product. For this discussion, this data will be referred to as the "practical outcome" for clarity and consistency between different types of experiment.

Participants in these interviews often referred to completing the laboratory, obtaining the appropriate outcome, or obtaining high quality outcomes. Indeed, only one participant 2_01 did not explicitly mention the practical outcome of a laboratory session, however they did reference "finishing" the laboratory, which could be linked to an outcomes-focussed aim.

P: then I won't finish. And then what am I going to do kind of thing.

Figure 73: Excerpt from interview with participant 2_01 on the topic of finishing the experiment.

Two students explicitly referenced the importance of completing the experiment within the allotted teaching laboratory session.
In their first interview, participant 3_21 indicated that they wanted to make minimal errors and therefore complete the experiment. The researcher clarified the response and obtained the student's agreement in linking this to the practical outcome of the experiment.
Participant 3_21 was consistent in their response in relation to practical outcomes being an aim for them in the laboratory in their second interview, with an emphasis on personal thresholds of acceptable working focussing on safety and good practice.
In their second interview, participant 1_12 identified different types of practical outcome, linked to what the laboratory script or instructions indicates that should be achieved.
Four students referenced the importance of the quality and precision of their data set in relation to either obtaining the practical outcome, or assessment.
Participant 3_19 indicated that in their first year, they had aims related to the practical outcome, making them more similar to participants 3_21 and 1_12 as discussed above. However, this participant identified a change in their aims once they were more familiar or comfortable with the teaching laboratory environment, switching to focus on the quality of their outcomes, but they do still emphasise the purity and yield of the product or practical outcome.

Participant 1_12 indicated in their first interview that they aimed to follow the instructions provided within the laboratory script, with the aim of producing high quality practical outcomes. Participant 2_07 also indicated that one of their aims was to obtain a high-quality practical outcome.

Participant 2_11 indicated that to obtaining the best results possible was their main aim, indicating that accuracy in operation and avoiding rushing leads to increased quality of results.

P: We should always aim to have get the best results possible.
I: OK,
P: which sometimes means taking more time to accurately weigh. Accurately measure
I: mm hmm
P: solutions actions and all this, and I think it's also important not to rush. So when you come in rushing. trying to get out early shouldn't be a priority
I: ok
P: It should… the main aim is always going to be get the best results you can
I: yeah
P: The most reliable, most accurate results you can.

Figure 74: Excerpt from interview with participant 2_11 on the topic of practical outcomes and quality.

Practical outcomes linked to assessments.

Four students linked completing the experiment to a post-laboratory assessment, assignment or grading process.

Participant 4_01 referenced assessment in response to the discussion of aims in the teaching laboratory in both of their interviews. In the first interview they mentioned emphasising obtaining data promptly to facilitate writing up the experiment after the scheduled session to avoid forgetting details in the interim. In the second interview, the participant indicated that they aimed to get any practical outcome at all, but preferably of high quality.

In their second interview, Participant 4_01 reported a consistent aim of obtaining some data, preferably of good quality. The meaning of “good data” was discussed and the experimental process being followed was identified as a factor that can limit the quality of practical outcomes.

Participant 2_02 explicitly linked practical outcomes to assessed work and emphasised that they aim for high quality practical outcomes because the students are assessed on them.

Participant 3_19 indicated that they aimed to achieve both high quality practical outcomes and a good grade. The researcher queried if these were linked, and the participant agreed with enthusiasm, and linked both to the degree of effort a student is willing to put into their work.

Participant 1_12 indicated that making the “correct” product or practical outcome was linked to self-esteem, reducing stress and assessment, as the “report” is an assessed teaching laboratory artefact. Managing stress in relation to the teaching laboratory is a theme that will be discussed later in this section.

Participant 2_07 displayed a different motivating factor in relation to high quality practical outcomes instead of grades or assessment. This participant indicated that, in common with participant 1_12, they gain a degree of self-esteem from doing well within the laboratory, they indicated that although they may obtain a higher grade because of high-quality practical outcomes, that was not their main motivation. It is possible that this question was asked in a leading manner, as the question was closed, but the student responded with an open and reflective answer.

P: for the most part is just simply getting the best set of results I possibly can and using machine and use the equipment as effectively as possible I can.
I: is that because you want to get good results because you want to achieve a task to high quality or is it tied up with assessments and grades?
P: I just want to do who do well per.. do well, personally, Umm… generally the better I do within the labs themselves, obviously the better grade I get corresponding to that lab, so it’s a win win. (stutters, trails off)

Figure 75: Excerpt from interview with participant 2_07 on the topic of practical outcomes and self-esteem.

These practical outcomes focussed attitudes are highly similar to the “cooking chemistry” attitudes identified in literature, with students focusing strongly on the end product and following all the correct steps to make the product. A focus on quality is not typically emphasised in these studies, so that may be regarded as novel.

Time efficiency

Six participants mentioned time efficiency, saving time or time management as an aim for the teaching laboratory sessions.

Participant 2_01 indicated that they review the experimental procedure in advance and estimate the time they will allow for each step of the procedure to allow themselves to complete the experiment in a timely manner.

Five other participants reference efficiency or time savings more broadly, with participant 4_01 referencing working in a time efficient manner to be able to leave the teaching laboratory as soon as possible.

P: I mean I like to get out as quickly as possible. I: mm hmm **P: with a lot of experiments and. Erm you know, so just working in a time efficient way, but you know still getting good data, it's like hmm, ok.**

Figure 76: Excerpt from second interview with participant 4_01, on the topic of time efficiency.

Participant 2_07 indicated that they prepare elements of their experimental work before the teaching laboratory session as much as possible, to save time within the laboratory session itself.

Participant 2_02 indicated getting out on time as an aim, but when queried further they indicated they aim for time efficiency rather than speed.

Participant 3_21 referenced efficiency in two different ways, once in each interview. In interview one, the participant referenced working at a reasonable speed to avoid having to wait for equipment, as queueing was seen to be wasting time. The participant also identified that they preferred to be the first person to use equipment or reagents as students can leave workspaces messy which makes it harder to work. The student expanded upon this in the subsequent question "how do you achieve these aims?" by elaborating that queueing occasionally results in results being delayed into later timetabled sessions.

In the second interview, participant 3_21 indicated that they aim to finish in time and that working in a clean, safe, and professional manner allows them to save time within the teaching laboratory. An element of professionalism is contained in both responses, but they do differ in that the first interview response focusses mostly on their interactions with others in the teaching laboratory, while the second interview response focuses more on the participant's own behaviours.

These time efficiency behaviours link to the practical outcomes, as students relay that they need to obtain all data required, or complete the experiment, as such time efficiency should not be regarded as an entirely discrete theme.

Participant 2_11 identified that they aimed to be organised within the teaching laboratory, however being organised isn't necessarily an "aim" of theirs, as they believe it is developed with practice, and part of good practice within the laboratory.

Operational goals

As several participants had indicated in response to previous questions that they obtain and develop practical skills in the teaching laboratory, it could be anticipated that this would be a common aim for the students, however improving manipulative or practical skills were not frequently mentioned by students. This discrepancy in what is learnt, and what students have as an aim may stem from the way the students view the techniques and the teaching laboratory environment – if they are viewed as closely linked, it could mean that they do not feel the need to explicitly state the aim of development of practical skills. Another explanation could be that the practical skills are scaffolded within the experimental instructions meaning that the effort required from the participant to learn those skills is reduced and the student does view this as an aim that they are required to set for themselves, as they don't consciously decide to develop their practical skills. This is an interesting discrepancy that could easily be studied further by investigating students' practical skill development throughout a degree programme, either by observation, auditing the techniques used in experiments, or interviewing students.

Participant 2_07 indicated that they aimed to use the machines and use the equipment as effectively as they can, to achieve good results.

Participant 3_19 indicated that they repeat techniques until they display a degree of competence.

P: It's it's fun to do new things and it's fun to learn. New techniques in the lab, I: ok P**: but that novelty kind of wore off as you started doing them over and over and over again to the point where it was very much case of I know how to do it, now I'm going to do it well,**

Figure 77: Excerpt from participant 3_19, on the topic of practical competence.

Participant 1_12 is the only participant to explicitly aim to improve their manipulative or practical skills. This participant identified a particular technique that they were struggling with, and the steps they had taken to improve their operation within the specific technique. The participant identified that improving their techniques also makes them feel less stressed. Stress within the teaching laboratory will be discussed later in this section. This participant 1_12 reaffirmed this goal of improving practical or manipulative skills in their second interview, stating that they wanted to learn along the way and record issues to improve from them in the future.

Safety and good practice were mentioned as an aim by 4 participants, although typically briefly, and often linked to finishing the experiment in time or correctly. As for the previous question, some participants seem to use the phrase "Good Laboratory Practice" to refer to good practice within the laboratory, rather than the accreditable concept of GLP. The accreditable concept of GLP (Fox 2003) encompasses elements of best practice for study development, quality assurance and data requirements, and is most often found in relation to specific studies rather than entire environments. Environments such as testing laboratories can be accredited under ISO requirements, such as ISO17025, which provides a standard of practice including auditing and record keeping.

Participant 3_21 suggested in their first interview that working to a high standard of safety and appropriate practice would increase their standing with academic staff, as an element of professional esteem.

Stress or anxiety

Three participants mentioned stress or anxiety in relation to the laboratory. Stress and anxiety are two separate phenomena, stress is defined by (APA 2018b) as "the psychological response to internal or external stressors". Whereas anxiety is defined by (APA 2018a) as "an emotion characterized by apprehension and somatic symptoms of tension in which an individual anticipates impending danger, catastrophe, or misfortune." further explaining that anxiety is distinct and separate from fear despite being often conflated.

Participant 1_12 mentioned strategies to reduce stress in both of their interviews, the first interview detailed reducing stress by developing skills and therefore producing the practical outcome. The second interview focussed on effective preparation and time management resulting in reduced stress.

Participant 2_01 declared that they find the teaching laboratory to be a stressful environment. They did declare that they have ADHD and anxiety, however the laboratory makes them feel the anxiety they usually feel more keenly. Their aims were often about self-management within the laboratory, aiming to reduce stress, keep themselves calm and seek help when required.

Participant 3_19 uses phrases that could indicate a degree of anxiety about being within the teaching laboratory when referring to earlier years of their study, while the laughing indicates a degree of humour, and the comments relating to terror may be an exaggeration, the student clearly indicates a level of discomfort with the teaching laboratory environment in earlier years, although they do confirm that they are more comfortable in later years of study.

I: so on.. in 1st year maybe you weren't… so focused on doing it well, just doing it.
P: pretty much the word is just "terror" in first year (laughs)

P: **For the first year and some of 2nd year was very much case of "get through it" because I don't know. I didn't have a broad enough understanding of what was going on at that point because I was new to it"**

Figure 78: Excerpts from interview with participant 3_19, indicating discomfort in the teaching laboratory environment in early years of study.

Pre-laboratory preparation

Three participants made referenced being prepared for the laboratory as one of their aims for the teaching laboratory.

Participant 2_11 indicated that they review the experimental script, either staff-provided or student-designed ahead of the experiment to help them know the steps involved in the experiment before they enter the laboratory. They indicate that this research or pre-laboratory work helps them learn, as their learning is impeded if they do not prepare.

Participant 1_12 indicated that they prepare themselves for the teaching laboratory in two different ways. In the first interview, they detailed the physical preparation before entering the teaching laboratory space, involving donning protective equipment, and ensuring that they logged into their device correctly upon entering the Superlab. In the second interview the student detailed preparative steps that they take linked to the experimental procedure, and time management within the teaching laboratory.

Participant 2_07 details how they prepare for the teaching laboratory by reviewing the experimental procedure, or script, in advance of the scheduled sessions, which allows them to save time in the experiment by being aware of the steps involved. This participant was asked if they were directed to review these documents, or if it is something they had chosen to do. The student indicated that academic staff do expect students to review the experimental procedures, however not all students do, and those students lose the benefit of being prepared.

Additional student aims within the teaching laboratory.

Two students detailed unique aims that do not fit well with the other themes identified by students, and they are identified in this section. To accurately represent the student's aims, it is important represent all their aims, even if they are not common with other students interviewed.

Participant 2_02 indicated that they aimed to "get as much out of the lab session as possible" as this is a subjective phrase, the researcher asked the student to expand upon it. The participant indicated that the teaching laboratory was a good opportunity to ask questions.

P: and try and get as much of it as possible than just try and rush it to go.

I: What do you mean by getting as much out of the lab session as possible?
P: So if I don't understand something, I'll go and ask.
I: ok
P: I won't just stand there (laughs) because I like to know. OK, why is this happening? Whereas not everyone is like that, but I'm just a person that likes to know and then later on I could be like, OK, this is what I was told in the lab session session, which is why this happens and I can sometimes (inaudible) into my work.
I: Is that more usually relating to theory or practical stuff? Or... operation in the lab?
P: theory

Figure 79: Excerpts from interview with participant 2_02 on the topic of theoretical learning in the teaching laboratory

Participant 3_21 detailed an interesting aim in their second interview of using the teaching laboratory as a social environment. The participant identified that the common experiences in the teaching laboratory act as an opportunity to approach fellow students in a safe environment, allowing the development of relationships using the common ground of the teaching laboratory experiences as an icebreaker. This participant did identify elsewhere in their second interview that they do have anxiety, and that the common ground allows them to overcome their anxiety and strike up a conversation.

Discussion

The student aims identified here are slightly different to the aims that staff participants thought students held. Students were deemed to have a high degree of focus on practical outcomes and assessment by staff, however students have identified a broader set of aims that encompass preparation and stress management. The focus is still often on completion; however, it is not exclusively for the purpose of assessment or completeness and is perhaps more complex than staff participants had indicated. The extensive focus on outcomes is consistent with cookbook chemistry styles of learning (Boyd-Kimball and Miller 2018; Venkatachelam and Rudolph 1974) and the "Achieving" style of approach to learning (John B. Biggs and Moore 1993) where a student is focussed on the end outcome, and maximising efficiency of effort balanced with a perceived valued outcome such as a grade. The perceived "value" is not however limited to the grade as described by Biggs and Moore (1993), instead encompassing some more operational targets such as developing practical competence and best practice within the teaching laboratory. These are less short-term than the “grade” outcome but are not deep enough conceptual learning to be associated with the “deep learning” category.

The themes of stress or anxiety arose within the student responses in this section. Anxiety within the teaching laboratory is a documented phenomenon (Sesen and Mutlu 2014; Bowen 1999) and is linked by Sesen and Mutlu to the ability to operate safely in the environment in relation to hazardous materials, while Bowen additionally links the anxiety to the laboratory environment, time management and data recording within the teaching laboratory. Students were not directly asked about stress or anxiety levels within the teaching laboratory, as that was not an initial research aim for this study, however several students separately mentioning the theme indicate that it bears further inquiry.

Three students have identified that their aims are different depending on the context, with one student indicating different modules, and two further students indicating that their aims vary dependent on their personal circumstances, either motivation or comfort. Motivation has been linked to student outcomes and therefore is an important element to consider in relation to the teaching laboratory (Liu et al. 2012) and indeed is explored further in section 4.3.5. Preparation is mentioned in this section by students as an aim, however as it is an action that is within the students’ control it will be discussed more extensively in section 4.3.4 where student strategies are collated.

4.3.4 Student strategies for success in the teaching laboratory

In this section, students were asked “What do you do to achieve your aims?” Not all participants were asked this question as a stand-alone question, but as a part of the aims question, or some participants were not explicitly asked for their activities to achieve their aims but volunteered the information in response to another question such as the aims question. Responses drawn from the questions on aims will be flagged as (***Aim***) for aims question in this section for clarity. Participants 1_12 (second interview) and 2_07 were not asked this question explicitly, but it was grouped within the other questions as lines of inquiry. Participant 4_01 was asked this question out of sequence, after the staff aims question. Responses to these questions are grouped by type of activity or action undertaken by the student.

Pre-laboratory preparation

Six students identified activities that they undertake before entering the teaching laboratory to prepare themselves for their timetabled sessions, with several identifying that they read the laboratory “script”, which is typically a set of instructions or procedure for the experiment, perhaps with some theory. The perceived outcomes of reading the laboratory script vary a little between participants, with organisation and setting of expectations are common themes.

Participant 1_12 identified in their first interview that they read the laboratory script to allow them to anticipate any linked steps within the procedure. This was reinforced in their second interview in the ***aims*** question, where the participant detailed that they read the laboratory script to know what to expect from the experiment, identify any challenging items and identify unexpected steps within the procedure.

Participant 2_02 indicates that they read the laboratory script because they like to know what they're doing before the lab, which allows them to be more organised within the laboratory. This participant indicates that pre-laboratory work is typically directed by the academic, however if they are not directed to undertake pre-laboratory reading, they generally read through the laboratory script anyway.

P: So I would read the lab script beforehand
I: ok
P: because I like to know what I'm going to do in the lab
I: mm hmm
P: rather than wait till I'm in there. That also kinda makes me a bit more organised
I: yep
P: So when I go in I know right … This is how I'm going to start.

Figure 80: Excerpt from interview with participant 2_02 on the topic of reading the laboratory script.

Participant 2_07 discussed in the ***aims*** question reading the laboratory script before entering the teaching laboratory as a measure of saving time by undertaking some steps required in the experiment prior to entering the teaching laboratory environment. This participant indicated that the students are expected to prepare for the teaching laboratory by reading the laboratory script, however not all students will complete this.

(*Aim*) P: I think that's generally expected of us, but it does seems like quite a few cases people will just not care for it. For example, I know for the organic labs for our year after we have to calculate the exact amount of reagent, so will have to be… to use. So, for example, were given amounts in millimoles. We then have to convert that into, say, grams and mLs

Figure 81: Excerpt from interview with participant 2_07 on the topic of pre-laboratory preparation.

Participant 2_11 indicated that they research the experiment before entering the teaching laboratory, either by undertaking their own research or by completing a set pre-laboratory exercise. This was a repetition of a comment in response to the ***aims*** question. When asked why they undertake this preparative step, they indicated that it helps them understand what to expect within the teaching laboratory.

(Aim) **P: Well, normally if you've researched the experiment**
I: mm hmm
P: that you're doing and do some pre lab work, then you should generally know if it's organic each synthesis and each what you're making, what you're forming, I feel like it's a lot easier to go into the lab. With an idea of what you're doing and what you want to make and how you're going to make it.

Figure 82: Excerpt from interview with participant 2_11 on the topic of pre-laboratory preparation.

Participant 3_21 identified in their first interview that they read the laboratory script to allow them to prepare for the teaching laboratory, allowing them to minimise wasted time and familiarise themselves with the procedure.

Participant 4_01 indicated in the second interview that they typically read the laboratory script in detail before entering the teaching laboratory to allow them to identify any challenging elements or unfamiliar techniques or procedures within the experiment, to allow further research if necessary, indicating research helps them anticipate the form of reagents and products, and act accordingly in the laboratory.

In addition to reading the script, two participants also indicated that they prepare documentation or calculations before entering the laboratory. Participant 4_01 in their second interview identified that they use their pre-laboratory preparation to identify appropriate information and undertake calculations that may be required in the experiment, such as concentrations. In their second interview, participant 1_12 indicated a similar aim of preparing their proforma, to minimise the amount of typing that was required on the tablets, due to a preference for typing on other devices. The term proforma is used for a template provided by academics to allow students to report results in a uniform format which is often in Microsoft Excel, Word or a PDF format.

P: Ummm… Umm… Sometimes I also do it too prepare some parts of the proforma
I: mm hmm
P: for. Like for inorganic we have to do the lab reports actually in the lab,
I: mmm hmm
P: and because I don't really like the tablets because I just don't like typing on these tablets.

Figure 83: Excerpt from interview with participant 1_12 second interview on the topic of preparation before the teaching laboratory.

Comments from participant 4_01 suggest that the ability to prepare for the teaching laboratory effectively is a skill they developed over time, however participant 1_12 is a first-year student and details preparation for the teaching laboratory at an early stage of their studies. This suggests that there is a variation in levels of preparation in students at different levels, but with so few respondents of upper and lower levels of study it is not possible to generalise at this stage.

Time management

Four students mentioned actions relating to the speed of their work or planning their time within the teaching laboratory.

Participant 3_21 emphasised in their first interview that they wanted to work at a reasonable speed, and plan ahead to avoid queues for equipment or reagents to allow them to finish on time.

Participant 2_02 said that they remain very aware of the time, and they plan their time by estimating the length of time tasks will take during an experiment. The student identified that they estimate these time allowances based on their own prior experiences.

Participant 2_11 mentioned that they avoid rushing in the ***aims*** question, focussing on working accurately and avoiding mistakes. This would prevent the need to repeat steps of the experiment and save time.

Participant 2_01 talks extensively in the ***aims*** question about how they work to organise themselves and manage their time by setting up check-point times within the experiment, reminding themselves of where they are in the experiment, and focussing on what step they are currently on. The student and identifies that this is an element in the laboratory that they struggle with – which they later link to their ADHD and anxiety, as they identified that they struggle to focus and organise their thoughts. This participant identified that some instructional styles are more challenging for them than others, with bullet points being ideal for the laboratory.

In their first interview, participant 4_01 indicated that they prepare as much as possible prior to the lab but did not provide details of this preparative activity. This preparation was to facilitate time efficiency, to reduce queueing in the laboratory. This student was part of a particularly large cohort and noted that there was a large amount of queueing in the teaching laboratory in their first year because of this. This question was asked out of sequence, after the staff aims question.

Follow the procedure.

3 students identified the importance of following the experimental procedure closely.

Participant 1_12 indicated that they followed the script as closely as possible, reading ahead during the teaching laboratory session to ensure they are prepared for the next step.

P: when I followed the script in the lab I still try to go a bit further than like the line or the step. I'm reading

I: yeah

P: just to see if there is anything I should have done differently…

I: oh, yeah

P: … from the previous step

Figure 84: Excerpt from first interview with participant 1_12, on the topic of following the experimental procedure.

Participant 3_21 indicated in their first interview that following the procedure correctly is important to success within the laboratory. This participant indicated a similar action in their second interview in response to the ***aims*** question, suggesting that following the script to a personally acceptable level, being safe and following GLP allowed them to finish within the time limit of the scheduled session.

Participant 3_19 indicated that following the procedure is useful, they also supplement this by observing others within their cohort to compare experimental outcomes and identify any errors.

I: What do you do to achieve the aims?

P: right I… whilst following the lab script is very, very useful.

I: mm hmm

P: I also found it quite useful to keep an eye on what other people were doing

I: ok

P: just because, like if my solution goes red and everyone else is blue, then I'm in trouble, but. I yeah I haven't like… being in an environment of people in the same situation as me was very useful in teaching labs because we all just kind of helped each other.

Figure 85: Excerpt from interview with participant 3_19 on the topic of observing others within the teaching laboratory.

Following the procedure is a very practical-outcomes focused activity and is consistent with the actions identified by Gunstone (1990) where students tend to focus highly on operational tasks.

Best operational practice

Five students identified that they try to act on feedback or guidance to use best operational techniques or practice when using equipment or instrumentation within the teaching laboratory in order to either avoid mistakes or obtain more precise and accurate results.

Participant 2_11 indicated that they receive and act upon advice from technicians within the laboratory to achieve best practice for techniques, such as using an appropriate flask for a recrystallisation. This participant also reviews their experiments and identifies any issues for improvement in the future, which is indicative of critical reflection.

Participant 1_12 indicates that they try to avoid mistakes by working precisely and acts upon advice from staff to improve their operation within the laboratory in the future.

Participant 3_21 discussed problem solving and addressing mistakes within the teaching laboratory extensively in their first interview, identifying that they first try to solve the problem themselves, then ask nearby student colleagues, then staff members particularly technical staff for support. These mistakes were described as operational ones, where the student had undertaken some of the experimental steps in a different manner to other students.

Participant 2_07 indicated that they use the equipment provided in the teaching laboratory as effectively as possible, to obtain high quality results, but they do not discuss how they know what best practice is.

Participants 3_19 indicated that they were not initially comfortable with approaching lecturers for support within the teaching laboratory regarding operational practice, so they sought affirmation from research using Google and self-directed research.

Participant 3_19 also indicated that working safely was important within the laboratory. This theme of safe working was echoed by participant 3_21 in their second interview in response to the ***aims*** question.

Purification and critique of product quality

Participants 2_02 and 2_11 both mentioned undertaking purification procedures to improve the quality of their products.

Participant 4_02 identified in their second interview that they reflect on the quality of their practical outcomes by receiving critique or feedback from staff members, and then confirmatory tests such as infra-red spectroscopy. The participant also indicated they would compare their practical outcomes to their peers.

In their second interview, participant 4_02 detailed a further way of identifying if an experiment has been successful, by comparing the practical outcome to the anticipated product from the experimental design process or instructional documents.

A desire for best operation or high levels of purity was linked by these three participants in their interviews to high quality practical outcomes. The participants who are aiming for high quality practical outcomes must necessarily aim to follow best available techniques. This is consistent with the high level of focus on operation within the laboratory as described by Gunstone (1990), however there is an extension to the critique of quality that could be linked to high conceptual levels from Bloom’s Taxonomy (Krathwohl, 2002).

Additional actions within the teaching laboratory

These actions do not fit within the broad themes identified above and therefore are represented in isolation.

Participant 4_01 indicated in their first interview in response to the ***aims*** question that they write up data week by week to stay on top of their experimental record and avoid forgetting information.

Participant 2_02 indicated that they ask questions to get the most out of the lab, as discussed in the responses to the ***aims*** question.

Participant 3_21 indicated that they plan their time to allow for social interactions, identifying quiet periods in the teaching laboratory sessions to keep in touch with peers.

Participant 2_01 identified techniques for stress management, detailed in the responses to the ***aims*** question.

Participant 2_11 suggested that being “switched on” or paying attention and having common sense is important within the laboratory. The participant indicated that although this isn’t necessarily a conscious action, and it’s more passive, but it allows them to follow good practice within the teaching laboratory as much of best practice is identified by this participant as common sense.

Discussion

Students have identified several actions or choices that they undertake to achieve success, some relating to operation within the teaching laboratory, and some linked to preparation.

The theme of preparation is interesting as literature would suggest that students are often underprepared for the teaching laboratory (Rollnick et al. 2001; Carnduff and Reid 2003; Agustian and Seery 2017), however the student participants are reporting undertaking preparatory work. It is possible that these responses are affected by a form of social desirability bias which can be present in qualitative interviews (Bergen and Labonté 2020). In this context, social desirability bias may result in students wishing to appear to be prepared when questioned by a person who is related to the institution and course and therefore exaggerate their preparation or describe it in a more favourable manner.

An alternative possibility is that students are undertaking preparative activities, however it is not effectively preparing them for their studies in the teaching laboratory in a way that tends towards long term retention and understanding. The elements identified by the students are often tending towards a passive rather than active learning activity, with examples given of reviewing the provided materials and highlighting unfamiliar elements, and these passive activities tend to be less effective in promoting long-term learning by promoting cognitive engagement (Pitterson et al. 2016).

Investigating the actions undertaken as part of students’ pre-laboratory preparation would be a beneficial avenue for study in the future, however as it is often undertaken away from institutionally controlled environments, it is challenging to measure precisely what the students are doing in an accurate manner.

This theme of passive learning reoccurs in the students indicating that they follow the procedure and best practice, with little reference to self-critique or reflection. Literature suggests that the teaching laboratory is intended to be an active learning experience (Coppola 2016; Modell et al. 2004), however the passive approach described by some students is reminiscent of "cookbook chemistry" (Gallet 1998; Boyd-Kimball and Miller 2018; Venkatachelam and Rudolph 1974; Bertram et al. 2014). As the actions section is only a smaller sub-section of the overall interview, it is possible that the discussion of actions is not exhaustive and therefore does not encompass the full student experience. A possible way of overcoming this would be to employ a real-time observation protocol to ensure the full range of activities are represented (Velasco et al. 2016) or alternatively, to probe decision-making and thought processes, a think-aloud protocol could be followed (Rayment 2023).

4.3.5 Motivation in the teaching laboratory

As for the actions to achieve their aims, students sometimes identified their motivations within the question regarding identifying their aims. As such not all participants were asked this question as a stand-alone question, but as a part of the Aims question, and it is possible that some participants were not explicitly asked for their motivations but volunteered the information in response to another question. Responses drawn from the questions on aims will be flagged as (***Aim***) for aims question in this section for clarity.

This question was not consistently phrased by the researcher, with 3 phrases identified, paraphrased below:

- Why do you do "action/choice" in the teaching laboratory?
- What are your motivations when you do "action/choice"?
- What motivates your decision making in the teaching laboratory?

Although these questions are similar, they are not directly comparable. Results are still presented as students presented some interesting motivating factors; however, this question is less reliable than would have been expected if the question was posed more consistently.

Completion, quality and assessment

There are two motivations identified by participants that are tied to the practical outcomes of the teaching laboratory. Firstly, completion of the procedure or making the product, and secondly any associated grade or credit attributable to assessments linked to the practical outcome of the experiment.

Participant 2_01 implied throughout earlier sections of the interview but did not explicitly state that they are motivated by a desire to complete the laboratory, and when they do not undertake the activities such as time planning and reminding themselves of actions, they have previously not finished on time. The motivating factor was identified as prior experience, and a desire to complete.

Participant 1_12 identified in their first interview that "good results" are a motivating factor to them, however this is a vague phrase, so the researcher asked further clarifying questions. The participant clarified that both high quality practical outcomes of product or data and the grades associated with these practical outcomes were motivating factors to them.

As mentioned by students earlier in the aims of the laboratory question, often the quality of product and the grade outcome for assessments associated with teaching laboratory are correlated, as such grades can be considered linked to practical outcomes.

Two students have mentioned that grades or assessments are a motivating factor to them within the laboratory.

Participant 4_01 mentions grades or assessments in both of their interviews. In the first interview, the participant was asked “What makes you want to work harder?” which was re-worded to “work smarter” and the participant identified that assessment weighting and credit would be likely to make them exert more effort in an experiment. The participant provided an example of a non-credit bearing assessed piece of work where they put in less effort than they would have done if it were credit bearing.

P: If it's not graded, then it's not going to be my best work really.

Figure 86: Excerpt from first interview with participant 4_01 on the topic of credit bearing or non-credit bearing assignments.

In the second interview with participant 4_01, the participant responded that they were mostly motivated by the grade obtained from the linked assessment. The participant identified a couple of actions they could undertake to obtain a few extra marks, and that they put this effort in to obtain those marks as they perceived it to be useful to obtain credit in advance of the exams in the course.

Participant 2_11 mentions assessment within the context of peer comparison, which will be discussed in the peer motivation theme. Grades were identified as important in terms of future careers, as qualifications, however skills are more important long-term.

Participant 3_19 did not explicitly mention grades or practical outcomes as motivating factors within their response to the motivation question, however they had referenced it in passing throughout the ***aims*** and ***actions*** questions. The researcher confirmed this by asking the student explicitly if this was the case, although this question phrasing could be deemed to be leading.

Pride or validation motivated

Participant 2_11 indicated that they are motivated by the pride of improving, which can be an internal self-esteem pride, or an external pride linked to family or peers.

Participant 3_19 had mentioned obtaining high quality results in relation to grading extensively throughout the interview, the researcher queried the motivation behind aiming for high quality results and the participant indicated that this was not associated with grades, but instead with the satisfaction of a job well done, or a sense of perfectionism.

Participant 1_12 indicated self-esteem and validation of career choice as motivating factors within the teaching laboratory in both of their interviews, indicating that performing poorly in the teaching laboratory would make them question their future career in chemistry-related fields.

Peer motivated

Four students identified motivational factors related to interactions with their peers.

Participant 3_19 was asked about decision making and self-critique and identified the importance of having peers in the teaching laboratory for support, but also as a measure of how well the participant had performed in the experiment.

I: What motivates the decisions you are making and so things like when you are critiquing yourself and deciding whether your product is good enough in your data set is good enough, or your performance in lab has been good enough what benchmark are you measuring that against?
P: Umm.. is this in teaching labs?
I: yeah
P: So having peers with you made it a lot easier.
I: mmm hmm
P: Ummm… Because I could see how my results compared to the average.
I: ok
P: I'd say the average. I mean, I'd have about 6 that would be in contact with about 6 people.

Figure 87: Excerpt from interview with participant 3_19 on the topic of peer motivation and comparison within the teaching laboratory.

Participant 2_07 was asked about decision making within the teaching laboratory particularly in relation to at which point they would be satisfied with the quality of a practical output, and they indicated that decision this would be motivated by how they were progressing in the experimental procedure in comparison to their peers. They also agreed that they compare their practical outputs to their peers. The participant did agree upon prompting that they can compare their outcomes to literature values, however subjective measures of success, such as the appearance of a product are more likely to be measured in comparison to peers.

I: What kind of things would motivate you to make those decisions?
P: Umm… Often it depends on how quickly people are going around me. So for example, if I feel like I'm like behind, I have a feeling need to catch up. And I mean if I'm going towards being the front and then I will start to take my time. But generally I want to keep up with everybody else in terms of timing.
I: OK, so you're very much aware of how people are progressing around you and what their work is like,
P: yeah

Figure 88: Excerpt from interview with participant 2_07 on the topic of motivation within the laboratory, and peer benchmarking.

Participant 2_01 identified that they compare themselves to their peers and that can be stressful and decrease their esteem or confidence. The participant agreed that this is an isolating experience and identified that it was worse in their first year as they felt they had much less laboratory experience than their peers due to having previously been in a different educational system to most of their peers, as they did not study in the UK for their pre-18 study. This participant also identified that they felt they struggled within the teaching laboratory environment at least in part due to their ADHD and anxiety, which makes it difficult to process information and follow instructions. This may be an important factor, as it could make the teaching laboratory a more challenging environment in comparison to their peers, so peer-comparison may not always be a helpful or constructive measure for this student.

P: and it's also like you know when when you see everybody else around you like. They know what they're doing kind of thing,
I: mmm hmm
P: and then it just kind of feels like, Oh well, I'm the only one who's confused.

Figure 89: Excerpt from interview with participant 2_01 on the topic of peer comparison.

Participant 2_11 identified two possible external factors for motivation, peer and family motivation. The student identified friendly competition in relation to grade as a motivating factor for them, and when questioned about the relative motivation of practical outcomes, physical product such as crystals were identified as more motivating than data because data less subjective.

Other motivations

Participant 2_02 only identified one motivation, which was to develop skills related to a career in industry.

Participant 4_01 indicated in their first interview that they make decisions in the teaching laboratory based on a balance of factors, and that they were more likely to expend effort on the work if it was credited, as discussed earlier, but also if it was a teaching laboratory session that they were enjoying.

Participant 4_01 indicated in their second interview that there is likely a difference between motivational factors that they experience as a student in a teaching laboratory and those they would experience as an employee in a chemistry focused career. The artificial time limit and perceived high workload were cited as factors affecting the teaching laboratory that may not be present in the same way in a career, and the student indicated a degree of rigour would be required of them in employment that may not be possible to execute in a teaching environment.

Participant 3_21 discussed the impact of their anxiety of their decision making in the laboratory extensively when asked for motivations. This participant identified that they struggle with anxiety in a lot of different environments, identifying lectures, assignments, labs and even meetings as anxiety-provoking events. The participant mentioned that as the researcher was aware of the participant's anxiety before the interview process, that the interview itself was not too anxiety-provoking. The participant identified that the key factor that can increase the level of anxiety is a feeling of lack of preparation or unfamiliarity.

I: What's the motivation behind them. Why do you want to? Get the right product and why do you want to be viewed as a professional scientist?
P: My anxiety, really? (chuckles)
I: ok
P: I don't like being seen in a negative viewpoint. I don't like being seen as that person in air quotes.
I: yep
P: And just the person who can't do anything without anyone's help

Figure 90: Excerpt from first interview with participant 3_21 on anxiety as a motivating factor within the teaching laboratory.

Discussion

Student motivation is impacts on student approaches to other learning activities (Schunk et al. 2014), therefore it is reasonable to posit that this will be true for the teaching laboratory. The activities and motivations of students are clearly linked within these interviews, with participants who have motivations linked to completion often citing that they follow instructions closely. In contrast, those who approach the laboratory in a more research-driven manner indicate more exploratory tasks. This agrees with the different approaches to learning as described by (Biggs & Moore, 1993b).

As is predicted by the literature (Gunstone, 1990), these participants exhibit a high degree of focus on practical outcomes, with several students exhibiting motivation linked to assessment consistent with the "*achieving*" attitudes detailed in Biggs and Moore (1993) where students are balancing the time or effort expended in relation to the credit gained, with few students exhibiting the "*deep learning*" attitudes of questioning and critical actions within the laboratory.

The outcomes-focussed approach of students to an activity is described as Goal Orientation by Zusho et al. (2003), and is described as the participant's purposes when approaching a task. Goals are separated into two categories, mastery or performance goals.

> *Mastery goals* are the goal to developing a skill to a high level of quality, and have it endorsed as such – students wishing to develop their practical or manipulative skills to evidence them for future careers may fall into this category.
>
> *Performance goals* are linked to validation of performance in relation to peers, which links more closely to the peer motivations cited by the students, where comparing one's own practical outcomes to others was mentioned by several students.

It would also be possible to frame some of the strategies undertaken for success and the motivations within Expectancy-Value theory (Schunk et al. 2014), where a student measures their outcomes against their anticipated achievement.

Other motivating factors were identified by students and are substantiated by literature. Pride is well documented as a motivational factor (Williams & DeSteno, 2008) and it is unsurprising to find this in an environment such as the laboratory that is so extensively assessed. The career-focussed motivation identified by participant 2_02 could also be linked to with "*Task Value Beliefs*" (Zusho et al., 2003), which are beliefs related to the student's perception of the usefulness of the activities they are undertaking. The students place value on the laboratory activities because they develop their skills towards a perceived desired skillset that is required for a career. Although Zusho et al. (2003) suggest that anxiety within assessment is linked to the affective element of motivation, the comments relating to anxiety and stress appear to be linked a different element within their definitions, "*self-efficacy*" which is a student's self-assessed ability to complete a task. Anxiety is known to negatively impact on the cognition of students during cognitively demanding tasks (Maloney et al., 2014).

4.3.6 Recognition of achievement of aims or success

Students were asked about how they knew they had achieved their aims within the teaching laboratory. The researcher phrased this question slightly differently to each student. If students had not previously detailed what a successful teaching laboratory session would look like, they were asked that before asking about how they would know they were successful. Questions were not always asked in the same order, and some participants had already answered this question through previous responses, so were not asked this question as a separate query. Participant 2_01 was asked what a successful laboratory session was, but not how they recognised their aims. Participants 3_19 and 4_01 (second interview) addressed this question elsewhere in their interview, so the question was not directly asked, and data has been drawn from other questions where appropriate.

Themes arising from this question include correctness or quality of practical outcomes, a feeling of success or achievement, comparison to peers and staff feedback. Participants also indicated that successful learning is a measure of success and identified some more varied aims that are categorised under "other measures of success".

"What does a good lab session look like to you?"

Students often described what a successful teaching laboratory session would be to them, and these descriptions are presented below. Themes arising include correctness and development of understanding.

Five participants indicated that a successful teaching laboratory session would include either a correct product, or a lack of errors.

Participant 1_12 identified in their first interview that a successful teaching laboratory session is one where nothing has gone wrong, indicating that the experiment will have followed the expectations set out by the experimental procedure.

Participant 2_02 indicated that a successful teaching laboratory session was one where they achieved a good yield of an appropriate looking product and that they finish on time. They indicated that they would feel a sense of achievement.

P: when I feel like I've done the best I could.
I: ok, so how do you know you've done the best you could?
P: so most… most times if I know that let's say the colour of my product is correct or
I: mm hmm
P: umm… let's say like my value that I've gotten is close to my QC [quality control sample] in Analytical.
I: yep
P: umm I'm quite a precise person and I like to be a perfectionist.
I: yeah
P: (laughs) so that's when I feel like "Ooh, ok, that's the best I could"

Figure 91: Excerpt from interview with participant 2_02 on the topic of a successful teaching laboratory session.

Participant 2_07 indicated that a successful teaching laboratory session would be one with minimal waste, a clean environment and obtaining a good yield of the right product. This participant indicated that if any mistakes were to happen, they should be able to be corrected.

Participant 3_19 described a successful lab session as one where there were no crises, and that they were confident they had made the right product, ideally working efficiently, and finishing on time.

Participant 3_21 indicated in their first interview that a successful teaching laboratory session would be one where they get all required tasks complete. They indicated that this is usually linked to being appropriately prepared which enables them to obtain the required data in a timely manner allowing them to write up the experiment after the teaching laboratory session.

In their second interview, participant 3_21 said that a successful teaching laboratory would be one with minimal or fixable errors, and that a session with no errors is rare, but should be aimed for. This participant emphasised that in a successful teaching laboratory session, that people would work safely, tidily and with appropriate technique employed when handling chemicals. They also referenced their social aims discussed earlier in this chapter.

Two participants indicated understanding would characterize a successful teaching laboratory session.

Participant 2_11 indicated that if they feel they've learned something and developed for the future, then achieving the correct product is less important to them. In an ideal world, this participant would like the experiment to proceed as expected, but the experiment can still be successful without the correct practical outcome.

Participant 2_01 indicated a successful lab session had a clarity of thought during the process, with minimal confusion. They indicated that these labs are usually ones where they are appropriately prepared and able to get on with the experiment with minimal support.

I: What's happened in that lab session to make you feel that something's been really successful?
P: I've understood what I'm doing without having to turn to somebody and say, you know, "what does this sentence even mean?"
I: ok
P: I've known what I'm supposed to have had prepared beforehand if there's any calculations I know how much I'm supposed to be weighing out or measuring
I: ok, yep
P: and I've just been able to get on with it without pausing again and again to think
I: ok
P: "am I doing the right thing?"

Figure 92: Excerpt from interview with participant 2_01 on the topic of a successful teaching laboratory session.

Practical outcomes

As anticipated due to the high degree of focus in the student aims question, nearly all participants indicated success could be measured by the quality or correctness of their practical outcomes or product from the teaching laboratory session. Students indicated that they either compared to descriptive information in literature or experimental documentation or they perform a test such as a melting point or infra-red spectroscopy to quantify the quality of their product. Participant 2_01 did not mention the practical outcome in their answer, instead focussing on the process followed during the teaching laboratory session rather than the outcome.

Participant 2_07 indicated they would compare their practical outcome to the experimental script and consider the yield value.

Participant 3_21 indicated in their first interview that the pre-laboratory information often gives details of the anticipated product form for the practical outcome, but if this was not provided, they would research further using safety sheets.

In their first interview, participant 1_12 does not mention the quality of their results; however, they do mention unexpected outcomes of an experiment being considered as a problem.

I: What has happened in that lab to make you think that was amazing.
P: Um, I think no problems, definitely. Nothing going wrong or just something … If the script says this and that should happen and something else happens – that's a problem.
I: ok, so nothing unpredicted
P: yeah

Figure 93: Excerpt from first interview with participant 1_12 on the topic of a successful teaching laboratory session.

Participant 1_12 indicated in their second interview that a successful teaching laboratory session would be one where they obtain the practical outcome that is they expect from the information contained in the experimental script, and for an experiment generating a data set they would compare to the anticipated data trend specified in the theory.

Participant 3_19 was not asked this question separately as they had previously addressed measures of success as high quality and yield practical outcomes.

Participant 2_11 indicated they would identify any issues with their practical outcomes by using analysis methods such as infra-red spectroscopy and melting points, and that they recognise they should always test their products.

Participant 2_02 indicated they would identify success by comparing their product to a theoretical value, such as a melting point. They also identified that they could critique the form of their product such as the colour and compare precision of a data set using a quality control sample.

Participant 4_01 indicated in their first interview that they cannot always identify a successful teaching laboratory session within the timetabled session, and that there was an element of luck involved. They identified that they often do not know if their experiment has been successful until they have left the teaching laboratory and are reviewing their data or outcomes in post-laboratory work. The participant identified that it is a bit easier to manage when a data set is poor quality in physical or analytical chemistry teaching laboratory sessions, because poor precision or accuracy data can be written about still, whereas for an incorrect product, it is harder to understand why the procedure has produced an incorrect practical outcome.

Participant 4_01's response changed in their second interview, when they indicated that they would compare their practical outcomes to the expected outcome from literature, which is more consistent with the comments on this theme from other participants.

A feeling of success/achievement

Five participants said that would identify a successful lab session by how it felt.

Participant 4_01 indicated in their first interview that they said that an unsuccessful teaching laboratory session would leave them feeling frustrated, and a successful session by contrast would not result in the frustrated feeling.

Participant 3_21 indicated a sense of relief at the end of a successful teaching laboratory session, which they linked to the fact they often feel stressed in the teaching laboratory anyway. They know it's been a good teaching laboratory session when they feel glad that they are glad they attended.

Participant 2_07 indicated that how they feel is a measure of the success of the teaching laboratory session, but that they don't always reflect on whether the session was successful or not immediately after the session.

Participant 2_11 indicated that they get a feeling when things have not gone well, and then they compare themselves to their peers. This participant is describing a feeling they get when their practical outcome does not appear to be in the correct form.

Participant 2_02 indicated a feeling they get when they've done a good job or achieved success within the teaching laboratory, which the participant linked to whether they had made mistakes during the experiment.

Peer comparison

Seven participants referred to comparing themselves or their practical outcomes to those of their peers within the laboratory as a measure of success.

Participant 1_12 referred in their first interview to comparing their progress and speed of working in the teaching laboratory to their peers to ensure they are working in a timely manner. Participant 1_12 mentioned time efficiency in both of their interviews, but there is a change in the way they measure this time efficiency. In their first interview they were primarily comparing their progress to their peers and the length of the timetabled session, in their second interview they were comparing the anticipated time of tasks to their prior experiences of undertaking similar tasks and their knowledge of the processes involved rather than measuring this externally against their peers.

Participant 3_19 identified that leaving on time is a measure of success. They identified that they compare this to the time scheduled for the laboratory and the progress of their peers.

Participants 1_12 in the first interview and 2_07 both mentioned comparing their practical outcomes to their peers as a measure of quality.

Participant 2_11 referred to using peer comparison as a method of identifying mistakes or issues within the experiment. They referred to a good teaching laboratory session as one that they felt they had worked out if there were issues with the practical outcome, that they had identified why the experiment had not proceeded as it should. The participant identified that they would know that something had gone wrong if their practical outcome was different to those of their peers, and that after the scheduled session they may be able to identify what went wrong.

Participant 2_02 referred to errors within the laboratory and the researcher struggled to have the student elaborate on this. The participant did confirm and expand upon the question of peer comparison eventually, but the questioning style is leading upon reflection, and an open question would have been more appropriate to reduce the likelihood of acquiescence bias where a default position may be to tend to agree with a posed question (Baxter et al. 2015).

Participants 3_19 and 3_21 (first interview) both identify in other question responses that they compare their practical outcomes to other those of other students to measure quality and success of the teaching laboratory session.

In response to a possibly leading question regarding staff feedback within the teaching laboratory, participant 4_01 did identify that they compare their practical outcomes to their peers, in comparison to a self-developed reference scale of “what a good crystal looks like”.

Staff feedback or input

Three students indicated that they use feedback from staff members to identify when they have been successful.

Participant 1_12 indicated in their first interview that they feel good about their performance within the laboratory if a staff member confirms that their practical outcomes are appropriate. In their second interview, this student made three separate references to staff feedback of different sources or types. They referred to confirmatory feedback from staff members, matching their first interview, indicating that they approach technicians to see if their practical outcome had an acceptable yield. They also indicted that although it hadn’t happened to them yet, staff members will praise high quality products or practice. The student also mentioned that for teaching laboratory sessions that generate data sets, such as analytical chemistry experiments, it is typical that the supervising staff member is required to review and sign off the data set, so feedback could be received then.

Participant 2_07 indicated that they sometimes get feedback within the teaching laboratory if their work is assessed within the scheduled session, but this is not always the case.

In their first interview participant 4_01 identified that they measured success by having a good quality product, but the researcher struggled to ask questions to identify what measure of quality was being used. The student did respond affirmatively, but the reliability of this response should be questioned due to the leading nature of the question. In their second interview, participant 4_01 did identify staff feedback as a measure of a successful teaching laboratory session with their response to the ***aims*** question.

Successful learning

Four students indicated a successful teaching laboratory session would be characterised by successful learning.

Participant 1_12 indicated in their second interview that a successful laboratory session would be characterised by opportunities to ask questions or improvement in operation within the laboratory prompted by reflection on errors. The learning was identified as mostly linked to the post-laboratory activities such as writing up a report after the timetabled session. The participant indicated that knowledge gained within the teaching laboratory is often extra to the examined curriculum and often would not necessarily be required of exams in that stage.

Participant 2_02 has an aim of 'getting the most out of the teaching laboratory', and they measure the success of this by considering their understanding of what they have done within the timetabled session. They indicated that this would mean they could answer questions about why the experiment had proceeded as it did and linked the ability to do this to appropriate preparation prior to the timetabled session. The student indicated that sometimes they think of questions after the laboratory and as result research answers to these questions using a search engine or ask a staff member if they happen to see them again promptly after the teaching laboratory session.

Participant 2_11 indicated that a successful teaching laboratory session would be identified by improving on practice or understanding. They later identified that an unsuccessful teaching laboratory session could be one where everything did proceed correctly, and they did not necessarily learn from errors.

P: I think successful lab whether you, complete the experiment or not isn't the most or get the desired end result
I: mmm hmm
P: isn't the main focus.
I: ok
P: like I feel, feel good after a lab if. If even if I. Made the wrong product or something?
I: Yeah,
P: as long as I. I know where I've gone wrong
I: mmm hmm
P: Or Can clearly see that I've taken something away from the lab session,
I: OK
P: Not necessarily the quality of the lab session, but as long as I can see that. I've learned something along the way and pick something up that I'll know for next time.
I: OK
P: or I understood the chemistry behind it better

Figure 94: Excerpt from interview with participant 2_11 on the topic of a successful laboratory session.

It is interesting that all three participants have referenced to understanding developing after the taught session, with questions arising after the taught session. Participants 1_12 and 2_02 also indicated that they know they understand something by undertaking a task, a post-laboratory assignment for 1_12, and answering questions for 2_02. This clearly illustrates that the teaching laboratory does not exist in isolation and instead should be considered within the wider context of the students' learning experiences as a whole.

Other measures of success

This section includes measures of success that are not readily included in the broad themes identified as part of the analysis of these responses.

Participant 3_21 commented in their first interview that it is difficult to know if they had been successful in preparing themselves for the teaching laboratory until they are undertaking the experiment. The main measure of success was identified as obtaining the required data for the post-laboratory write up.

Participants 2_07 and 2_11 indicated that a successful laboratory session would have minimal errors that were able to be corrected and still reach the end-point of the required data or practical outcome. Participant 2_07 was asked how they obtain support and they indicated that they initially reach out to their peers for support and then ask demonstrators within the teaching laboratory for support when things do not proceed as expected. Participant 2_11 indicated that they would seek support from staff members such as a technician or the academic leading the teaching laboratory.

Discussion

Students are often linking a successful teaching laboratory session to the achievement of the end-goal of producing a practical outcome which is consistent with the outcomes focussed answers in response to previous questions and identify methods of recognising success including peer comparison and staff feedback on the quality of their final product. There are comparatively few references to learning or understanding in this in when contrasted with the staff measures of success.

Peer comparison, also referred to in literature as social comparison (Levine 1983) is a documented phenomenon within educational environments. Raat et al. (2013) identify that peer comparison can influence a student's estimates of their own future performance. The Raat et al. study situated within medical rotations states that the comparison, depending on the performance and gender of the peer the student is choosing to compare to, can have a strengthening or diminishing effect on a student's own perceptions of achievement and impact on their behaviours. This is consistent with experiences described by student participants in this study, where they describe both positive and negative comparisons with peers, indicating that they may feel success or a need to alter their behaviour dependant on their outcomes in relation to others.

Staff feedback has been extensively explored in the literature, with purposes of staff feedback identified by Dawson et al. (2019) where improvement in the quality of subsequent work was identified as the main purpose for feedback from staff to students, which is also described as formative feedback (Shute 2007). Dawson et al. also document the positive affective impact of the feedback on the students, such as motivation or support and note that these were the only theme mentioned for some of the students but most mentioned the affective themes in combination with other features of feedback, which is mirrored in the responses from students in this study. Formative feedback has been proven to be effective in developing student confidence when embedded within a longer laboratory course (Williams 2016), however more recently, there are calls for review of that the way feedback is delivered within the teaching laboratory to ensure that it does indeed facilitate development (Agustian et al. 2022).

Understanding how to approach learning within the teaching laboratory and develop one's own learning would come under the umbrella of metacognition (Mahdavi 2015), with more feedback from staff members having been shown to develop student's metacognition (Miller 1990). Furthermore, within the context of Higher Education in Chemistry, Lavi et al. (2019) states that ***"that explicit metacognitive regulation, specifically monitoring coupled with planning, can improve students' learning performance."*** This shows that the feedback given to students which their responses in this study indicate that they value, can lead to improvements in learning performance, not only by acting on direct points of feedback, but also through metacognitive development long-term.

4.3.7 Staff aims for students in the teaching laboratory

Participants were asked what they thought their lecturers' aims for them were in the teaching laboratory. Students indicated that aims may vary between different teaching laboratory sessions, or levels of study. The students indicated a variety of aims that their staff members may hold for them including aims relating to their operation within the teaching laboratory, future careers and conceptual learning.

Variable aims

Some participants indicated that aims vary either between lecturers or between different taught laboratory sessions. Participant 4_01 indicated in their first interview that different lecturers may have a different primary focus, with some lecturers thinking that practical or manipulative skills are most important while others put more emphasis on the data analysis. Participant 3_19 indicated that they think that their lecturers in their module-related taught laboratory sessions have different aims to their supervisor in their project laboratory sessions. The lecturers in the module-related teaching laboratory sessions were deemed to focus on safety within the teaching laboratory environment and teaching appropriate techniques with apparatus or equipment, with little emphasis on the conceptual learning of Chemistry. In contrast supervisors in the project laboratory sessions were deemed to prefer productivity, with the production of data being the primary target, with a secondary focus on purity and yield of practical outcomes.

Unclear aims

Two participants expressed a lack of clarity or transparency in the aims of staff within the teaching laboratory. Participant 2_02 indicated that students aren't explicitly informed of the aims of teaching laboratory sessions, and that although they did offer a suggestion of possible aims, they really weren't sure.

I: What do you think your lecturers' aims are for lab sessions?
P: oh… erm… I don't really know. We don't really get told the aims in the labs.
I: ok
P: so I wouldn't really know! I feel like he aim probably is for you to understand what you're doing.
I: mmm hmm
P: umm, and also to feel like if you had to do it on your own, you could.
I: ok
P: (long pause) but yeah.. yeah, I don't really know.

Figure 95: Excerpt from interview with participant 2_02, on the topic of staff aims within the teaching laboratory.

Participant 2_02 continued to identify a specific module-linked teaching laboratory experiment that was deemed to have obvious aims which were problem-based student-designed experiment. The participant also identified that this lack of clarity of aims was not specific to teaching laboratory sessions, and that often their taught content was focussed on preparing them for assessment.

Participant 3_21 suggests in their second interview that academics often have "ulterior motives", suggesting that although the practical outcome of the product is important, academics often have another motive, namely to show students that their experiment may not work, or may have a lower-than-expected yield.

Both students agree that aims are not explicitly identified by staff members, at least at the start of the teaching laboratory session, although participant 3_21 seems to suggest that the aims may eventually be revealed, while participant 2_02 indicates that they are still unclear on the aims of staff.

Operation and best practice

Four participants have identified that staff have the aims of teaching best practice for operation of either apparatus or instrumentation within the laboratory, or a level of operational competence within the laboratory. Comments relating to safety have been included with this theme, as safe practice is encompassed within best practice.

Participant 2_01 indicated that staff want students to be familiar with working with the new equipment in the teaching laboratory, providing examples of rotary evaporators and needles. The student identified unfamiliarity as a significant barrier to them within the teaching laboratory, as being comfortable with using items safely was very important to them.

Participant 4_01 expressed similar comments in both their first and second interviews, indicating that staff aim for students to be able to operate equipment found within the laboratory appropriately.

I: What do you think staff wants for you? What are their aims for you when they're in the lab?
P: I think they want you to be able to use the equipment that they're showing you.
I: mmm hmm
P: 'cause Yeah, that could be important for the careers. Or if you're going to do a PhD, especially with them,
I: yeah
P: they don't want to spend a lot longer teaching you…
I: (laughs)
P: …stuff that you didn't learn in second year.

Figure 96: Excerpt from second interview with participant 4_02, on the topic of staff aims of practical or manipulative skills.

Participant 2_11 indicated that staff help students set up and demonstrate the operation of apparatus or instrumentation.

Participant 3_19 indicated the primary aim of staff members is for the students to be working safely, and then the next most important is for the staff to teach techniques with apparatus or instrumentation appropriately the first time they are used, continuing to demonstrate best practice throughout the teaching laboratory course.

Participant 3_21 indicated that safety is an important aim that staff members have for their students.

Career focused aims

Participant 1_12 indicated in both their interviews that the staff aimed for the teaching laboratory to develop the students towards their future careers.

Participant 4_01 indicated in their second interview that being able to effectively use equipment is important for their future career if they continue in their studies and undertake a PhD.

Independence

Four students indicated that staff members aimed for them to be independent, display a degree of independence or not intervene in the experimental process.

Participant 2_02 indicated that staff members aimed for students to be able to repeat a technique on their own because of the teaching laboratory session.

In their second interview, 4_01 indicated that the staff probably aim for independence in their students, however the primary focus was learning practical techniques.

P: Yeah, I'd say that's. Probably the main thing so you can learn the techniques, use the equipment things like that.
I: OK.
P: I mean, there's probably a small bit of you know, applying what you've learned from lectures, seeing if you're able to do independent work,
I: OK,
P: that's sort of thing. But yeah, I'd say it's mostly learning techniques,

Figure 97: Excerpt from second interview with participant 4_01, on the topic of staff aims within the teaching laboratory of practical operation and independence.

Participant 3_19 indicated that their project supervisor wanted them to be independent in the project laboratory sessions, with an emphasis on productivity and student-led inquiry.

P: My supervisor seems keen for me to be independent and do my own thing.
I: mm hmm
P: Which is great because that's enjoyable. It doesn't. He gives the impression that whatever outcome I get to, or whatever conclusion I get to rather, like he won't be too fussed

Figure 98: Excerpt from interview with participant 3_19 on the topic of supervisor aims in project laboratory sessions.

Participant 2_11 indicates that an aim for staff members within the laboratory is to not intervene in students' laboratory experiences too much, to promote student independence and allow space for learning.

I: what aims do you think staff members have for you when they're in the lab?
P: I think that their aims are to… not get too involved with everyones' experiments 'cause I feel like it there is a big part of independence in the lab and to some extent working things out. And breaking things down so you can adapt as a learning progress

Figure 99: Excerpt from interview with participant 2_11 on the topic of staff aims of student independence in the teaching laboratory.

Learning chemistry theory

All participants mentioned learning chemistry theory in the teaching laboratory as an aim that staff members held for their students. This was discussed in different ways by the students, applying theory, linking the learning in the teaching laboratory to the rest of the course, and checking the understanding of students.

Four students identified that staff members aimed for them to apply theory learnt within the rest of their course within the teaching laboratory, but with varying degrees of emphasis.

Participant 3_21 indicated in their first interview that staff members aim for the students to learn from the laboratory, this was probed more by the researcher and the student indicated that the conceptual learning that happens within the teaching laboratory is linked to the theory learned elsewhere in their course. The student identified that teaching laboratory sessions are an educational environment and should be focused on learning.

I: OK, you mentioned very very briefly and that they want you to learn. What do you think they want you to learn?
P: I'd say it would depend on the lab and depend on the lecturer and what they teach,
I: ok
P: but I believe it's usually what they teach in the lecture. They will apply to the lab,
I: ok
P: and so I feel like it just goes across horizontally.

Figure 100: Excerpt from first interview with participant 3_21 on the topic of staff aims of application of theory.

Participant 2_07 indicated that staff members use the laboratory to check the understanding of their students, almost as a plenary exercise, and that questioning by staff members prompts this reflection on their current understanding of theory presented within the laboratory.

Participant 2_01 indicated that staff aim for students to apply knowledge within the teaching laboratory. This was probed further by the researcher to understand what the student meant by “knowledge” and the student indicated that it encompassed both operational knowledge and theoretical chemistry, but an emphasis was put on safety within the teaching laboratory. This lack of focus may be due to a poorly phrased question on the part of the interviewer.

Participant 4_01 mentioned that staff members aim for students to apply theory within the teaching laboratory but this was identified as a minor aim in comparison to practical or manipulative techniques. This participant indicated that most of their conceptual learning occurred within the lectures, and that applying the theory was a different process that happened within the teaching laboratory, and most of their theoretical chemistry learning happened in the rest of their course, external to the teaching laboratory.

Three participants indicated that staff members aim to situate the content of the teaching laboratory within the rest of the students’ course.

Participant 1_12 indicated in both of their interviews that the staff aim to show practical elements linked to the theory learnt elsewhere in the course. In the second interview this participant identified that staff use the teaching laboratory is a good opportunity to ask questions to foster conceptual learning.

Participant 3_19 indicated that their lecture content was more clearly linked to their teaching laboratory content from second year onwards, and in first year they felt less linked together. This participant also explicitly stated that teaching laboratory content is not linked to their end point examination assessments.

Participant 2_02 was unsure of the aims but suggested that the staff aimed for students to understand what they were doing, particularly how the experiment they are undertaking links to the chemistry theory they have been taught elsewhere.

Two students identified that staff use the teaching laboratory as an opportunity to check their understanding.

Participant 1_12 indicated in their first interview that when staff see their students do well, it may boost staff morale or esteem. When questioned further the interviewer struggled to get responses further than agreement to statements relating to checking up on understanding. This is likely because of a more closed questioning style employed in this section, where the interviewer refers back to previous answers from the participant.

Participant 2_07 indicated that staff use the teaching laboratory to check their student's understanding in a similar manner to participant 1_21, indicating that staff members question their understanding during the in-laboratory assessment processes.

Other staff aims in the teaching laboratory

Participant 2_11 indicted that the staff in the laboratory want the students to get the most out of the experience of being in the laboratory by asking questions and offering support and explanations. This is an interesting echo of very similar phrasing from participant 2_02 in earlier question regarding actions to achieve aims.

Participant 3_21 indicated in their first interview that the staff want the practical outcomes of the experiment to be achievable for students, within the time limit applied to the timetabled sessions. This participant specifically said that if an experiment was operationally difficult to undertake, resulted in a poor-quality product or low yield, that the staff member would usually explain this in the teaching laboratory. This participant suggested that this is a difference between experiments completed in teaching laboratories, and those that may be undertaken in an industrial (research and development) setting, as experiments in an industrial setting do not have to known to be feasible.

Participant 3_19 was asked an additional question of what actions they undertake to achieve the staff aims that they had identified. This participant indicated that they indicated they watch their peers and compare progress throughout the experiment. They indicated that although they're not always comfortable asking questions of academic staff, they research questions they have through search engines online to source solutions to problems, and that they would manually draw out structures or mechanisms to allow them to think more clearly about the phenomena happening within the experiment.

Discussion

In this section, students were asked to discuss the aims that staff had for them in the teaching laboratory. Staff aims identified by students were wide-ranging which is consistent with the wide-ranging aims identified in the literature discussion in chapter 2. The topics covered by students and staff during their in-person interviews do have some similarities, covering both understanding of chemistry theory and practical skills or best practice, however staff members emphasised appropriate behaviours in the teaching laboratory and following the scientific method whereas the themes of independence and future careers were discussed more by the student participants.

The career focus may be linked to the comments relating to future careers by the students in response to the motivation question. Additionally, many of the students interviewed in this section were less than halfway through their degree, with most of the participants being in year 2 (FHEQ level 5), as such they may have had limited opportunity to engage in experimental design as described by the staff, as this was indicated to be a higher-end goal that was more likely to be achieved at the end of the course. Ogunde et al. (2017) shows that while Chemistry students mainly wish to pursue a career in Chemistry, they are aware of the possibilities of careers in other fields. Over 50% of the students surveyed indicated that they chose Chemistry as a study field because it has career prospects or links to a better job, while a smaller amount chose Chemistry as a study field because it is valued by employers or linked to a specific job. The highest motivating factor in Ogunde et al. (2017) was subject interest or enjoyment, which is not a motivating factor mentioned by students in this study. It may have been overlooked as participants were aware that they were being interviewed by an interviewer with prior Chemistry study and a vocal and enthusiastic interest in the area.

4.3.8 The technology-enhanced teaching laboratory environment.

Students were asked to compare the Superlab environment to the other teaching laboratories they had experienced. This question was omitted in some interviews by the researcher. Participants 1_12 (second interview), 2_01, 3_21 (both interviews) and 4_01 (second interview) were not asked directly about the impact of the presence of the technology in their learning. However, some students did mention elements of digital technology present in the Superlab environment in response to other questions that will be included in this section. As participants were in different years of study, they will have had access to different teaching laboratory environments at NTU, which are summarised in table 44.

Participant responses are represented individually for this question, as the variety in responses do not readily lend themselves to grouping without loss of depth of data. Students identified benefits to working in the Superlab including a sense of professionalism and the convenience of using the tablets for seamless access to information. Students also indicate a difference in preparation for the Superlab in comparison to other environments, broadly linked to the functionality of the tablets.

Table 48: A summary of the prior teaching laboratory environment experiences of participants.

Participant number	Superlab Large group, technology enhanced	Rosalind Franklin (Analytical) Paper permitted, tablets available	Erasmus Darwin Paper-based laboratory, no tablets.	Other labs
1_12	Yes	Yes	No	No
2_02	Yes			“without tablets”
2_07	Yes	Yes	No	Radiochemistry in Erasmus Darwin
2_11	Yes			“without tablets”
3_19	Yes	Yes	No	No
4_01	Yes	Yes	Yes	Yes (specific microscopy experiment)

Participant 1_12

Participant 1_12 identified a feeling of professionalism within the Superlab, linked to the containment procedures requiring students to wear laboratory coats that button to the neck, and the inability to bring non-sanctioned items (paper, pens) into the Superlab environment.

I: umm.. do you think there's any difference in the way you approach the labs? umm.. sort of the kind of things you do to prepare? The way you work while you're in the lab?
P: Umm.. definitely if I go into the Superlab, I know like, I feel a bit more, not professional but just 'cause we're not allowed to bring anything in here and we have (inaudible) proper lab coats and everything like that. It feels more serious than the analytical lab.

Figure 101: Excerpt from first interview with participant 1_12 on the topic of the Superlab environment.

The participant indicated that these containment procedures do not impact on their operation within the Superlab, and that they work the same in both labs.

I: ok, so um, how does that impact on the way that you work within the lab?
P: it doesn't really, to be honest
I: ok
P: I work the same in both labs
I: yeah
P: it's just this one, the Superlab, feels a bit stricter. But I work the same in both labs, yeah.

Figure 102: Excerpt from first interview with participant 1_12, on the topic of operation in technology and not technology enhanced teaching laboratories.

Participant 2_02

Participant 2_02 was asked if the presence of the tablets affected the way that they approached technology enhanced Superlab in comparison to the non-technology enhanced teaching laboratories in response to a comment they had made, however it was very out of sequence in comparison with the other students. The participant indicated that having access to the tablets enabled them to prepare before the timetabled laboratory session and have access to those documents in a seamless manner.

I: Umm... Do you think that having the tablets present affects the way you approach the labs?
P: hmm...
P: Yes, 'cause I can prepare beforehand. erm, because obviously it's electronic,
I: yeah
P: I can save it to my one drive at home and then access it on the tablet in the lab.
I: So what are you preparing beforehand?
P: Erm So either, let's say like a pre-lab. So what I need to weigh out because this year we have to calculate you know, how many grams of something we need. How much volume of something we need? So
I: ok
P: if I can do that beforehand, that saves time in the lab.

Figure 103: Excerpt from interview with participant 2_02 on the topic of the tablets within the Superlab.

Participant 2_07

Before being asked about the impact of the technology in the Superlab, participant 2_07 indicated that the presence of the tablets was helpful to them outside of the Superlab.

They identified that calculations are easier using Excel rather than manual or calculator methods, and that in their experiences, the tablets are used extensively even in the "upstairs laboratory" which is the Rosalind Franklin wet laboratory, typically hosting Analytical Chemistry or Physical Chemistry laboratory experiments.

[on the topic of the Analytical laboratory sessions in the "upstairs" Rosalind Franklin teaching laboratory]
P: No. I think people use tablets a lot more these days,
I: oh, ok
P: at least from my from my lot because we're used to the whole super lab procedure, but I genuinely find them bit more helpful because,
I: ok
P: well, it's easier to calculate something on Excel compared to actually having to bring out another calculator then write it all down and then no doubt get an error somewhere.

Figure 104: Excerpt from interview with participant 2_07 on the topic of frequency of tablet use outside of the Superlab.

Participant 2_07 identified that there is a difference in the way they work in the Superlab environment. They identified several limitations of the devices present within the Superlab, indicating that working in paper is easier for some tasks. In the Superlab, there were some small USB-keyboards available for students to plug into their devices to assist with typing, and this student indicated that this resolved some of the issues as it made it easier to type, but the main difficulty they faced was challenges in inputting information into the device.

P: Yeah, I feel like working in the Superlab is just a bit more stressful to a slight extent. that if I find it easier personally to work on paper than I do with tablets for certain things. Things like making notes for example is a lot easier to do on paper or checking some quick calculations 'cause my biggest downfall I find with the tablets is if you disconnect them like
I: yep
P: this as such from the keyboard.
I: yep
P: Then there they just essentially become small screens. They've doesn't allow you any form of input because I've tried before to just use the keyboard that normally shows up on screen, but for some reason for me it doesn't show up.

Figure 105: Excerpt from interview with participant 2_07 on the topic of inputting data into the tablet devices in the Superlab.

When asked further about the stressful nature of working with the tablets over paper, the participant indicated that the flexibility of paper lends itself to being more accommodating to unexpected results within the laboratory and identified that it is quicker to write than to type.

Participant 2_07 said that one benefit of having the tablets within the Superlab was the ease of accessing information quickly.

I: and you're happy using them for some elements of your work operations,
P: yeah,
I: anything else you find useful?
P: It's convenient to essentially have a computer with you at all times, because then you can check reference values easily, or any health and safety information.
I: yep
P: Download lab scripts, upload results,
I: yep
P: and so on and so forth. It's really, really helpful, but at the same time I just tend to prefer personally working on paper,

Figure 106: Excerpt from interview with participant 2_07 on the speed of accessing information within the Superlab.

Participant 2_11

Participant 2_11 indicates differences in the way they prepare for the Superlab in contrast to the more traditional paper-based radiochemistry teaching laboratory. The participant indicates that using the tablets is less efficient and more difficult than using paper and a pen, and they prepare more before the scheduled session to avoid using the tablets so extensively, as a method of time management.

I: Do you approach those labs in the same way or a different way? Or...
P: different way.
I: Different way? How so
P: The paper based (overtalking) with the radio chemistry umm I found erm, not necessarily easier to write up or to assess, but pens and paper is more natural for me, so I found umm there was less... Less (inaudible), less things to do before the lab?
I: Yeah?
P: whereas in the Superlab and on the tablets I find it's always good to get a structure beforehand.
I:Yeah,
P: so you don't have to faff about with little buttons and stuff on the tablets or anything when you could be using your
I: yeah
P: time more valuably.
I: OK, so the type of preparation you do is different?
P: Yeah, I'd say...
I:OK.
P: Yeah, I'd say I'll do more work before the lab if I'm coming into the Superlab for that to make sure that I know I have a good starting point.

Figure 107: Excerpt from interview with participant 2_11 on the topic of preparing for the technology enhanced and paper-based teaching laboratory.

Participant 3_19

Participant 3_19 has a strongly negative view about the tablets within the Superlab. These negative attitudes are linked to difficulty of inputting data, requiring an external keyboard and stylus to be able to control the tablets easily, and the tablets often being slow and unresponsive. The participant indicates that they will go to significant lengths preparing documents before the taught session to avoid having to use the tablets to generate documents.

I: Could you compare your experiences in the lab with the tablets to experiences in other labs without tablets.
P: ok, so I have something of a vendetta against doing work on tablets in the labs, 'cause I thought that was hugely inefficient and I'd rather bring in a piece of paper, write down it, write it yeah, write my stuff down on it. Umm, and then if I can't take it out, I'll take a picture of it with something like. That's completely fine.
I: ok
P: 'cause I hated writing. I hated having to type stuff. Like, sometimes we have to do our lab reports in the lab and that would just be the worst possible thing.
I: ok
P: Like we'd practically write the lab report before coming to lab just so we didn't have to do on the tablet
I: ok
P: because from a… from a writing perspective. It was like that they were sometimes unresponsive, and you have to think about gloves on gloves off like do I get a keyboard like towards the end of it I got little stylus and I just took a keyboard every single time

Figure 108: Excerpt from interview with participant 3_19, displaying strong negative attitudes relating to the tablets in the Superlab.

As the attitude was so strongly negative towards the tablets, the researcher asked if the student was negative specifically to these tablets, or technology in general within the laboratory, and the participant indicated that technology impedes the processes they follow within the teaching laboratory and were deemed to be inefficient.

I: is that to do with the actual tablets we're using or is that using technology?
P: it's just using technology, like it's so much easier to just write it down
I: ok
P: 'cause you can scribble bits out and make any kind of, any kind of systematic notes. With like… I mean you use colours if you wanted, but like I, I don't know if it's just me, but I I definitely having a lab book that I could just write in
I: yeah
P: whenever I want to like notes and stuff I can write down observations as I go as well. I don't have to see the observation go get my lap, go get my tablet, come back, get the right bit struggle to keep it all. it wasted more time than it… made it better.

Figure 109: Excerpt from interview with participant 3_19 on the topic of technology within the Superlab environment.

Participant 3_19 did identify some useful elements of having access to the tablets within the Superlab, such as the ability to source information easily such as researching information on Google or obtaining the experimental script, however these useful elements did not out-weigh the downsides of using the tablets to record data being cumbersome and time consuming.

Participant 4_01

Participant 4_01 displays a similar attitude in their first interview to participant 3_19, although slightly less vocally negative. The participant indicates a degree of preparation of documents before the timetabled session to avoid generating documents within the Superlab on the tablets.

I: do you think there's any change in the way that you learn, or the way you operate in the labs with and without the tablets.
P: Yeah, I think when I know I'm working in the Superlab, I put a lot more effort in getting umm like a Word document set up so that. 'cause I found the tablets quite hard to use. I prefer if I can, just, you know, tap on the box and type what I need to in there
I: mm hmm
P: without having to try and use the tablet to create a table.
I: OK
P: so I mean. If I need to add other bits then I just write it in like note form abbreviations, that sort of thing.

Figure 110: Excerpt from first interview with participant 4_01 on the topic of preparing documents before entering the Superlab.

The participant indicated that they prefer to write on paper, and they spend more time preparing for the Superlab than they would for other taught laboratory sessions. This was partly attributed to being provided with documents for recording data in other taught laboratory sessions, so it was not required to make a document prior to the scheduled laboratory session, however the participant indicated that constructing such a document in a notebook would be easier than on the tablets.

Participant 4_01 was very critical about the original Samsung tablets that were present in the Superlab upon its opening. The participant indicated that the tablets were not valued by students as they were less functional, due to a high degree of time lag on input. The newer Windows tablets were identified as an improvement as they have more programs available to the students and they are easier to use as they are more up to date than the previous Samsung version.

Comments in other questions relating to digital technologies present in the Superlab

Participant 1_12 indicated that they prepare a data recording document before the timetabled laboratory session, in a similar manner to participants 3_19 and 4_01, for the same reasons of difficulty of inputting data during the teaching laboratory.

P: Like for inorganic we have to do the lab reports actually in the lab,
I: mmm hmm
P: and because I don't really like the tablets because I just don't like typing on these tablets.
I: mm hmm
P: I did some of the parts of the proforma that were more general, like my name or a table or something like that. I did that. I did this before the lab
I: ok
P: and then send it to myself and then fill it in Whilst in the lab, which save me a lot of time to be honest.

Figure 111: Excerpt from second interview with participant 1_12, on activities to achieve aims within the teaching laboratory.

Participant 3_21 mentioned the tablets in their first interview in passing during the discussion of a successful teaching laboratory session, stating that they write data up on the tablets, however there was no deeper information in this section. This participant indicated a little later in their first interview that they do use the tablets to research data within the laboratory if they have time and do not yet fully understand a concept.

Participants 3_21 (second interview), 2_01 and 4_01 (second interview) did not discuss the technology present within the Superlab.

Discussion

The digital infrastructure of universities is complex and reaches far beyond the teaching laboratory environment (McLachlan 2024) and in the context of the Superlab, the students are expected to engage with NTU's virtual learning environment (VLE), cloud storage, a variety of tablet-based apps, and in some circumstances additional software on further analytical devices such as infrared spectrometers or their attached control computers.

The Digital History Survey results have indicated that most students at NTU use technology extensively in their everyday lives, and within their studies, however this does not necessarily translate to high levels of digital literacy and high levels of complex usage of technology (Henderson et al. 2015)

Given the previously discussed non-homogeneity of the Superlab environment, with each student in these interviews likely to have had different experiences within the Superlab, it is to be anticipated that their attitudes will vary. The student participants have indicated a variety of approaches to the teaching laboratory by identifying different tasks that they undertake. It is not possible to correlate or compare their responses to digital literacy levels, as that data was not collected as part of this study, although that would be a useful avenue to explore for future studies.

Some of the students were critical of the tablet functionality within the Superlab. When considering negative responses to any technology, Selwyn (2016) identifies four different contributing attitudes to negative responses to technology and the perception that technology is either unhelpful or unsuccessful in relation to university studies.

- Distraction – students becoming distracted, moving off task or procrastinating.
- Disruption – technology failing to work on individual instances, stalling work.
- Difficulty – ongoing challenges in using digital technology to complete work such as inconsistencies, poor design or lack of accessibility.
- Detriment – perceived poor-quality learning due to the implementation of technological solutions such as online learning or digital file systems.

Participant 2_07, 2_11, 3_19 and 4_01 all cited negative elements of the tablet user experience that would be categorised as Difficulty within Selwyn's discussion of downsides of technology, notably slow responses, lack of flexibility of the platforms and the time-consuming nature of the tablets.

It appears that to compensate for the difficulty of using the tablets, some students are preparing more extensively before the timetabled sessions for the teaching laboratory sessions within the Superlab, although this is for two distinct reasons. One group of students prepares documents to avoid using the tablets for tasks they deem to be inefficient, ineffective or time consuming on the tablets, while the others prepare to increase their efficiency, while remaining neutral to the tablets. This demonstrates that the student's attitude to the tablets can be different while displaying the same outcomes of preparing before the session.

Although the former group of students present the experience of having to prepare before to avoid using the tablets as a negative one, the side effect of requiring the students to prepare documentation for recording their results is not necessarily inherently negative for their learning and could result in students being more thoroughly prepared before entering the teaching laboratory, which literature suggests can improve learning outcomes in teaching laboratory settings (Jongsma et al. 2024).

Some of students who are actively avoiding using the tablets or developing strategies to avoid using certain functions cited specific examples of issues they'd faced within the Superlab which would account for concern regarding reliability, however several stated that they found handwriting easier and quicker, particularly when making short observations. One possible explanation for this is that it has been hypothesised and tested that typewriting may be more resource-demanding for students, even for students who have some level of typing skills, as they have not been formally trained in typing in an academic or professional context (Bouriga and Olive 2021). In further support of the complexities of using typing in an educational context, Mogey et al. (2012) undertook a study where students were offered the choice of undertaking a long-form exam on either a computer, or handwritten. Very few students chose to word process their work on a laptop, however those that did chose to review and edit their work to improve the quality, which has been found to increase the mark awarded. This study highlighted several concerns raised by the students regarding working in the word processor which could transpose to the teaching laboratory environment, including time consuming editing processes to resolve presentation issues in their work, which discouraged students from engaging in the technology-based solution. The difficulty in using the word-processing software as described by Mogey et al. seems very similar to the difficulty in typing on the tablets that some of the students have indicated in their responses, where they cite struggling to enter data or manipulate documents.

Understanding precisely why students are reluctant to engage with the technology is important and should be investigated further. It is not possible to widely generalise the outcomes of this study without sufficient participant numbers, given that some of the issues raised by the students in this study were highly platform specific, with one student directly comparing the "old" Superlab Samsung Android tablets and the "new" Superlab Lenovo Windows devices.

4.4 Online student interviews

A second set of interviews were delayed due to the 2019/20 pandemic in the hopes of resuming in-person interviews. Due to the length of the crisis, to avoid further delay, it was decided to hold the interviews remotely using MS Teams. Participants attended via video link from their own preferred space, and interviews were video recorded. This allows for an additional aspect of transcription, in that body language cues such as nodding could be included in the transcript where possible. Interviews took place in January-February 2021.

In the first set of interviews that took place in-person, references by the interviewer to specific types of technology and technology related questions were intentionally kept minimal to impact the student's recollection of technology as little as possible. It was hoped that participants would voluntarily reference the technology in the teaching laboratory without needing to be prompted, however this was not the case, and a separate set of technology questions were included to elicit student experiences of technology. It was noted that during the first set of interviews that were undertaken in person, no definition of technology was provided to the students, and they spoke about a selection of digital technologies that were present in the Superlab environment. To further explore the students' experiences of technology, students in the online student interviews were asked to define technology and additionally identify how they use technology in their learning more broadly, as well as specifically in the teaching laboratory environment.

As these MS Teams interviews were longer, the value of the Amazon voucher incentive was increased to £20 per participant, however in this second phase of interviewing, only one interview was offered per student per year.

Themes and guide questions identified for interviews.

Purpose of laboratory sessions – e.g., what do you think purposes of lab sessions are?

Learning associated with laboratory sessions – e.g., What do you think you learn in a lab session?

Student aims of laboratory sessions – e.g., What are your aims for a typical laboratory session?

Strategies implemented by students to achieve aims – e.g., What do you do to achieve these aims?

Decision making associated with laboratory sessions – e.g., Why do you do these activities?

Recognition of achievement of aims – e.g., What does a successful lab session look like to you?

Staff aims of laboratory sessions– e.g., What aims do you think staff members have for you during laboratory sessions?

Definition of technology - What you think technology is? Please give some examples.

Technology in learning – What types of technology do you use in your learning? How do you think using technology affects your learning?

Technology in the lab – Specifically in the lab, what types of technology do you use in your learning? How do you think the presence/use of technology affects your learning in the laboratory?

Comparison of Superlab – e.g., Considering the Superlab and other labs, what impact do you think using technology in the lab has on your learning?

Educational, experiential, teaching and family history of staff and students may be discussed, in reference to the themes above. E.g., prior experience of laboratory work, familiarity through family experiences etc.

Figure 112: Interview themes for online interviews with student participants, new questions are highlighted in bold.

Demographics of respondents – Student interviews phase 2 (online)

Table 49 Demographics of participants for phase 2 of student interviews (2021)

ID code	Age	Gender	English as first language	Previous Qualification	Disability?	Course year	Course	Placement
3_1	21 and under	Female	No	A level	Yes (impacts on lab	3	BSc Chemistry	Not yet
2_2	21 and under	Male	No	A level	No	2	MChem Chemistry	Not yet
3_3	21 and under	Male	Yes	A level	No	3	BSc Chemistry	No
4_4	21 and under	Female	No	A level	No	4	MChem Chemistry	No
1_5	21 and under	Female	Yes	A level	No	1	BSc Chemistry	No
3_6	21 and under	Female	Yes	A level	No	4	BSc Chemistry	Yes
3_7	21 and under	Male	Yes	A level	No	3	BSc Chemistry (FT or SW)	No

Two additional participants were recruited but failed to provide appropriate contact details, so they are excluded from the demographic data.

As for the in-person interviews, the students were allocated ID numbers based on the order of their responses in the recruitment survey. As the low response rates to the selection survey rendered sampling unnecessary and as all participants who provided appropriate contact details were interviewed, the students did not need to be categorised before selection. The second part of the student's ID number is therefore their chronological survey response label e.g. participant 3_6 is the sixth respondent to the selection survey, who is a third-year student.

Student 3_6 indicated that they are a BSc Chemistry student who has undertaken a placement so is in their fourth year however as they are in their third taught year, they are labelled as 3_6 instead of 4_6. The 4_ category label is reserved for students in their integrated Masters year (FHEQ level 7).

It is of note that participant 1_5 has only completed two elements of the laboratory cycle due to the coronavirus precautions ceasing in person laboratory sessions, the analytical chemistry and physical chemistry sessions. Both teaching laboratory courses are taught external to the Superlab, but in laboratories where tablets are accessible to students, however students are permitted to have paper. This student has entered the Superlab for orientation and induction but has not studied within it.

Online student interview outcomes

Results are published thematically, grouped by question to allow consistency of analysis with the in-person student interviews.

As these interviews were still semi-structured, the questions were asked in slightly varying ways, however there was generally more consistency in the structures of these interviews as the remote format allowed the interviewer to have a copy of the protocol and cross off questions as they were answered. Participants were typically in a comfortable private environment which led to a more relaxed feeling interview from the experience of the interviewer.

4.4.1 The purpose of the teaching laboratory

In this section, the students were responding to the question "*What do you think the purpose of the teaching lab sessions are?".* Several topics were discussed by students including the gaining of theoretical knowledge, skills of various types, and hands-on experience particularly in relation to career development.

Learning Chemistry Theory

Four participants identified that a purpose of the teaching laboratory is to allow the learning of chemistry theory.

Participant 3_7 indicated that using equipment within the teaching laboratory reinforced the theory of how the machines worked. [Author note] In this context, "the machines" likely refers to instrumentation within the teaching laboratory.

Participant 4_4 states that the purpose of the teaching laboratory is to show the practical element behind the theory. This participant indicates that their teaching laboratory sessions are typically linked to their lecture content, and that undertaking work in the teaching laboratory helps them understand the theory more.

Participant 3_6 indicates that the purpose of the teaching laboratory is for students to apply the theory learnt during their course. This participant notes that it is not necessary for theory to be encountered in lectures before it is encountered in the teaching laboratory but indicates that the cross-reference between the two modes of teaching support one another to foster learning.

Participant 3_3 indicates that the purpose of the teaching laboratory is to display abstract theories in action. This is not exclusively theoretical learning as the participant does indicate some operational element to this, as the student indicates that this helps them understand reaction conditions and critique the data produced by the technique, however there is also an element of displaying a theoretical process in action.

P: I think it's a purpose of umm.. If you want to be more, in terms of the core side of it, it's more of seeing what you have been learning. It's more of like, if we take organic chemistry, for example, there's a… you're doing some sort of aldol reaction. It's all well and good getting a pen and just writing it down. What it looks like, but actually doing it you can prove to yourself, OK, the reaction conditions are this. It comes out as this… is my data correct or not? If not, what did I do wrong?

Figure 113: Excerpt from interview with participant 3_3 on the topic of the purpose of the teaching laboratory.

Development of skills

Three students indicated that the purpose of the teaching laboratory is to develop laboratory-specific skills through practice.

Participant 3_1 indicated that a purpose of the teaching laboratory is to develop students' confidence and skills within the teaching laboratory. This participant identified that a lot of their skills had been developed by the analytical chemistry course, indicating that they had developed in their understanding of significant figures, sample handling to prevent contamination and practical techniques with apparatus and instrumentation. This student indicates that these skills will be required in future careers.

Participant 1_5 indicated that a purpose of the teaching laboratory is to allow students to learn how to use machinery and instruments. When probed further, the student identified that they mostly meant analytical instrumentation however, that may be because at this time they had only done analytical and physical chemistry teaching laboratory rotations.

Participant 2_2 indicated that a purpose of the teaching laboratory is to improve the student's practical skills towards best practice. The student indicates that repetition of technique can result in reduced errors, and that having familiarity with methods would allow them to optimise methods and get high quality results in their future career.

Hands-on experience

Five participants indicated that a purpose of the teaching laboratory is to allow students to have hands-on experience of laboratory related equipment or techniques.

Participant 3_1 indicated that a purpose of the teaching laboratory is to give students hands on experience. This experience is credited for developing the skills and confidence described earlier in this section.

Participant 2_2 suggested that the purpose of the teaching laboratory is to give students experience that can be used later in their professional careers. When asked which future careers this would be useful for chemistry related or laboratory-based careers, and the student provided an example of analytical methods and syntheses.

Participant 3_3 indicated that a purpose of the teaching laboratory is to give students experience that will assist them in gaining employment, explaining that a lot of jobs in chemistry-related fields are laboratory-based. This participant described the laboratory in a humorous way, suggesting that the teaching laboratory is a safer space to make mistakes than a workplace.

Participant 3_7 indicated that a purpose of the teaching laboratory is to gain experience of using machines, likely instrumentation, within the teaching laboratory.

Participant 3_6 indicated that a purpose of the teaching laboratory is to gain practical experience using instrumentation and techniques that they had learned about during their course.

Two participants mentioned a link between the skills developed during the lab and their future careers, however two participants went one further and indicated that the laboratory set their expectations of being in a laboratory and what a future career may be like. Participant 3_3 indicated that the teaching laboratory had a purpose of letting students know what to expect from a laboratory-based workplace. Similarly, participant 4_4 indicated that a purpose of the teaching laboratory is to set expectations of careers in science fields.

Discussion

In response to this question, the in-person interviews raise 5 main themes:

- Learning theory,
- Manipulative or practical skills,
- Transferable skills,
- Familiarity or comfort within the laboratory setting
- Differences in purpose between different levels or types of laboratory session.

Learning Chemistry theory was discussed as a purpose in similar manners within the two interview sets, with application of theory and links between the theory and practical being discussed by four students in the online interviews. Reinforcement learning and being memorable was mentioned in response to this question by the in-person participants, however this concept was not present in the online interviews.

In each interview set, one student has mentioned how the teaching laboratory shows abstract theories in action (2_02 and 3_6). This is an indirect reference to the concepts represented within Johnstone's Triangle or Chemistry Triplet, where students are required within chemistry to appreciate links between different forms of presentation of information (Johnstone 1993). As abstract concepts are recognised as being difficult for students to learn (Taber 2013), it is encouraging to know that students are reporting that the teaching laboratory is aiding with this challenge.

Participants in the online interviews discussed development of specific practical skills and transferable skills developed within the teaching laboratory much less extensively than the student participants in the in-person interviews, with only two students specifically mentioning manipulative instrumental skills in terms of using the equipment or best practices within the laboratory, and one of those mentioned confidence in the teaching laboratory which was discussed by two students in the in-person interviews.

However, a practical-skill related theme arose in the online student interviews that did not arise in the in-person interviews, with participants identifying that a primary purpose of the teaching laboratory was gaining hands-on experience within the teaching laboratory. This was not mentioned by students in the in-person interviews, other than specifically to develop practical or laboratory-related skills. This is a prevalent purpose identified in the online interviews with five of seven participants indicating that the teaching laboratory provides hands-on experiences. The requirement of these hands-on experiences is elaborated upon later in the interviews and will be discussed in subsequent questions but is typically related to career outcomes. A possible explanation for the different way students have discussed practical skills within the teaching laboratory is the COVID-19 pandemic, and the differing experiences of the students who were interviewed online in comparison to the much more traditional experiences of those who were interviewed a few years before in person. Laboratory sessions had been delayed and modified due to COVID-19 precautions and therefore it would be understandable for the tactile, in-person nature of the teaching laboratory to stand out as an important element for these students, as it was greatly reduced in their experiences this year. Simmons and Mistry (2023) studied student perceptions of teaching methods utilised within 12 HE institutions during the COVID-19 pandemic and a complementary study for staff practice and perceptions. Simmons and Mistry identified that although some hybrid methods had remained within Chemistry teaching, there has been a significant return to in-person instruction in the teaching laboratory as a method of developing practical skills, and that the in-person interaction in the teaching laboratory is valued by both staff and students.

4.4.2 Learning in the teaching laboratory

In this section, the students are responding to the question *"What do you think you learn in a lab session?"* As some participants undertook both structured "taught" sessions, and less-structured "project" sessions, they were permitted to discuss these separately if they preferred. Students indicated that they learn a variety of skills in the laboratory, encompassing both laboratory-specific skills and transferable skills. The students also identified that they learn chemistry theory from being in the teaching laboratory.

Chemistry theory

Participant 3_1 indicated that they learn by using theory and practical skills that they had developed previously and applying them to a problem within the teaching laboratory.

Participant 3_7 indicated that working within the teaching laboratory changes the way they think through allowing the application of theory. The participant indicated that having not having a teaching laboratory session would make things more difficult to learn. When asked if learning theory with or without the teaching laboratory was more challenging, the participant identified that it is different and indicated that they do not have teaching laboratory sessions for all the theory that they learned, but that they can always link an experimental method to the theory if they wished to.

P: It. I don't know with me. It sort of changes the way that I think actually working in a lab.
I: OK
P: compared to just learning material because. Of that factor, if you have to apply it so you can take the theory that you've learnt and sort of apply it to a practical scenario.

Figure 114: Excerpt from interview with participant 3_7 on the topic of learning theoretical chemistry within the lab.

Participant 4_4 indicated briefly that they learn theory in the teaching laboratory by stating that they learn the chemistry behind things.

Participant 3_1 identified a type of theoretical learning that they specify only occurs in the teaching laboratory. This was agreed to be supplemental theory which is shared by staff within the teaching laboratory when a problem is encountered by a student. This theory is not assessed and not required for the assessed content but can support or scaffold understanding more broadly. The participant did not provide more detail.

Skill development

All participants indicated that they learned skills within the teaching laboratory, including practical skills using instrumentation or apparatus, laboratory-specific skills such as safe operation, or transferable skills such as communication.

Participant 2_2 talked extensively about skills that they learn within the teaching laboratory. This participant talked about practical skills with equipment or instrumentation and laboratory-based skills such as understanding experimental instructions and producing calibration graphs together as a broad set of laboratory skills rather than distinguishing between the two. This participant also cited good laboratory practice (GLP) as a skill developed within the teaching laboratory, explaining this as appropriate data recording, and safety.

Participant 3_7 indicated that they gain practical skills that can't be gained from lectures. This participant indicates that they learned to work efficiently and to a good standard of execution, as well as learning good laboratory practice (GLP) which they described as ways of measuring and safety.

Participant 3_3 indicated that the most important thing that they have learned in the teaching laboratory is safety. They also indicated that they have learnt proper use of equipment, providing an example of equipment they had not previously used and had to learn to use, e.g. the rotary evaporator. The student indicated that the teaching laboratory teaches students techniques that can be applied to experiments, giving an example of a specific course of teaching laboratory sessions that developed from a technique per session at the start of the course, to the more complex level of combining the techniques to perform a whole experiment later in the course.

Participant 3_6 indicated that they gain laboratory related skills from the teaching laboratory. The participant indicated that they require good laboratory practice (GLP) for their future career indicating that GLP encompasses safety within the laboratory, appropriate disposal methods and practical skills.

Participant 1_5 indicated that they learned laboratory related skills but did not cite practical skills. They indicated they have learned how to follow instructions, record data, process data and compile a report.

Participant 4_4 indicated that they have learned a variety of transferable skills within the laboratory, including time management, team working and communication. The student emphasised the importance of being prepared for teaching laboratory sessions to ensure effective operation.

P: Second of all, definitely time management because many times many times I had to think ahead of what I have to do next just to get things done on time. And..
I: OK, like there's a planning kind of thing in there as well, yeah?
P: yeah, yeah, definitely. You definitely have to come prepared. There's no way you can go into lab and just, just do the thing you have to read it before. (laughs)

Figure 115: Excerpt from interview with participant 4_4 on the topic of preparedness and the teaching laboratory.

Behavioural Outcomes

Participant 3_1 indicated that they have learned to be independent throughout their teaching laboratory courses, indicating that the level of trust and confidence has built over the three years of study.

Participant 3_3 indicated that they learn how to set their own expectations of a technique or process using their prior experiences as a measure. This participant indicated that they would assess the difficulty of a technique and whether it was familiar or new before entering the teaching laboratory.

Discussion

In response to this question, the in-person interviews raise 5 main themes:

- Learning chemistry theory, e.g. application of theory and methods of learning.
- Practical skills,
- Transferable skills,
- Behavioural outcomes of the teaching laboratory including independence and expectation setting.

More students discussed learning chemistry theory in the in-person interviews, with 6 of 8 students referencing learning some kind of theory, or a method of learning in relation to theory. Only 3 of 7 students in the online interviews mentioned learning chemistry theory within the teaching laboratory, with 2 students referencing the application of theory and one student referencing learning the chemistry behind things. All three students were studying in higher levels of their studies, in years 3 and 4. No other in person student participants mentioned learning chemistry theory in response to this question. This is a slight difference, and it is not appropriate to draw significance from smaller scale differences in a small sample size, but it would be useful to examine this further with a larger sample size.

In both sets of interviews, all students mentioned skills that they developed within the teaching laboratory, however the distribution of themes is slightly different when compared between the two modes of interview.

In the in-person interviews, all students mentioned practical skills relating to the use of reagents or equipment, two students referenced good practice within the teaching laboratory, and four students identified transferable skills they had developed within the teaching laboratory.

In the online interviews, four of seven students identified practical skills relating to handling equipment or reagents, three students referenced good practice within the teaching laboratory, with an additional student referencing safety. One student, 4_4, identified transferable skills they had developed within the teaching laboratory. A final student 1_5 identified a very different set of skills that could be deemed laboratory related such as following laboratory instructions, recording a, processing and presenting data but did not mention practical skills such as handling reagents or apparatus. This student had limited time within the NTU teaching laboratories and had only studied in the physical and analytical chemistry teaching environments due to measures required during the COVID-19 pandemic. From this author's experience in the teaching laboratories at NTU, the analytical teaching environment is known for a heavy emphasis on the recording and processing of data.

Regarding behavioural outcomes of the teaching laboratory, the responses between the two interviews are quite consistent. In the in-person interviews, two students identified that they developed independence, and another student identified that studying in the teaching laboratory had helped them learn how to set expectations of their experiments. In the online interviews, one student referenced independence or confidence within the teaching laboratory and one student referenced the ability to set expectations within a laboratory environment.

The learning identified by students in both sets of interviews is broadly consistent, covering learning of chemistry theory and development of skills within the teaching laboratory. There is a slight difference in the types of skills being identified by the two sets of participants, particularly that the theme of practical skills is less prevalent in the online interviews, which is consistent with the lower focus on the purpose of practical skill development in the previous question. As discussed in the previous "Purpose" question, this may be a result of the quarantine and containment measures required as part of the response to COVID-19 (Simmons and Mistry 2023). In 2020 students had a higher proportion of remote teaching, less time in the teaching laboratory handling equipment and materials and may have been exposed to more remote content related to the teaching laboratory, which could have influenced their perception of which skills were gained in which contexts. Safety and practical skills were still a prevalent theme, with just over half of students interviewed online mentioning these themes, but they were less prevalent than in previous years. Additionally, "following instructions" as mentioned by participant 1_5 could be related to practical skills as it could be "following instructions to use equipment or reagents", but was not included within the main practical skills set, as it was not an explicit reference to practical skills.

In both sets of interviews, skills was a much more prevalent theme than theoretical learning, which is consistent with the literature (Gunstone 1990; Gallet 1998) that students are less likely to focus on theoretical learning in the teaching laboratory environment, instead prioritising outcomes such as a final product or data set. There are several studies that explore the area of promoting theoretical learning and employing metacognition within the teaching laboratory to allow students to take advantage of teaching laboratory environments, often focussing on problem solving or student-led experiences (Boyd-Kimball and Miller 2018; Venkatachelam and Rudolph 1974; Case et al. 2001; Bertram et al. 2014). The staff interviews indicated that the style of teaching and aims vary throughout the course of the teaching laboratory, and that many of the staff aim for independence in their students by the end of the course but recognise that this trait may not be developed in their earlier studies – as such it is not surprising that the students making reference to applying theory and learning theory in the teaching laboratory are of higher levels of study.

4.4.3 Student aims in the teaching laboratory

In this section, students are responding to the question *"What those aims are for a typical lab session?"* The researcher usually suggested that the participant may have several aims, encouraging the students to think deeply about their responses rather than only provide their main aim. Aims identified by the students include practical outcomes, development of understanding and gaining experience of techniques within the teaching laboratory.

Practical outcome focussed or completion

Six out of seven students indicated an aim relating to finishing the teaching laboratory session or producing a practical outcome such as a data set or a tangible physical product.

Participant 3_1 indicated that their aim was to obtain one complete set of data as a reference point and then refine their method or reproduce data.

Participant 3_3 indicated that in inorganic and organic laboratories one of their aims is to synthesise a product with the best quality or yield, and in analytical or physical chemistry teaching laboratories it is to obtain a good dataset. A good product would be identified by confirmatory tests or comparison to literature values for tests.

Participant 3_7 indicated their main aim is to complete the session. The participant was not forthcoming in response to this question, and the researcher asked the participant if they meant a practical outcome focus of obtaining a product or data set and the participant agreed.

Participant 4_4 indicated that their most important aim was to finish on time with a correct result for the session, which the participant indicated may be a product or a dataset.

Participant 3_6 indicated that they aim to achieve the objectives specified within the teaching laboratory instructions, typically making a product, or analysing an object.

Participant 1_5 indicated that an aim for their physical chemistry teaching laboratory sessions is to finish the experiment and complete the associated spreadsheet.

Participant 1_5 indicated that analytical chemistry teaching laboratory sessions are similar to physical chemistry but were described as "*more*", which is not a clear description of the student's experience. As this is very ambiguous, the interviewer asked for more detail and the student related that the model of working is very precise, and there is a higher degree of unfamiliarity. The participant's main aim was to leave on time in the analytical chemistry sessions, with a longer deadline for completing the associated spreadsheet or assessment.

Understanding

Five of seven participants stated an aim related to development of understanding linked to the teaching laboratory.

Participant 1_5 indicated that they aim to know what they are doing, describing understanding of processes used within the teaching laboratory. The student indicated that this was linked to not becoming startled and having to ask questions. This could have been exclusively related to self-sufficiency, however when asked if the student is happy to ask for support in the teaching laboratory, the student emphatically agreed that they would ask their peers and academic and technical staff members for support, even with COVID restrictions in place increasing the difficulty of gaining support. This participant puts more emphasis on understanding how to operate effectively within the laboratory with understanding of the processes than the independence.

Participant 3_3 indicated that in organic and inorganic teaching laboratory sessions that they aim to be able to apply the theory they know to figure out what has happened in their experiment and why. In physical chemistry and analytical the focus of understanding was more related to critique of the data in relation to theoretical ideals and reflective criticism on experimental improvement.

Participant 3_7 indicates that they aim to understand theory in the teaching laboratory, and not to follow the experimental instructions like a robot. The participant indicates that they focus on why things are happening in their experiment, suggesting that they are attempting to connect theory to the physical phenomena they observe.

Participant 3_1 indicated that they wish to be able to verify that methods are applicable to their current experiment, which indicates verification of an underlying chemical theory.

Participant 2_2 indicated that their aim is certainly not to get the best mark in the assessment, but rather to get the most out of the teaching laboratory session by asking questions. The purpose of these questions was identified at developing understanding of the techniques used in each teaching laboratory session. This aim is consistent with a aim from participant 2_02 in the in-person interviews, and a staff aim indicated by participant 2_11.

Hands-on experience

Two participants indicated that an aim of the teaching laboratory is to develop hands-on experience.

Participant 2_2 indicated that they aimed to gain hands-on experience which they suggested is part of getting the most out of the teaching laboratory session.

Participant 3_6 indicated that they aim to familiarise themselves with the techniques being used in the teaching laboratory. As this is a general statement, the interviewer asked for more detail and the participant indicated that they wanted to gain an understanding of the general principle of using a type of machine. By way of example, not all flame atomic absorption (FAA) spectrometers will have the controls in an identical position, but they should follow a similar functional structure.

Preparation

Two participants indicated that they have an aim to be prepared for the teaching laboratory.

Participant 1_5 indicated that they aim to be prepared before entering the teaching laboratory, particularly for the analytical chemistry teaching sessions which were deemed more unfamiliar.

Participant 2_2 indicates that they review the experiment ahead of entering the teaching laboratory to allow them to form appropriate questions to pose within the teaching session.

Discussion

The aims of students in the second set of interviews, undertaken online, are quite different to those of students in the first set of interviews.

The themes arising from the in-person interview were:

- Aims that vary by student development and comfort or that vary by module.
- Achieving a practical outcome – either a product or data set.
- Attainment in assessment in relation to the teaching laboratory.
- Being time efficient or completing on time.
- Operational goals such as good practice or safety.
- Managing stress or anxiety.
- Aiming to prepare prior to the teaching laboratory session.
- Additional aims such as a social experience or getting the most out of the experience.

Several of these aims are completely absent from the online interviews. No students mentioned that aims could be variable in different teaching sessions or by level of comfort, and none of the students that were interviewed online mentioned assessment in relation to the teaching laboratory.

Time efficiency was not mentioned by any students in the online interviews; however, three did mention completing on time or within the allotted session. These responses were less linked to intentionally operating efficiently and more on completing the experiment and therefore were included in the "Practical Outcome / Completion" theme, as they do differ thematically from the time efficiency responses from the in-person interviewees. The in-person interviewees identified that they had to take intentional actions to complete within the time limit, whereas the online interviewees responses were less specific about managing their time and focussed more on completing.

It is unclear if the omission of these themes is an impact of the change in the interview format, or a change in the attitudes of the students. The aims for the online interviews are more consistent between participants, with high degrees of focus on practical outcomes and completeness, understanding and hands-on experience.

Understanding is a new theme for the online interviews, with 5 of the 7 participants referencing a form of theoretical understanding or understanding of process within the teaching laboratory. These reflect the ways the students have said that they learn in the teaching laboratory. It is of note that the three participants who stated that they more advanced approaches to learning within the teaching laboratory such as applying and verifying were year 3 (FHEQ lv 6) students, and therefore more advanced in their study. Participant 1_5 indicated that they want to know what they're doing, which is more indicative of recall or remembering.

Interestingly participant 2_2 indicated that they wanted to get the most out of the teaching laboratory session by forming questions and preparing thoroughly, which is very similar to the stance taken by participant 2_02 in the in-person interviews.

Hands-on experience is discussed again by two participants, 2_2 and 3_6 in response this question. This theme was absent from the in-person interviews, but this may be linked to a renewed appreciation of the teaching laboratory as an environment where these students are less able to experience it due to COVID-19 restrictions, as discussed in section 4.1.1.

A strong theme in response to this question in both in-person and online interviews was obtaining a practical outcome such as a data set or product which indicates that the time limits on timetabled sessions something that students are considering when setting their aims and approaches for the teaching laboratory sessions. However, the participants in the online interviews were much more likely to mention understanding the theory and linking their experiments to the lecture material as an aim than those who were interviewed in person. This may represent a change in the approach of the students or a change in the approach of the teaching, as during COVID-19 precautions at NTU. In this author's experience, and substantiated by student's descriptions of their experiences in the interviews, the approach by NTU staff to accommodating COVID-19 precautions was to undertaken in-person teaching laboratory sessions with fewer students and social distancing in place. This necessitated shorter timetabled slots to allow for a greater throughput of students, as the capacity of the teaching laboratory was greatly reduced by the safety precautions. To compensate for this contraction in time, some traditionally in-person teaching laboratory sessions were replaced by virtual elements such as videos or simulations, and the remaining in-person sessions were supplemented with supplementary materials such as videos that were explicitly targeted at developing understanding of techniques and theories. As the supporting materials were designed to scaffold the teaching laboratory session, they are effectively a form of pre-laboratory exercise (Carnduff and Reid 2003), and it is to be anticipated that they would increase student learning and understanding, which could account for an increased prevalence in discussion of this theme.

4.4.4 Student strategies for success in the teaching laboratory

In this section, students were asked *"What do you do to achieve your aims?".* Not all participants were asked this question as a stand-alone question, but as a part of the aims question, or some participants were not explicitly asked for their activities to achieve their aims but volunteered the information in response to another question such as the aims question. Activities commonly identified by participants include asking for help within the teaching laboratory, and preparation prior to the teaching laboratory, particularly in the form of reading laboratory documentation.

Participant 3_1 was not asked this question as they had already identified that they repeat experiments and adjust to refine techniques and check for repeatability in their response to the question regarding their aims.

Participant 2_2 was not asked this question as they had already indicated that they prepare for the session by reviewing the technique and asking questions in the teaching laboratory to gain more knowledge in response to the question regarding their aims.

Pre-laboratory preparation

Six participants indicated that pre-laboratory preparation was a strategy that they used to succeed in the teaching laboratory.

Participant 3_3 indicates that they undertake pre-reading of the experimental documentation, identifying important points in the procedure. If the technique is unfamiliar then the participant re-reads the documentation in greater detail.

Participant 4_4 says that they re-write the instructions from the experimental documentation in the format of bullet points. The detail included in these bullet points is mostly the steps of the experiment but will also include important observations such as colour changes to anticipate. This participant indicated that in the teaching laboratory they mostly focus on operation, and they focus on understanding the theory after the session when they are writing up any associated assignments.

Participant 1_5 reads the laboratory manual before entering the teaching laboratory, and in some of the virtual teaching laboratories undertaken this year due to COVID, videos were provided of the instrumentation as a pre-laboratory exercise which the participant deemed to be helpful. The participant indicated that some instructions provided in the laboratory documentation do not make sense when you read them prior to the teaching laboratory session, but once you undertake the action in the experiment, they start to make sense.

Participant 3_6 indicated that prior to entering the teaching laboratory, they read the provided experimental documentation such as a laboratory script. This allows the participant to familiarise themselves with the objective of the experiment and ensure they understand all the processes involved.

Participant 2_2 indicated in response to the questions regarding their aims that they review the experimental documentation prior to entering the teaching laboratory to review the techniques in the experiment and develop questions to ask.

The final participant describes pre-laboratory preparation in a slightly different manner, focussing less on operation and completeness, and more on understanding the processes that are undertaken. Although it is possible that the activities identified by students such as “reading the script” and reviewing additional materials could be linked to understanding chemical processes, participant 3_7 is the only student who explicitly stated that they think about what should be happening within the experiment and why these things are happening in conjunction with reviewing the experimental materials.

Asking for help

Three participants indicated that asking for help facilitates them meeting their aims within the teaching laboratory.

Participant 1_5 indicated that they seek peer support for activities in the teaching laboratory. Teaching laboratories at NTU typically operate on a cycle, where students are split into groups undertaking teaching laboratory sessions from different areas at different times, on the same day. This participant indicated that they had a friend in the morning session who would cover the material they would be covering in the afternoon of the same day. This participant indicated that they would ask that friend for reassurance from their friend by asking questions about any particularly challenging elements of the experiment. This participant also indicated that peer support is helpful for the analytical chemistry teaching laboratory as individual experiments are taken by students in a cycle, so they can usually find someone who has undertaken the experiment previously. This was cited as very helpful particularly as the data recording proformas are challenging to fill in at the start of the course.

Participant 3_6 indicated that if they don’t understand a process within the teaching laboratory, they ask for help from peers or a lecturer.

Participant 2_2 said in response to the question on their aims that they identify questions prior to the teaching laboratory to ask staff members during the session to increase their own understanding of the techniques.

Other actions

Participant 4_4 indicated that they try to be organised within the teaching laboratory, particularly working in a tidy manner, and remembering the next steps of a procedure. Participant 3_6 mentions a similar action of working methodically in the teaching laboratory.

Participant 3_3 indicates that they review and act on feedback provided to them in previous teaching laboratory sessions.

Participant 3_7 indicates that they aim to work quickly to allow time to think within the teaching laboratory, which facilitates their understanding.

Participant 3_7 indicates that they take notes of observations in the teaching laboratory to facilitate their writing up of the experiment in associated assignments.

Participant 3_1 indicated in response to the question regarding their aims that they adjust experimental procedures to refine their outcomes and repeat the experiment to ensure reproducibility.

Discussion

In the in-person interviews, the following strategies for success were identified by students:

- Pre-laboratory preparation such as reading the script or preparing recording documents.
- Time management and planning within the teaching laboratory.
- Following the provided laboratory instructions.
- Following best practice as advised by peers, staff or other sources.
- Undertaking purification steps or critiquing their product.
- Other strategies including contemporaneous record keeping, social interactions and stress management.

The most prevalent strategy identified by students in the online interviews was preparation prior to the teaching laboratory, particularly reviewing the experimental script or instructions. This is consistent with the high emphasis on preparation identified by the students in the in-person interview phase and is in contrast with the literature as previously stated (Moffatt, 1994). The preparation methods identified by the students are often to read the experimental documentation, which is a less active learning activity, and could be the reason for students expending time on preparation while there are reports of students being unprepared. An exception to this is participant 3_7 who explicitly states that they consider what is happening theoretically and why it is happening, they also indicate that they scaffold in time to think during their experiment.

An important element to consider is that there may be bias in the recruitment process, where more engaged students who prepare more effectively and manage their time well are likely to participate in this research, as they feel they have the time to take part, and under-prepared students may feel unable to participate in this form of research.

Time management was mentioned less extensively in the online interviews, with only participant 4_4 referencing a strategy of remaining organised and participant 3_7 indicated that they work quickly to allow more time for thinking.

The theme of following best practice again was represented, but to a much lesser extent than in the in-person interviews, with only three students referencing asking for help in relation to techniques or best practice.

No new themes arose as part of this question in the online interviews in comparison to the in-person interviews, and the responses were much less diverse. This may be partly because of the lower number of hours that the participants had spent in the teaching laboratory in the year that they were interviewed, due to COVID-19 restrictions as previously discussed, which could impact on the diversity of experiences. Additionally, the interview format may have skewed their answers; the in-person interviews were undertaken physically in the Superlab environment to prompt recall of experiences within the lab, rather than prior to or linked afterwards. It is possible that participants in the online interviews were discussing their actions within the teaching laboratory differently as they were not in the same environment (Bjørvik et al. 2023).

4.4.5 Motivation in the teaching laboratory

Students were asked this question in a more consistent manner than for the in-person interviews with only two phrasings used:

- *What are your motivations when in the laboratory?*
- *Why do you do X? With X being an activity they had noted in the previous question.*

Motivations identified by students include management of stress or other negative feelings, motivations relating to completion or quality within the teaching laboratory, assessment grade and development of understanding.

Managing negative emotions

Four participants indicated that managing stress or other negative emotions within the teaching laboratory are a motivator or reason for their actions.

Participant 3_6 self-describes as anxious or panicky person and states that preparing lets them stay calm in the teaching laboratory.

Participant 1_5 indicates that they undertake the actions of preparing before the teaching laboratory and seeking help within the teaching laboratory to avoid embarrassment. This participant indicates that going wrong in the teaching laboratory causes a feeling embarrassment in front of peers. This participant asked if this was an internal or external feeling, as they indicated that they compare themselves to their peers. The participant emphasised that the feeling of embarrassment was a self-originating feeling, and it is not developed from when concern for external factors or negative consequences.

Participant 4_4 stated that if they didn't finish a teaching laboratory session that they would be worried. An aim for this participant is to not be stressed when writing up any assessment associated with the experiment.

Participant 3_3 indicated that completing within the scheduled time for the teaching laboratory with a correct outcome would mean that they don't have to fret about the assessment, particularly about explaining any errors.

Completion and Quality

Three participants indicated that they are motivated by factors related to the quality of their practical outcomes, or completion of the experiment.

Participant 3_1 indicated that they are motivated by a desire to obtain high precision and accuracy results.

Participant 4_4 self-described as a perfectionist stating that they have never failed to finish a teaching laboratory. This was discussed further with the student and was linked to pride of completion.

Participant 3_3 indicates that their motivation behind making decisions or changes in their experimental processes are focussed on obtaining the practical outcome for the experiment. This participant indicates that although their decisions are based on theory, the motivation is completion.

Grade or assessment

Two participants made comments related to completion or quality of practical outcomes being associated with an assessment or grade.

Participant 3_3 indicates that producing an appropriate practical outcome in the teaching laboratory is linked to the grade and that failure to obtain a product may cap their grade. This student reports that they recall a teaching laboratory session where students who did not complete the sessions received a grade penalty cap with a maximum grade of a low 3rd for the associated teaching laboratory element.

Participant 3_7 indicated that their motivation behind obtaining good quality data is to be able to write it up in an associated assessment, and although it is possible to complete an assessment with poorer data, better data helps. This participant stated that better data corresponds directly to a better grade.

Understanding

Two participants stated that their actions are motivated by a desire to develop their understanding.

Participant 3_7 indicated that they are motivated by aiding their understanding.

Participant 3_1 indicated that they are motivated by displaying understanding to staff members and developing understanding by reinforcement through repetition in the teaching laboratory.

Other motivations

Participant 2_2 stated career related motivations. This participant indicated that having a good grade is not always important in securing a job opportunity, instead diverse experiences in the teaching laboratory would be more important when seeking a career after their degree.

Participant 3_1 said that they are motivated by a desire to explore wider than the experiment as defined in the experimental documentation, when asked this student confirmed that this is linked to curiosity. This student has also received positive feedback from staff members when they have gone further than the described experiment.

Discussion

When discussing the motivation behind decisions and actions, the in-person interviewees raised the following themes:

- Obtaining practical outcomes, such as making a product or collecting a set of data, linked either to completing a session or obtaining a grade.
- Pride or validation of chemistry ability.
- Peer motivation, through comparing one's own attainment to peers.
- Other motiviations were identified including managing anxiety and career prospects.
- One participant identified that they recognised that their motivations varied by session, and that their motivations in a teaching laboratory were different to those they may hold in a career environment.

Obtaining the practical outcome such as data or a product remains a consistently prevalent motivating factor for students, with five of 8 in person participants, and 5 of 7 online participants indicating that these were important motivating factors for them, which is consistent with the literature supporting a often product-driven attitude within the teaching laboratory (Gunstone 1990).

A new theme for motivation that occurred in the online interviews is that of understanding. Two participants referenced wanting to understand the material as motivations behind some of their actions. This was not represented in the motivations discussed in the in-person interviews but is a desired outcome of the teaching laboratory (Reid and Shah 2007), so this being identified by students as a motivating factor is encouraging. It is notable that the students who have identified that they aim to develop understanding were both in their 3rd year (FHEQ lv 6), and therefore likely more established in their laboratory experiences than other participants, however despite interviewing other students at this level and higher in both the online and in-person interviews, understanding or gaining knowledge was not mentioned as a motivating factor by other students.

The themes of peer comparison and pride or validation were notably absent from the online interviews, with participants typically reflecting less on others within the teaching laboratory environment, and more on their own personal feelings and experiences. This may contribute to the additional theme that has arisen in the online student interviews of managing stress, anxiety or other negative emotions. Laboratory anxiety is a documented phenomenon that can negatively impact on students' capacity to learn within the teaching laboratory (Sesen & Mutlu, 2014) (Kolil et al., 2020). A tool has been developed for the measurement of anxiety within the teaching laboratory (Bowen, 1999), and the application of these to future research on the laboratory could be a useful method of quantifying the impact of anxiety as a motivating or detrimental factor within the teaching laboratory. It is important to consider the effect of the COVID-19 pandemic on the students who were interviewed online, and note that anxiety was shown to increase in students during the pandemic (Jehi et al. 2023), and this particularly impacted students who had certain personal characteristics such as having spent the quarantine in isolation or undertaking the transition to online learning. These high levels of psychological distress have been documented one year after the beginning of the pandemic (Schmits et al. 2021), and this is still an evolving picture. All students interviewed in the online interview phase were affected by changes to higher education during the pandemic, and therefore it is perhaps unsurprising that they talked more about negative emotions experienced within the teaching laboratory, however no students mentioned that their anxiety was directly linked to either contracting COVID-19, or the safety precautions in place. Instead, students relayed anxiety in relation to finishing their required work, or feeling embarrassment at making a mistake, which is very reminiscent of laboratory anxiety, although multiple stressors is a contributing factor to the increase in anxiety and depression during the pandemic more broadly (WHO - News Release 2022).

4.4.6 Recognition of achievement of aims or success.

Students were asked *"What does a successful lab session look like to you?"* Students did not typically concisely describe a successful teaching laboratory session in response to this question, as such descriptions of successful teaching laboratory sessions are not included in this analysis, in contrast to the in-person interviews.

A common theme arising from this question is that students are aiming to complete the teaching laboratory session, either in a timely manner, with a correct product or with the appropriate information. Students identified a variety of other measures of success in the teaching laboratory, including achieving aims set by themselves or staff members, understanding or an emotional state at the end of the session. Any responses that do not fit within the broad themes of responses are grouped under "other measures of success".

Achievement of aims

Four participants indicate that a successful teaching laboratory session is one where they have met aims set by themselves or others.

Participant 3_3 indicates that a successful teaching laboratory session would be one where they met the aims that they had identified earlier in the interview. For inorganic and organic teaching laboratory sessions this was to complete the required experiment in an appropriate time without panicking. For physical and analytical chemistry teaching laboratory sessions this was to be prepared for the teaching session and anticipate any difficult steps in the experiment.

Participant 3_1 indicates that they set their own personal aims or goals for an experiment, which are mostly linked to the aims identified earlier in the interview of obtaining at least one reproducible data set, with the opportunity for repetition or refining their technique or process.

Participant 3_6 states that a successful teaching laboratory session would be one where they achieve the objectives of the session, which are set by staff members. These objectives were stated by the participant to be synthesize a product or obtain a data set.

Participant 3_7 says that a successful teaching laboratory session is one where they manage to get everything required of them done on time and to the best of their ability, producing data that is usable. Usable data is likely a reference to post-laboratory analysis or assessment, as this participant has already referenced the quality of data being linked to post-laboratory assessments in the interview.

Timeliness/efficiency

Four participants of the seven total interviewed made references to the time spent within the teaching laboratory as a measure of success.

Participants 3_6 and 3_7 indicated that a successful teaching laboratory session would be one where they finish the teaching laboratory session on time.

Participant 4_4 indicated that for a teaching laboratory session to be regarded as successful, they would finish ahead of the schedule deadline for the session.

Participant 1_5 indicated that a successful teaching laboratory session would be one where they find themselves ahead of their anticipated schedule for the session. When asked how they estimate the length of time tasks should take, they stated that they base this on prior experiences in the teaching laboratory.

Participant 2_2 mentioned time management in a slightly different manner to other participants, stating that a successful teaching laboratory session would have not wasted time.

Understanding

Four students indicated that development of understanding would indicate a successful teaching laboratory session.

Participant 2_2 stated that a successful teaching laboratory session would be memorable and help them remember the technique or procedure after the session.

Participant 3_1 indicates that they would characterise a successful teaching laboratory session by the learning of extra information that is not necessarily within the set curriculum.

P: But it's really nice to be able to want to go in and find that little awkward question or answer that you might ask the staff and they might be able to help you with it, or tell you a story or an example about it. It's quite an enjoyable experience to feel like you can come out of a lab feeling that it's a success.

Figure 116: Excerpt from interview with participant 3_1 on the topic of a successful teaching laboratory session.

Participant 3_7 indicated that a successful teaching laboratory session would be one where they have understood what is happening within the experiment. This participant stated that they do not aim to follow instructions as a robot would. This participant had discussed reflection and thinking during the teaching laboratory, and this was raised in this section for further inquiry. The student indicates that they think within the teaching laboratory, but also critically reflect after the scheduled session during the write-up.

Participant 1_5 indicated that a successful teaching laboratory session would be one where they had understood what they were doing. When asked for further clarification, the participant indicated that this related to chemistry theory linked to the operation of the instruments within the teaching laboratory environment.

Correctness

Three participants indicated that they would identify a successful teaching laboratory session by the level of correctness in their outcomes.

Participant 3_1 indicated that it is good to know that they have done something right, because if something has gone wrong, they then need to investigate why it has gone wrong.

Participant 3_7 indicated in a humorous manner that a successful teaching laboratory session is one where nothing goes wrong.

Participant 4_4 indicated that knowing they have done the right thing, with the right product and data would indicate that the teaching laboratory session had been successful.

In addition to the examples above, Participant 3_3 described the quality of their practical outcome, suggesting that having a “nice product” is a measure of a successful teaching laboratory. This participant had previously linked the quality or yield of their practical outcome, and therefore completion and correctness, to the grade that they obtained for the teaching laboratory associated assessments. The interviewer introduced the concepts of grades at this point in relation to the practical outcome, reflecting on earlier comments. This participant was not asked a follow up question but volunteered that having a poor practical outcome is likely to result in being marked down in associated assessments, without sufficient explanation.

Verification of right product

Two of the participants who identified making the right practical outcome as their aims and were subsequently asked how they know they have obtained the correct practical outcome.

Participant 3_3 was asked during the aims question how they would identify the "right product", and they indicated that they would undertake confirmatory tests and compare their outcomes to a textbook standard value.

Participant 4_4 was also asked the same follow-up question in the aims question theme after they identified an aim of making the "right product". This participant indicated that they often don't know until after the teaching laboratory session is over if their data is correct, however they can estimate a measure of correctness from the form of the product. By contrast, in the same interview, participant 4_4 responded to a similar question in the recognition of success question theme differently. In the recognition of success question, the student had indicated obtaining the right product or data would be a measure of success. When asked how they would know they had the right product, this participant indicated that for synthetic methods they could undertake confirmatory tests such as a melting point.

Staff feedback

Two participants indicate that staff feedback helps them identify that the teaching laboratory session has been successful.

Participant 4_4 states that at the end of a teaching laboratory session, a lecturer reviews their data and says if it's correct. Participant 4_4 also indicated that lecturers may praise students for their performances within the teaching laboratory, such as praising the quality of their practical outcome, or the speed of their work.

Participant 1_5 indicated that a successful teaching laboratory session may be marked by praise from staff members and cited a specific example of this.

Lack of Stress or panic

Two students indicated that remaining calm or lack of panic would be a measure of a successful teaching laboratory session.

Participant 3_3 indicated that time pressure or lack of completion can lead them to feeling panicked. They would identify a successful teaching laboratory session as one where they did not feel panicked, completed on time and were able to leave the teaching laboratory feeling like they've finished.

Participant 3_6 indicated that a successful teaching laboratory session would be one that is calm, as they identified previously as a panicky person.

Other measures of success

Participant 2_2 wanted to be able to use the examples of techniques experienced within the teaching laboratory for their interviews for upcoming internships as part of a sandwich placement, therefore being memorable is important.

Participant 3_1 indicated that a successful teaching laboratory session would be one where they felt confident in undertaking the laboratory session.

Participant 3_1 reflected more broadly on the mode of teaching and identified that they enjoy that teaching laboratories challenge them in a healthy manner. This participant indicated that they enjoy chemistry and are happy and thankful that they are able to pursue a career in this field.

Discussion

In the in-person interviews, students identified the following measures of success:

- Obtaining the correct practical outcome, or a high quality or yield outcome.
- A feeling of success, achievement or esteem.
- Feeling positive in comparison to peers.
- Positive staff feedback.
- Successfully learning, mostly after the taught laboratory session.
- Avoiding mistakes or errors in the experiments.
- One participant identified that they sometimes find it difficult to know if they are successful in preparing for the teaching laboratory until they are undertaking the experiment.

As for the in-person interviews, the online interviews with students identified measures of success that are linked to completion and product focus. One large category represented this in the in-person interviews, with all students mentioning the practical outcome when discussing completing the teaching laboratory exercise, and providing more limited details, while the online interviews students expressed more detail in their responses, allowing for more granularity of this broad category of completing the experiment. Students in the online interview described the concept of completeness in a variety of ways, each encompassing various sub-elements allowing a greater understanding of how students view the concept of "completeness" in relation to the teaching laboratory. Online participants responses allowed several related but smaller themes to be identified, differentiating the broad completionist attitude into smaller sub-groups, namely timeliness, achievement of aims, correctness and verification of the correct product. Timeliness relates to completing the whole exercise within a given time limit or not wasting time within the taught session, which was related to a possibility of non-completion. Achievement of aims was described in two different ways, either meeting the student's own aims or the aims that staff held for them – both of which encompass completing the experiment or obtaining a practical outcome. Correctness encompasses avoiding making errors, which was identified within other aims in the in-person interviews by two participants, and by three participants in the online interviews. Correctness can be viewed as a linked theme with verification of the correct product, as verifying is a way of testing correctness, as stated by the students interviewed online. Therefore, completing the teaching laboratory session, for the online participants, can be determined to be achieving the correct outcome as determined by comparison to the literature, in a timely manner and achieving the outcomes as predetermined by the lecturer running the teaching laboratory, or themselves determined from the experimental material. This measure of success is highly reminiscent of cookbook chemistry (Gallet 1998; Venkatachelam and Rudolph 1974; Bertram et al. 2014), with students placing high levels of importance on the rightness of the outcome in relation to pre-determined ideas, rather than developing understanding during the experiment. Staff feedback was mentioned in both sets of interviews too, often with a focus on feedback or praise relating to practical outcome quality or correctness.

In addition to this, the measure of success relating to learning or understanding were mentioned in both sets of interviews but described differently by the two cohorts. In the in-person interviews, three participants indicated that they do measure success in relation to the teaching laboratory by identifying successful learning, however two participants indicated that this is mostly occurring after the teaching laboratory session, while a third participant indicated that they learn from making mistakes, which indicates reflection. In the online interviews, four students indicated that a successful teaching laboratory session would be one where they developed their understanding within the teaching session. These participants varied slightly in their representations of what understanding meant, varying from a session being memorable to being able to link theory to the practical and reflect critically on what had happened during the experiment. This suggests that some students are indeed measuring success in relation to deeper learning, which suggests a slight variation from the cookbook chemistry as indicated in the previous measure of success. This indicates that although students may emphasise having "cookbook" style measures of success when first questioned, they can still hold value and develop higher level aims such as understanding. This is more consistent with an ***achieving*** approach as described by Biggs and Moore (1993), where students carefully balance their desire to learn and achieve highly against perceived time or resource limits. The emphasis on understanding, particularly the mentions of critical reflection by participant 3_7 may be indicative of a higher level of metacognitive development (Merkebu et al. 2023) where a student is intentionally scaffolding time to reflect within their own learning experiences within the teaching laboratory without prompting from an external source.

The generally positive feelings such as success or achievement were discussed by participants in the in-person interviews, sometimes encompassing the lack of a negative emotion, such as frustration or a feeling of relief when finishing the session. These may be linked to the responses in the online interviews that relate an absence of stress or panic being a measure for success, but the language in the online interviews was much stronger – referring to stress and panic rather than frustration or things having "not gone well". As such, these are not identical themes but are correlated more broadly within the affective domain of emotional experience of the teaching laboratory, and determining success by the absence or lower prevalence of negative emotions. It is possible that the wording in the online interviews could be impacted by the generally higher levels of psychological distress that is likely to be presented by students after the pandemic(WHO - News Release 2022), however with such a small sample size it is not possible to draw this conclusion.

Similarly, peer comparison is notably absent as a motivating factor from the online of interviews, and indeed peer influence has been mentioned less throughout the entirety of the online interviews in comparison with the in-person interviews. This is possibly linked to the social distancing measures described by some participants such as greater spaces between students and smaller lab groups, which could result in students being less able to compare themselves to their peers during their current studies, and as such reporting this as a measure of success less than students had in previous years. The students in the in-person interviews were interviewed in the teaching laboratory, and occasionally other students would be in the environment too, perhaps prompting recall of peer interactions. This could be investigated further by interviewing students who have not been affected by the social distancing regulations by starting their studies after

2021 to see if they report similar levels of peer-influence to the in-person cohort or more like the online cohort.

4.4.7 Staff aims for students in the teaching laboratory

Participants were asked *"What aims do you think staff members have for you during laboratory sessions?"* The students indicated a variety of aims that staff may hold for them including understanding the theory behind an experiment, linking the teaching laboratory to the rest of their course, and behavioural outcomes such as confidence and working safely. Any aims that do not fit within the broad themes are grouped under other staff aims.

Initially, participant 2_2 suggested that they did not know what aims staff had for them in the teaching laboratory. The participant indicated that they know the aims are written in the module or laboratory documentation, however they have not read all the available documentation. This participant explained that not all documents are very useful to them, and they would typically ask a staff member for support in the teaching laboratory if they did not understand.

Understanding

Five participants out of seven interviewed indicated that staff aim for them to develop understanding within the teaching laboratory.

Participant 3_1 indicated that staff members want students to be able to understand the content presented in the teaching laboratory. Understanding the laboratory was linked to contextualising the teaching laboratory in the broader experience of the course rather than treating it as a stand-alone experience.

Participant 1_5 indicated that staff members want students to leave with knowledge of the instrument that they are using in the teaching laboratory. It is unclear if this student is referring to theoretical knowledge or operational knowledge.

Participant 4_4 indicated that staff members want students to be able to be able to undertake the techniques used in the teaching laboratory sessions in the future. The participant was asked if this was operational knowledge or theoretical knowledge. The participant responded that academic staff wanted students to understand the theory, while technical staff want students to understand how to operate the instrumentation.

Participant 3_6 stated that staff members aimed for their students to build their knowledge and understand what they are doing in the teaching laboratory.

Participant 3_7 indicated that staff members aim for students to understand what's happening and be able to answer questions posed by staff members. This student refers to staff members using the teaching laboratory as an opportunity to check up on student's learning, almost as a plenary exercise.

Linking learning experiences

Three students indicated that staff aim for their students to create a link between the theory they are taught elsewhere in the course, for example in lectures, and the teaching laboratory.

Participant 3_1 indicated that staff members want students to link the theory from lectures and the practical element from the teaching laboratory. This student approaches the teaching laboratory as part of the whole learning experience.

After indicating that they don't know the aims that staff hold for them, participant 2_2 suggested that the aim that staff have for students is to link the experiment to their learning from lectures.

Participant 4_4 mentioned a conceptual link between theory and the teaching laboratory, suggesting that a staff aim for the teaching laboratory is to show the practical side of the theory.

Independence

Two students said that they think staff aim for students to develop independence within the teaching laboratory.

Participant 3_6 indicated that staff aim for students to think for themselves, providing an example of locating equipment without immediately asking a technician for assistance.

Participant 3_7 indicated that especially in later years that staff aim for students to be independent. This participant indicated that there is a fine balance between support and independence and that this balance varies throughout the years, but they must have space to learn.

Correct behaviours in lab

Two students indicated that staff aim for students to develop appropriate behaviours within the teaching laboratory.

Participant 1_5 indicated that staff aim for students to understand how laboratories work and that the first year of their course was focused on comfort or familiarity in the teaching laboratory.

Participant 4_4 indicated that staff aim for students to learn correct behaviour in the teaching laboratory, the participant did not expand on this themselves but agreed that this would encompass knowing how to behave in a professional role in industry.

Outcomes focused

Two participants indicated that staff have aims of producing a practical outcome such as a product or a data set.

Participant 1_5 indicated that staff aim for students to complete the teaching laboratory session, and that obtaining good data would be regarded as a bonus.

Participant 3_7 indicated that staff aim for students to be able to obtain good data. This participant also indicated that staff want students to be able to apply theory to their practical activities to obtain a good result from the teaching laboratory. It is unclear if the result the student is referring to here is a practical outcome or a grade.

Other staff aims

Participants 3_7 and 4_4 both stated that staff members aim for students to do as well as they can.

Participant 3_6 indicated that staff members want their students to gain confidence in their laboratory skills.

Participant 2_2 indicated that staff aim for their students to get practice in the teaching laboratory, however the participant was not clear on whether they were referring to the theory or techniques used in the experiments.

Participant 4_4 suggested that staff members have career aspirations for their students, stating that they want students to be able to succeed later in life in industry or research.

Participant 3_3 states that staff aim for students to act on feedback. This participant cites feedback from previous experiments provided by academics that they review prior to the next session in a laboratory course and also feedback on operation from demonstrators for best practice.

Participant 3_1 implies that staff have an aim for students to experience a range of instrumentation. This participant states that staff were disappointed that students were unable to use a particular piece of instrumentation due to COVID restrictions, and the in-person teaching laboratory session was replaced with a digital experience instead. This participant states that they enjoy teaching laboratories at NTU because of the access that they have to the instrumentation. This participant states that staff really care about their learning experiences and that learning at NTU feels very integrated across the different learning environments.

Discussion

In the in-person student interviews, the themes that arose when students were discussing aims that the staff held for them were as follows:

- Learning best practice
- Career development
- Fostering independence
- Learning Chemistry
- Other aims including "getting the most out of the session" and that aims should be achievable for students.

In addition to these aims, two students in the online interviews identified that aims held by staff vary either by lecturer or module type, and another two students indicated that staff aims are either unclear or undeclared during the teaching laboratory session.

Several themes were that were discussed by students in the in-person interviews were not discussed during the online interviews, including that aims may be variable or unclear in response to this question. Career development was only mentioned by one participant, 4_4 and therefore did not become a theme within the online interviews, but was noted within the "other aims" section.

Best practice with equipment was also omitted from the themes as it was not discussed in a cohesive manner within the online interviews. Students made references to developing within their practice within the teaching laboratory, but in a variety of ways, which did not match to a consistent theme.

- Participant 3_3 indicated that staff aim for them to act on feedback from staff and were the only participant to explicitly indicate that they get guidance on best practice from technical staff.

- Participant 3_6 indicated that the staff aim for students to confidence in their laboratory skills, which could indicate a degree of following best practice.
- Participant 2_2 indicated that staff aim for them to get practice in the teaching laboratory, which could indicate repetition leading to competence, but additionally this could refer to repetition of behaviours or theory.

Confidence was not discussed extensively in the online interviews, and therefore was not identified as a theme, but two new similar themes arose. Two participants indicated that staff want them to develop independence in the teaching laboratory. In addition to this, two participants indicated that staff aim for them to develop some form of correct behaviour, with participant 1_5 indicting that they develop confidence and familiarity, while participant 4_4 indicated that staff want them to develop correct laboratory behaviours that would be appropriate for a professional context.

Understanding was discussed extensively in both the online interviews and the in-person interviews. All in-person participants indicated that staff aim for some form of learning chemistry, summarised below.

In person:

- 5 participants – apply theory within the teaching laboratory.
- 3 participants – link the teaching laboratory to other content e.g. lectures.
- 2 participants – checking understanding within the teaching laboratory.

Three online participants indicated that staff aim for students to link their teaching laboratory sessions to other taught content e.g. lectures. The remaining online participant responses are more diverse and less readily grouped but do all fall under the general theme of Understanding. Descriptions of understanding within this encompassed gaining knowledge, being able to understand questions and understanding what is happening in the teaching laboratory environment.

New themes that arose in the online interviews included two participants indicating that staff want students to complete the teaching laboratory exercise, in an outcomes-focussed manner, particularly referring to obtaining data. Participant 3_7 indicated that obtaining good data requires the application of theory to guide decision making.

As discussed in section 2.2.3, an extensive amount of research has been undertaken on the aims of the teaching laboratory. It was found that aims of the teaching laboratory as identified in the literature are very wide-ranging and encompassing the list below, reproduced in a simplified manner from Table 3.

Practical skills:

- Safety, risk assessment
- Practical skills General experimental competence, including using apparatus or technique, and practical exam requirements.

Understanding:

- Understanding data, chemical terminology
- Retention of concepts

- Understanding theory including application of theory, elucidation of theory, verification of facts, elucidation of theory to aid understanding
- Making phenomena real, illustrating the abstract.
- Fact finding by investigation

Laboratory related skills:

- Observation, recording
- Data analysis, interpretation and reporting data
- Scientific thinking
- Understanding the scientific method
- Experimental design, hypothesis formation
- Communication of experimental process

Transferable skills:

- Critical thinking including accuracy, precision, reliability and validity
- Problem solving
- Learning from mistakes

Behavioural outcomes:

- Independence, confidence and student ownership
- Professional behaviour
- Developing or improving attitude to chemistry
- Motivation including enjoyment
- Organisation and time management

The responses in the student interviews, both in person and online, appear to show that students understand that staff wish them to meet a wide range of aims within the teaching laboratory. Many of the literature-identified aims above are discussed by the students to some extent within either the in person or online interviews, with the practical and understanding aims identified from the literature broadly represented to some extent within the discussions of the purpose of the teaching laboratory or the staff aims through the two interview sets, although some to a lesser extent. Students discussing understanding does tend to be focussed on recall, applying and exposition, which may be impacted by the styles of teaching laboratory session that are being employed within their courses (Domin 1999). This emphasis on expository outcomes, such as the practical outcome or applying theory is consistent with the review of staff and student aims for the teaching laboratory undertaken by George-Williams et al. (2018), where both students and staff were found to be more likely to focus on practical outcomes and applying theory rather than broader aims of the teaching laboratory such as transferable skills. When discussing laboratory related skills , students did not typically elaborate on their responses further than citing good practice, or GLP. Where possible, students were asked to discuss these concepts further, and students often identified safety or best practice in the teaching laboratory, which does not encompass the laboratory-related skills identified in the literature skills list e.g. observation and scientific thinking. This suggests that this may be an aim of the teaching laboratory that the students cannot easily identify or communicate, or do not recognise.

When considering understanding in the teaching laboratory, much of the recent research into laboratory teaching would have one believe that students are tending to passivity in their undertakings within the teaching laboratory (Venkatachelam and Rudolph 1974; Bertram et al. 2014), however some responses within this study challenge this, with students recognising that they do indeed develop their understanding within the teaching laboratory. For those students that are choosing not to prioritise the understanding in their approach to learning in the teaching laboratory, it is not necessarily that understanding is not important to them, but rather that completeness is of a higher priority. Student responses in both the online and in-person interviews encompassing aims and motivations suggest completing the experiment is a very important aim for most of the students, and that many of their decisions are motivated by whether they feel they will be able to complete the experiment in the scheduled time. While this emphasis on producing the product or data set is consistent with an outcomes-focussed approach (Gunstone 1990), students do indeed recognise that there are additional aims to the teaching laboratory. A comparison between staff and student aims perceived aims will be discussed more extensively in section 4.5.1.

Online student interviews – technology questions

The second part of this section covers the new technology-focused questions. These questions are presented in a separate section for clarity, as these questions were not asked during any in-person interviews. These questions were asked before the technology enhanced learning comparison question that is directly comparable to the in-person interviews. These questions were intended to further explore the way students identify technology and use it within educational contexts more broadly.

4.4.8 Definition of technology

Students were asked to define technology and provide examples. Responses to this question are short, but complex. Participant responses are represented individually for this question, to retain the participant's individual definitions of technology. Responses from students are categorised into response types. Examples of technology provided in response to this question are collated in table 50. Definitions of technology provided by participants are diverse, with students often indicating that this was a challenging question.

Table 50: Examples of technology cited by students (2021)

ID	Computer/ Laptop	Smart Phone	Computer Accessories	Other
3_1	X		Keyboard Headphones	Stock monitoring in shops, Equipment in laboratory
2_2	X	X		Internet
3_3	X			Instrumentation in laboratory, Refers to tablets in Superlab, Games console
4_4	X	X		
1_5	X			iPads, Software linked to laboratory instrumentation, Websites
3_6	X	X		Tablets in the Superlab
3_7				Calculator, Paper and Pen

Example-heavy responses

Participant 1_5 described technology as hardware and software, listing some examples of technologies including those used within the teaching laboratory. This participant did not provide further information on a definition or nature of technology.

Participant 3_3 focussed strongly in their response on the Superlab and provided examples of the technologies used within the teaching laboratories. The participant did not define technology in response to this question, instead focussing on examples of technologies that they used.

Time-sensitivity of technology

Participant 3_1 defined technology as broad and ingrained in their everyday life. This participant indicates that technology has changed significantly over time. This participant identified as dependent on technology and that they use technology extensively in their everyday life.

Participant 2_2 indicated that a technology is a useful item that is dominant in it's field and is advantageous or helpful to the user. This participant discussed how the definition of technology may change over time.

Interactivity

Participant 3_6 indicated that technology is electronic items that you interact with. When asked to differentiate between a smart phone and an analogue phone, the participant indicated that an analogue phone is still technology, but perhaps a different type of technology. The term digital technology was discussed to identify smart phones and similar devices, while technology would encompass analogue devices. The participant was asked if digital technology was typically internet enabled and the participant indicated that this is the type of technology they use regularly.

Automation

Participant 4_4 focussed on the automation element of technology, indicating that technology allows us to complete activities without intervention.

Effectiveness or efficiency

Participant 3_7 is the only participant to not focus on digital technologies in their response. This participant indicated that technology is any item that helps you undertake an activity more quickly or easily than you could do it without the item.

Discussion

The definition of technology has been discussed in literature extensively, pre-dating the digital revolution of the 1990s (McOmber 1999). More recently, specific definitions of digital technology (Baier et al. 2023) focus on purpose rather than individual technologies which can result in inconsistent interpretation between participants, due to the rapid development of new technologies. For this reason, it was deemed important to consult the individual participants on their own personal definition of technology. The definitions of technology are still being explored in the modern era in relation to digital technologies (Dusek 2023).

Importantly, *technology* has been used in previous research as a synonym for digital technology (Clagett 1998), and defining concepts prior to discussion with participants in interview is not in line with phenomenographic principles of participant-led research

(Bowden and Walsh 2000) where participants are expected to construct their own meaning with the support of the interviewer (Marton 1986).

While the definitions of technology from the students may appear to be varied, there is a broad theme of technology being a tool to save time or effort within their comments. This is consistent with literature definitions of technology as instrumentality, a neutral tool to achieve an objective (McOmber 1999). Students typically identified digital technologies when prompted for examples, which does suggest that the phrases “digital technology” and “technology” may be readily conflated or even synonymous for these students.

The response of participant 3_7 highlights the importance of defining terms to participants before asking questions, as they clearly have quite a different understanding of technology to the other six students. This participant’s answer is consistent with the instrumentality view of technology, but not specific to digital technologies. For future research, now that the understanding of technology has been explored within this study, it may be prudent when dealing with a concept as broad as technology to define the scope of technology within the teaching environment for future research, or ask students broad questions, followed by more pointed, structured questions about specific pieces of technology that the research is interested in.

4.4.9 Technology use in learning

Students were asked how they used technology in their learning and to provide examples. As for the definitions of technology, responses to this question are short, but complex. Participant responses are represented individually for this question, to retain the participant's individual experiences of technology. Responses from students are grouped into response types into positive, negative, and mixed. Examples of technology provided in response to this question are collated in table 51.

Table 51: Technologies used in learning by student participants (2021)

ID	Computer/ Laptop	Tablet	Smart Phone	Computer Accessories	Other
3_1		X		Stylus	
2_2		X	X		eBooks
3_3	X			Microphone	Recording (Camera)
4_4	X				
1_5	X	X			Online workspace (NOW) Software (MS Office) Internet
3_6	X				
3_7	X				Pen and paper Books Projector screens

Positive responses

Participant 3_1 indicated that they use a tablet computer with a stylus in their learning. A particular task they identified is taking handwritten notes on the tablet instead of on paper, which they indicate helps them file their notes in a more systematic manner. Part of the reasoning for using this paper-free format was Nottingham Trent University School of Science and Technology's paperless policy, which intends to reduce the cost and environmental impact of high volumes of printing (NTU SST Learning and Teaching Subcommittee, 2022). This participant indicated that using technology allowed them to overcome accessibility barriers linked to their specific learning disability and their other disability, by reducing screen time, and allowing long assessments to be broken up into smaller chunks to allow effective progress.

Participant 4_4 indicates that the main technology that they use in their learning is a laptop or computer, which they use to revise by rewatching lectures, complete laboratory report assessments and access documents online. This participant linked the impact of technology on their learning to ease of access to materials online, and technology was deemed to help their learning.

Mixed responses

Participant 2_2 indicated that they use smartphones, tablets and eBooks in their learning. eBooks were cited as particularly useful during the pandemic, due to lack of physical access to the library. This participant also indicated that they took breaks between learning periods to promote their wellbeing and used the internet during these rest periods. This student indicated that using technology had a mixed impact on their learning and cited the ease of access of information on the internet can be a benefit but can also lead to overwhelming amounts of information. This participant also suggested that their learning from books is of higher quality as they must locate the required information within a book, which is not the case online. This participant was also concerned about the health impact of prolonged screen use and the environmental impact of technology in the world more widely.

Participant 3_3 indicated that they use their laptop to attend lectures remotely during the pandemic but typically takes notes on paper. They complete their assessments on their laptop and provided examples of types of assessments they may have to complete including recording a video as a coursework piece. This participant indicated that technology has a mixed impact on their learning, citing it as a blessing and a curse. The positive aspects identified related to the pandemic and remote access to learning during the crisis. This participant indicated a change in quality of university experience through the pandemic, as they struggle to switch into a learning mode when they aren't in the university buildings. On the negative side, this participant identifies as having a short attention span and are easily drawn to procrastinate from their work by technology.

Participant 1_5 indicates that they use an iPad a laptop when they are learning, and access Nottingham Trent University's online workspace (NOW) regularly. The participant identified that they use Microsoft Office programs during their learning, as well as the internet. This participant indicated that their learning is currently mostly online, due to the pandemic. The impact of the remote learning was described as more freedom by this participant, with the opportunity to work more flexibly however not in a positive way. The participant described disengaging from material that they found less interesting and would prefer to be present in a lecture hall where they are less likely to be distracted. This participant stated that their response to this question was likely affected by the pandemic situation, and without that their response would probably be different.

Participant 3_6 indicates that they use a laptop in their learning which allows them to research, complete coursework and attend online lectures. This participant indicated that technology helps their learning a great amount, providing an example of times when they've struggled to understand a definition of a term, so they researched alternative definitions that they understood more. The participant indicated that being able access a variety of sources that present the same information in different ways has helped them understand concepts presented in their course. This participant indicated that there are times when technology is not advantageous, such as when experiencing technological difficulties in a timetabled session that require time and energy to resolve. This participant also indicated that due to the nature of chemistry, taking notes on a computer is challenging, as Microsoft Word does not have an effective or intuitive symbol or equation function, citing the time investment of learning to use functions as an off-putting element.

Participant 3_7 indicated that they use pen and paper and books during their learning, but due to COVID, they use a computer more extensively this year. This participant indicated that technology improves their access to information. Due to the pandemic, this participant has noted a decrease in interaction with their lecturers, which is noted as a negative impact of technology as face-to-face conversations are seen as an opportunity to learn for this participant.

Discussion

Participants are quite positive in attitude towards technology in their learning more generally, with some indicating that technology is pervasive within their everyday lives and learning, and often citing individual items of digital technology that they use, and the function that the technology achieves, in agreement with the *Instumentality* categorization (McOmber, 1999), where technology is defined as a tool that fulfils a purpose. The high number of examples in everyday life suggest that the students have a high degree of familiarity with technologies which is consistent with the results of the Digital History Survey which suggests that students are at least familiar with a range of devices and application. However, as noted previously, familiarity does not always correlate with competence and a high level of user skill (Henderson et al. 2015). Familiarity with technology can be a contributing factor to a positive reaction when presented with technology in a learning environment, due to increased student confidence (Staddon, 2023).

When considered as a whole, the mixed responses of the students cover all of the negative attitudes identified by Selwyn (2016),

- Distraction – students becoming distracted, moving off task or procrastinating.
- Disruption – technology failing to work on individual instances, stalling work.
- Difficulty – ongoing challenges in using digital technology to complete work such as inconsistencies, poor design or lack of accessibility.
- Detriment – perceived poor-quality learning due to the implementation of technological solutions such as online learning or digital file systems.

Participants 3_3 and 1_5 both indicate that a negative aspect of technology is Distraction, or the ability to procrastinate that prevents learning.

Participant 3_6 indicated a level of Disruption in timetabled sessions when technological devices fail and require effort to resolve the issues. This participant also cited that there were elements of Difficult, in that the software on the tablets does not readily allow for intuitive integrated drawing of chemical structures or formulae.

Participant 3_7 has indicated that the lack of face-to-face conversation has narrowed their learning which fits within the Detriment category. Participant 2_2's response relating to the overwhelm of information has some similarity to the Detriment category, where the introduction of technology impedes on learning. However notably, the examples provided by Selwyn typically relate to the restriction or narrowing of learning opportunities, whereas Participant 2_2 has indicated the opposite, a glut of data which impacts on their ability to select and process high quality reliable information.

When considering technology more broadly than the Superlab, students have cited more wide-ranging negative impacts on their learning than the in-person interviewees did when questioned specifically about the Superlab.

Some participants have explained that they would prefer to use paper in their learning over a digital device as they feel it has a positive impact on their learning. This is understandable as there is research supporting the effectiveness of handwriting over typing as an effective method of promoting recall (Smoker et al., 2009). A preference for handwriting notes is consistent with responses from students in the in-person interviews, who cited a preference for handwriting over typing within the Superlab, typically explained as a more efficient or easier method for recording data which is consistent with attitudes presented in literature to typing in educational contexts (Bouriga & Olive, 2021; Mogey et al., 2012).

4.4.10 Technology use in teaching laboratories

Students were asked how they used technology in the teaching laboratories and to provide examples. Types of impact are grouped by theme, to allow consideration of common themes. This was not possible in the in-person interviews, as no broad themes arose, however online participants presented several concepts within their response rather than one complex response. Examples of technology provided in response to this question are collated in table 52. This question was omitted from the interview with participant 3_6.

Themes identified by the participants includes advantages to data recording and access, immediacy of access and experience of using the instrumentation. Several varying aims were identified by only one participant each, and as these do not fit within the greater identified themes, they are grouped as "other impacts of technology". Responses to this section are broadly positive and students identify many advantages to using the tablets in particular in the Superlab.

Table 52: Technologies used in the teaching laboratory by student participants (2021)

ID	Surface Pro Tablets	Instrumentation	Software	Other technologies
3_1	X	X	Cloud storage e-mail	
2_2	X	X		Fume hoods
3_3	X	X	OneDrive	
4_4	X	X		Computers connected to instrumentation
1_5	X	X		
3_6	Question not asked			
3_7	X	X		Glassware TV display screens (less used)

Data recording and recall

In response to the request to define technology Participant 3_3 indicated that the tablets are a workaround for the problem of the paperless environment.

Participant 1_5 indicated that recording information on the tablets made it neat and easy to store, and that it was good to have all the data in one place as they can access it at any time. The participant indicated that they have accessed tutorial content within a teaching laboratory context. Additionally, having all the files in the same place was deemed to assist with the post-laboratory write up of their work.

Participant 3_3 indicated that having continuous access in and out of the teaching laboratory is beneficial to their learning, and having the tablets permitted recording of data in the Superlab in the absence of paper.

Participant 3_1 indicated that having access to files in and out of the teaching laboratory helps integrate the teaching laboratory within their greater university learning experience.

Data security

Participant 1_3 indicated that a benefit of using the surface pro tablets is that their data is secure, and they cannot lose it.

Participant 3_3 indicated a different version of data security, in that data will not be lost if the tablets crash, due to the participant using OneDrive as a cloud storage solution that provides live saving.

Time saving or immediacy of access

Participant 3_1 indicated that the immediacy of access from data from instrumentation within the teaching laboratory is advantageous, and they indicated that previously they had used a memory stick to collect this data but now uses OneDrive which makes access to the data much more accessible to them.

Participant 3_7 indicated that access to the internet in the teaching laboratory enables them to research answers to things they are unsure of, which facilitates their understanding.

Participant 3_3 indicated that the presence of technology, particularly the tablets within the Superlab allows them to multitask during long waits in their experiments, where they take the opportunity to write up some of their assignments.

Experience of instrumentation

Participants 2_2 and 4_4 indicated that having experience of laboratory-specific technology such as instrumentation is important to their learning. Both participants linked this to knowing how to use the equipment, which participant 4_4 indicated would be applicable to their future careers.

Other impacts of technology

Participant 3_7 indicated that tablets are used as the primary source of displaying information in the Superlab, which in the absence of paper and the low usage of the television screens present, is the sole method of viewing information.

Participant 3_1 indicated that the tablets within the Superlab facilitate safe working in a Category 3 biocontainment area.

Participant 4_4 indicated that the presence of instrumentation within the teaching laboratory allows them to verify the correctness or quality of their product.

Participant 3_3 indicated that as the laboratory is a professional environment, it suppresses the likelihood of being distracted in an unprofessional manner, indicating that the technology in the teaching laboratory environment is used differently to that in their everyday life.

In response to a request for a definition of technology, Participant 3_3 focussed strongly on the Superlab environment. This participant indicated that they enjoyed using instrumentation and felt trusted to be permitted to use them at all levels of their course.

Discussion

The benefits identified by students of the technology in the teaching laboratory have elements in common with their definitions of technology, citing time saving and ease of use, particularly for the recall of data. These elements are reminiscent of *Seamless Learning* (Milrad et al., 2013) where students have access to their learning materials in a wide variety of contexts, over different platforms or formats. The students are citing that they can access their materials at home to prepare, in the teaching laboratory, and afterwards to complete any post-laboratory work. One student indicated that they could reflect on previous their previous teaching laboratory session notes to reassure themselves when using apparatus or instrumentation within their more recent teaching laboratory sessions. The themes of data recording, recall and immediacy of access all contribute towards this seamless learning model, allowing students to manage their own access to information at times both within and external to the Superlab.

Another strong positive theme arising within these interviews is the positive impact of the high level of analytical instrumentation the students have access to within their teaching laboratory experience. Students are appreciative of the access to the instrumentation and in previous questions, have cited that experience of the instrumentation is a strength that they plan to highlight in future job or placement interviews.

Participant 3_3's comment relating to using technology in a professional manner is particularly interesting, and highlights the difference between everyday use of technology, and competent professional use. This student is commenting on the differences in manner between casual use and higher order use of technology (Henderson et al., 2015) and is conscious of the difference between the two types of usage.

More broadly, students are again discussing the technology in the teaching laboratories in terms of function, which is consistent with the manner in which the students discuss the technology in their everyday lives in response to the prior question. The technology is viewed as a tool that is used to complete a task more easily or efficiently than would be possible otherwise. McOmber (1999) indicates that this stance towards technology as a tool, or the Instrumentality approach, holds that technology is neutral, and therefore can allow technology to exist alongside but separate to a culture, in this case the learning culture of the teaching laboratories and the broader university. The technology is seen to promote development of the culture, and as it is neutral and separate from the culture, this permits continuous development of systems to foster innovation.

4.4.11 The technology-enhanced teaching laboratory environment.

Students were asked to consider the different teaching laboratories that they had experienced throughout their course at NTU and answer the question "What impact do you think technology in the lab has on your learning?". For participant 4_4, the word "lab" was replaced with "Superlab" in this question.

Participant 3_6 was asked the questions in a slightly different manner as the interviewer asked three questions:

- Considering your time in labs at NTU, what types of technology have you used in your learning there?

- How do you think the presence or use of this technology effects your learning in the lab?
- Considering the Superlab and another labs, what impact do you think using technology in the lab has on your learning? So can you compare and contrast the two different environments?

Participant 3_6 listed several technologies in available the Superlab in response to the first question, identifying the tablets, earpiece and microphone system, overhead TV display screens and hotplates as technology within the labs. Answers to the two other questions are combined with the remaining themes in this section, as both questions relate to the impact of technology.

Participant 1_5 had not experienced teaching laboratory sessions within the Superlab and therefore felt unable to answer this question.

Comments were broadly positive, with students citing specific functions of the technology in the Superlab that have benefited them. Students also commented on the differences in manners of recording data between the Superlab and other teaching laboratories and indicated that the laboratory teaching fosters self-reliance in relation to the apparatus or instrumentation within the teaching laboratories.

Recording of data

Participant 3_1 indicated that an impact that the technology present in the Superlab has is to change the way they record their data, and they can access appropriate file formats to record their data.

Participant 3_6 indicated that they enjoy using the tablets due to the data storage capacity. This participant indicated that having one file that they access multiple times is preferable to multiple saved versions of the same file. This file would be accessed within and external to the Superlab.

Participant 2_2 indicated that the main difference is the lack of paper due to the containment procedures. This participant would much prefer to use paper due to personal preference, viewing paper as better than the tablets, and technical issues that prevent the saving of data on the tablets.

Participant 3_7 indicated that recording data is harder in the Superlab due to the number of steps involved in recording the data e.g. opening an app, typing the data.

Specific technology functions

Participant 2_2 indicated that having the tablets is an advantage due to the capacity to take photos and research on the devices.

Participant 3_6 has similar comments on the tablets, indicating that they use the camera to record colour changes for posterity, and the internet to search answers to simple questions that they cannot recall the answer to, such as converting a unit.

Participant 3_6 indicated that the TV screen system is beneficial to them as it means they do not need to switch between documents on their tablet. The earpiece system was described as not being used often within this student’s teaching laboratory sessions due to the small-group method of teaching used; however, it was indicated that these would perhaps be more useful in a different laboratory. [Author’s note] The upstairs analytical or wet chemistry teaching laboratory has parallel benches with raised shelves that reach about 1.7m tall with equipment, gas taps and electrical sockets throughout the benches. The participant also noted that the upstairs teaching laboratory is quite loud, and it is difficult to hear staff members, so earpieces would be beneficial in this environment.

Self-reliance

Two students indicated that working in the Superlab can improve their self-reliance.

Participant 3_1 indicated that having access to supporting materials within the Superlab via cloud storage on the tablets helps them feel reassured that they are following best practice and improves their practical outcomes. This student indicates that they can access videos provided on appropriate apparatus use but also indicates that they make detailed notes when a staff member demonstrates a technique and when they re-visit the technique in the teaching laboratory, perhaps with less detailed instructions, they review their previous notes to reaffirm best practice.

Participant 3_3 indicated that working in the teaching laboratories at NTU generally fosters their independence, this is not specific to the Superlab but does encompass it.

Other comments

Participant 3_7 indicated that the presence of instrumentation that is not available elsewhere in the university is seen as a positive and counterbalances any negative experience from using the tablets being slower.

Participant 4_4 indicated that the level of technology in the Superlab and other teaching laboratories at NTU is consistent, except for the instrumentation present in the instrumentation laboratory near the Superlab. [Author's Note] Tablets matching the ones used within the Superlab were introduced into other chemistry teaching laboratories across NTU in approximately 2019, however paper was available to students in the non-Superlab environments as well as the tablets.

Participant 3_3 focused on the benefits of using instrumentation within the instrumentation laboratory near the Superlab, indicating that they think it is beneficial to be entrusted with these instruments and that this fosters instrument-specific skill development.

Participant 2_2 indicated that broader technological issues such as installation failures, incompatible file formats and battery issues were a negative impact of the tablets within the Superlab.

Discussion

Online participants discussed the technology in the laboratory much more extensively than the participants in the in-person interviews, possibly in part due to the greater context gained with the additional technology questions in the online interviews. As such, themes have arisen more readily, however, there is still a wide degree of variation between the student responses, with only three themes arising from the data:

- accessing data,
- the benefit of specific technological functions,
- self-reliance.

The students in the online interviews are generally more positive about the tablets than the in-person student group were, identifying several benefits of the tablets within the teaching laboratory. Participant 4_4 even indicates that the Superlab is on a level technologically with other laboratories at NTU, suggesting that the technology in the environment may no longer be novel to the students at higher levels, given their prior years of experience using the environment.

Accessing data was mentioned in the first interviews, with participant 2_02 indicating that having cloud storage allowed for seamless access both within and external to the teaching laboratory, and this would now be included in the Accessing Data theme.

Two in-person participants 2_02 and 2_07 referenced specific functions of the tablet that they find useful to their learning experiences within the Superlab, which would now be included in the "specific functions" theme. As they were not referencing similar functions, this was not previously grouped into a theme, as they referenced accessing files on cloud storage and using Excel as a calculator or using Google to research respectively, which were deemed to be separate concepts at the time of the first interviews. As two participants referenced the same tablet function, using the camera to take pictures of their experiments, the commonality in the online interviews was more readily grouped into a theme. The focus on functionality is consistent with the way students have discussed technology in their wider experiences, and is again consistent with an instrumentality approach McOmber (1999) where students are viewing the tablets within the Superlab as a tool.

The discussion of the in-person interviews raised a broad commonality that students were preparing for the Superlab in a slightly different manner, with students citing that they avoid typing on the tablets and prefer hand-writing. These comments were less prevalent in the online interviews, with some brief references to slow operation, such as that by participant 3_7, however students were generally less critical of the Superlab experience, with only one participant citing difficulties faced within the Superlab consistent with Selwyn's (2016) Difficulty category of negative attitudes to technology.

One possible explanation of this would be familiarity or prior experience. In the in-person student interviews, the students may have experienced both the "old Samsung" and the "new Lenovo" systems, and in some cases, may have experienced paper-based teaching laboratories elsewhere on campus. In the years between the two sets of interviews, tablets were introduced in both the upstairs analytical teaching laboratory and another teaching laboratory building, ISTeC. Indeed, one participant 4_4, indicated that the technology levels available in different buildings and teaching laboratories is consistent, which is certainly different from the experiences of the in-person interviews, where participants did cite that they preferred using paper, and therefore must have had experience of it in a teaching laboratory setting. Prior experience or exposure to a phenomenon such as technology can increase the acceptance of that technology (Holzinger et al., 2011), and perhaps the consistent implementation of technology across the various NTU teaching laboratories has mitigated some of the negative attitudes. In addition to this, this author notes that there was a concerted effort on the part of the digital technology colleagues at NTU to resolve the issues such as slow operation and inconsistency of experience within the Superlab specifically and that these issues may well have been less prevalent by the time of the online interviews. It is noted that some of the issues cited by the students interviewed in person such as uncharged batteries, and slow WiFi connections were likely compounded by the number of students present in the teaching laboratory straining the available infrastructure. As such, the social distancing measures of smaller laboratory classes may have contributed to the online participants reporting fewer of these issues.

4.5 Outcomes of interviews – discussion

4.5.1 Comparison of staff and student responses

The purpose of the laboratory

The identified purposes of the teaching laboratory are quite consistent between staff and between in-person student interviews, however there is some disparity between the first and second group of student interviews (table 53) The strong emphasis on practical skills is a new theme has occurred of hands-on experience, which was related by some participants to future careers.

Staff participants suggest that students put a higher emphasis on practical skills than understanding, which is reflected in the student's responses with a high degree of emphasis and discussion of practical skills and hands-on experience. However, student responses do also indicate that with most students suggesting that at least some of the purpose of the teaching laboratory is to develop understanding.

A particular challenge of the question of the purpose of the laboratory is that the aims of the laboratory may vary throughout the years. Research into staff aims substantiate this change in aims for different level students (Bruck & Towns, 2013) (Connor et al., 2023), but the approach undertaken within this study of comparing students and staff working in the same environment appears to be novel and not yet represented in literature.

Student aims of the laboratory

The aims of the laboratory have resulted in some interesting variation between student groups, with the online student interview group having discussed an aim to develop understanding of theory or practice within the teaching laboratory, which was absent in the in-person interviews. The in-person interviews are closer to the staff-perceived student aims, while the online interviews are more reminiscent of the staff aims. It is unclear if this is an impact of the format of the interview, with the students being interviewed in the Superlab focusing more on the practical outcomes, or if this is a true shift in attitudes. This disparity is shown in table 54, where there is a clear difference between the two student groups.

Learning in the laboratory

The learning undertaken in the laboratory are broadly similar across all three interview groups, with understanding and practical skills being identified by all groups as happening within the teaching laboratory, although in response to different questions. Staff members identify the importance of the scientific method, while students in the in-person interview group identified the importance of developing independence in the teaching laboratory. It is possible that the in-person interviews with students have less emphasis on understanding happening within the teaching laboratory because the students are focusing exclusively on the learning happening within the teaching laboratory, while some of the participants in the online interviews have indicated that some of the learning associated with the teaching laboratory occurs after the session. Research suggests that the style of laboratory can affect student perception of conceptual development (Domin, 2007), which may account for the variety in the ways students have identified learning in the laboratory.

Motivation in the laboratory

When considering the student responses in comparison to staff perceptions of student motivating factors, the staff correctly identified that obtaining the practical outcome, completion and quality related motivations are highly represented within both cohorts of interviewees. However, the student identified theme of stress or anxiety is less prevalent in the staff responses, with only one staff member mentioning student stress within the teaching laboratory while four students in the online interviews and one student in the in-person interviews directly mentioned managing stress, avoiding embarrassment or other similar negative emotions as motivators behind their decisions and actions in the teaching laboratory.

Table 53: Comparison of the purpose of the laboratory across all interviews

Purpose of the teaching laboratory			Develop understanding	Practical skills	Laboratory skills	Transferable skills	Familiarity with laboratory	Practical outcome focus	Hands on experience
Staff purpose	Staff purpose	S2	■	■					
		S4	■	■			■		
		S5	■						
		S6	■	■			■		
		S7	■	■					
	Perceived student purpose	S2		■	■			■	
		S4	■		■				
		S5	■	■					
		S6		■				■	
		S7	■	■	■				
Students	Students - in person	1_12	■	■		■			
		2_01	■	■		■			
		2_02	■	■		■			
		2_07	■	■					
		2_11		■			■		
		3_19	■	■			■		
		3_21	■	■					
		4_01	■	■					
	Students - online	3_1		■	■				■
		2_2		■					■
		3_3	■						■
		4_4	■						
		1_5		■					
		3_6	■						■
		3_7	■						■

Table 54:Comparison of aims between different interview participants.

Aims of the teaching laboratory			Develop understanding	Scientific method	Practical skills	Other skills	Behaviours	Practical outcome	Assessment focus	Time efficiency	Stress management	Preparation	Hands on experience
Staff	Staff aims	S2	■	■			■						
		S4	■		■		■						
		S5	■				■	■					
		S6			■		■	■					
		S7		■	■								
	Perceived student aims	S2						■					
		S4											
		S5							■				
		S6						■					
		S7							■				
Students	Students - in person	1_12						■	■		■	■	
		2_01						■ "finish"		■	■		
		2_02						■	■	■			
		2_07						■	■ not main aim	■		■	
		2_11						■				■	
		3_19						■	■		■		
		3_21						■		■			
		4_01						■	■	■			
	Students - online	3_1	■					■					
		2_2	■									■	■
		3_3	■					■					
		4_4						■					
		1_5	■					■				■	
		3_6						■					■
		3_7	■					■					

4.5.2 Themes arising from student and staff interviews

Throughout the responses, several themes appeared repeatedly, and this will be discussed below.

Purpose of the teaching laboratory – Practical Outcomes

Student participants have indicated that they are often focussing on practical outcomes within the teaching laboratory, whether that be producing the correct data set or an appropriate product, with references to correctness and finishing the experiment throughout student participant responses. The extent of this practical-outcomes focus is detailed in the following tables.

Table 55: Summary of participant references to completing the experiment, obtaining a practical outcome, or product quality from the in-person student interviews.

In-Person Student Interviews		
Participant	**Location of comments**	**Summary**
2_01	4.3.3 – Practical outcomes and Time efficiency	Concern regarding finishing the experiment
3_21 1_12	4.3.3 – Practical outcomes	Practical outcomes are the aim of the session
3_19, 1_12, 2_07, 2_11	4.3.3 – Practical outcomes	High quality products or practical outcomes
4_01, 2_02, 3_19, 1_12	4.3.3 – Practical outcomes linked to assessments	Grades in assessment linked to the quality of practical outcomes.
2_07	4.3.4 – Best operational practice	Using equipment effectively to obtain high quality results
2_02 and 2_11	4.3.4 – Purification and critique	Purification to improve product quality
4_02	4.3.4 – Purification and critique	Critique of product quality.
1_12	4.3.5 – Practical outcomes-motivated	Desire for good results related to quality product and grades.
4_01	4.3.5 – Practical outcomes-motivated	Quality of product is linked to grades, and higher grades are desired.
2_11	4.3.5 – Practical outcomes-motivated	Peer comparison of product quality.
4_01, 2_07, 3_21, 2_02	4.3.7 – Practical outcomes	Comparing practical outcomes to literature or provided resources
1_12	4.3.7 – Practical outcomes	Unexpected results viewed as undesirable Success tied to correct outcome.
2_11	4.3.7 – Practical outcomes	Confirmatory testing to ensure correct product has been obtained.
1_12, 2_07, 3_19, 3_21	4.3.7 – Peer comparison	Peer comparison of product quality
2_11, 2_02	4.3.7 – Peer comparison	References to errors and incorrect outcomes.
1_12, 4_01	4.3.7 – Staff feedback	Staff confirm the correct practical outcome.

Table 56: Summary of participant references to completing the experiment, obtaining a practical outcome, or product quality from the online student interviews.

Online Student Interviews		
Participant	**Location of comments**	**Summary**
3_1, 3_3, 3_7, 4_4, 3_6, 1_5,	4.4.3 – Practical outcome focussed	Comments relating to finish the laboratory, obtaining the practical outcome (data or product)
3_1. 4_4, 3_3	4.4.5 – Completion and quality	High quality, precise or complete results
3_3, 3_7	4.4.5 – Grade or assessment	Appropriate practical outcome is tied to assessment.
3_6	4.4.6 – Achievement of aims	Meet staff set objectives, produce the product.
3_3, 3_7	4.4.6 – Achievement of aims	Completing the experiment.
3_1, 3_7 , 4_4	4.4.6 – Correctness	References to nothing going wrong or having done the right thing.
3_3	4.4.6 – Correctness	Quality of product linked to correctness.
3_3, 4_4	4.4.6 – Verification of product	Verification of the right product and correctness.
4_4	4.4.6 – Staff feedback	Praise for high quality product.

Although this does not preclude conceptual learning within the teaching laboratory, three students (3_21, 2_02 and 2_07) have indicated that when in the teaching laboratory, they are focussing more on what they are doing, rather than thinking about why they are undertaking actions during the teaching laboratory, which is in contrast with the desired outcomes of the teaching staff that were interviewed.

The approach to the teaching laboratory that some the student participants indicated in their interviews resembles an "achieving" approach by students where they value grade related outcomes and efficiency of effort, as described in Biggs & Moore (1993). This approach may not be setting them up for success in terms of cognitive development while in the teaching laboratory. But what can be done for these students to support them in overcoming their current approach to the teaching laboratory and fostering a more deep-learning approach?

Purpose of the teaching laboratory- Cognitive Development

All staff members have indicated that there are a wide variety of skills gained from, implemented and required for operating successfully within the teaching laboratory, with five staff participants indicating a development over time as students gain more experience in the teaching laboratory (table 57).

Table 57: Summary of staff participant references to developing levels of operation and student ability within the teaching laboratory setting.

Participant	Summary
Staff – S6	Participant S6 indicated the purpose of the teaching laboratory develops over time, with more scaffolding in earlier years and more independence in later years. This participant indicated that at lower levels of study the purpose of the teaching laboratory has more emphasis on safety, with different styles of learning at higher levels with more choice. S6 identified that their aims of the teaching laboratory for first year students is to learn a range of basic techniques, and at higher levels they will be learning more specialist techniques and improve their execution of basic skills. This participant gave an example of a calculation in this, so "skills" could encompass laboratory-related skills rather than just practical/manipulative skills. S6 indicated safety was a key aim of the teaching laboratory in the early years of study, and that their way of teaching is more strict on safety elements for first year students. S6 indicated that they aim for first year students to develop appropriate behaviours within the teaching laboratory session, and that these appropriate behaviours are built with levels of complexity in higher years. The appropriate behaviours learnt early allows the participant to undertake a less scaffolded teaching approach in higher years with a greater degree of student choice for techniques to pursue in experiments.
Staff – S7	S7 indicated that the purpose of the teaching laboratory is for students do develop skills commensurate with their level of study, particularly that if some skills were not learnt by a certain level, that this would be unusual. This participant did indicate that producing a definitive list of required skills would be challenging.
Staff – S2	S6 indicated that they have different aims for students at different levels, emphasising practical skills and accurate precise working with first year students as well as data recording skills. At higher levels, this staff member requires a greater degree of analysis from the students, as well as different processing levels. This participant specifically referenced that higher level students would employ higher order skills in Bloom's taxonomy.
Staff – S5	S5 indicated that an aim of the teaching laboratory is to obtain the correct practical outcome, however the emphasis on the outcome is lessened in later years of study, as experiments may be undertaken in a less optimal manner. The participant indicated that early sessions were intended to foster confidence.
Staff – S4	S4 reflected on what a successful teaching laboratory course would look like, and that at the end of a set of teaching laboratory sessions, a student should have developed the ability to evaluate their own data. This participant qualified that a laboratory course would extend over a longer period of time, not just one session.

Six students have additionally identified that there are differing levels of outcome within the teaching laboratory, recognising that their approach and understanding has changed throughout the years (table 58)

Table 58: Summary of student participant references to developing levels of operation and student ability within the teaching laboratory setting.

Participant	Summary
Student Participants – In Person	
2_11	2_11 indicated that the purpose of the first year of their degree was mostly to develop standalone skills, while in their second year, they have built these techniques into experiments.
3_19	3_19 indicated that they noticed a difference in the purpose and staff aims between taught module teaching laboratory sessions and the teaching laboratory sessions related to their projects. The taught module laboratory sessions were deemed to be more scaffolded and designed to teach appropriate behaviour and facilitate comfort in the teaching laboratory environment, while project laboratory sessions were described as problem solving. These aims of the teaching laboratory were reiterated by this participant when considering the aims that staff members may have for them. This participant indicated that from working in the teaching laboratory environment, they have learned independence over the course of their studies which has helped them in making their own decisions during experiments.
4_01	4_01 indicated that theory was more ingrained in the purpose of the teaching laboratory at higher levels, with content being more consistently or clearly linked to their lecture materials. This participant stated that higher levels required more independent learning and that they had been required to design more experiments than in previous years of their study. This participant also indicated that they have learnt to be more independent throughout their studies, as initially they worked with a laboratory partner, and in later years of study they work in the teaching laboratory on their own work.
Student Participants - Online	
3_1	3_1 cited that the a purpose of the teaching laboratory is to develop confidence and skills, and noted that they had developed many skills through their analytical chemistry teaching laboratory studies.
3_3	3_3 provided an example when asked what they learn in the teaching laboratory. The example showed where they had initially learnt individual techniques, and by the end of the course these techniques built into a full experiment.
3_7	3_7 indicated that staff aims likely change over the years. This participant indicated that staff aim for students in higher years to be independent, and that there is a fine balance between being supported and having the freedom to learn.

This variation in purpose and learning is supported by the Subject Benchmark Statement for Chemistry (QAA 2022) section 1.8, which indicates that the instructional style (Domin 1999) may evolve throughout the duration of a course, with problem solving skills more prevalent in higher years of study. There is a striking similarity between the development of skills employed within the teaching laboratory as described by the staff, and the hierarchical levels as identified in Bloom's taxonomy (duplicated as fig 117).

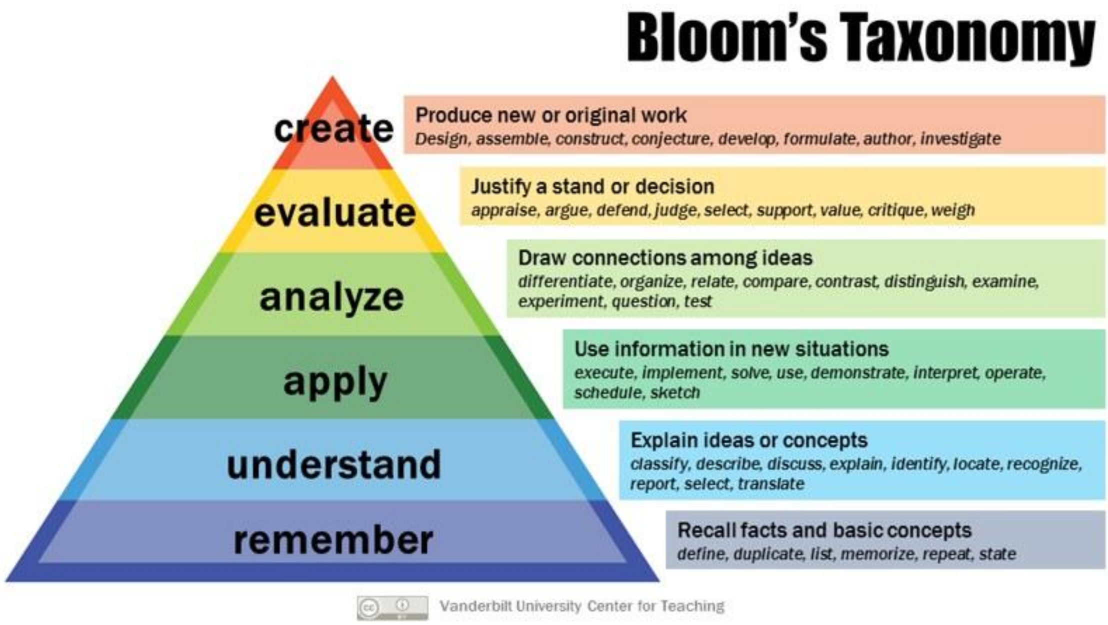

Figure 117: Bloom's Taxonomy reproduced under creative commons license (Vandy CFT, Creative Commons image).

To assist students in reflecting on their own learning and develop metacognitive skills in relation to the teaching laboratory, it may be beneficial to align the learning obtained within the teaching laboratory environment with the different levels of the taxonomy. It appears that this may have been attempted previously, using the standard revised Bloom's taxonomy with some success (dos Santos Veiga et al. 2022), however the full conference proceedings and accompanying paper of this study have been unobtainable.

By reviewing the Subject Benchmark Statement for Chemistry (QAA 2022), it has been possible to align the laboratory-specific elements identified in the Benchmark Statement to the different levels of the taxonomy (fig 118). This figure is intended to be illustrative rather than exhaustive, as there are several elements of subject knowledge that could be taught in the teaching laboratory, that are also able to be taught in another environment, for example data analysis, and this is dependent on course design.

Create	Plan out original investigations. Design experimental activities to test hypotheses. Design purification, isolation and characterisation methods. Design and develop sample preparation methods.
Evaluate	Predict the outcome of syntheses. Report the significance of experiments. Explain the limitations of classical and instrumental analytical techniques.
Analyse	Assess outcomes of experiments. Apply methods of waste reduction in practical activities.
Apply	Undertake creative problem-solving in relation to experiments that have not generated the expected results. Undertake knowledge-based risk assessments.
Understand	Behave in a safe and accurate manner in the teaching laboratory environment and enacting safe working practices. Undertake practical techniques with a degree of competency. Explain purification, isolation and characterisation methods.
Remember	Develop the necessary practical skills for a career in science. Use appropriate waste disposal techniques. Deploy purification, isolation and characterisation methods. Carry out sample preparation methods. Undertake practical analyses and measurement, communicating outcomes using appropriate terminology or notation.

Figure 118: Proposed taxonomic levels of operation within the teaching laboratory environment, adapted from Bloom's Taxonomy and benchmark documentation.

The taxonomic levels in the proposed laboratory environment taxonomy should not be viewed as strict and discrete categories, as some elements of laboratory learning may encompass more than one level of learning. By way of example, "Behaving in a safe and accurate manner" could be a level 1 activity, with students remembering and copying a behaviour without reflecting on why they are required to behave that way. However, over the duration of a laboratory course, behaving in a safe and accurate manner will require some understanding as the student is exposed to an increased variety of reagents and equipment that they may have less familiarity or guidance with, as such this is included at the higher level of "Understanding".

Additionally, as is the case with Bloom's Taxonomy, students do not abandon previous levels of learning when they develop higher skills within the hierarchy. Students will continue to use all available levels of the hierarchy throughout their laboratory studies and career, as new equipment and reagents are continually presented to them, however as a student develops cognitively, they are more readily able to move between the different levels and employ the higher order thinking skills.

The documented desire of employers for students to employ higher order skills (Coll and Zegwaard 2006; Overton and Hanson 2010), and the documented challenge in encouraging students to do so in the teaching laboratory environment (George-Williams et al. 2018; Venkatachelam and Rudolph 1974) is reiterated in this study by staff participants indicating that they scaffold in time for students to think and prompt their students to employ more cognitively demanding higher order skills such as critical thinking and reflection. Additionally, some student participants are indicating that they are only focussing on the lower order skills of operating within the teaching laboratory and leave the higher order thinking that requires more cognitive resource until after the teaching laboratory session.

A laboratory specific taxonomy of cognitive development could be a useful for staff members in curriculum design, and for students in skill reflection and recognising development.

Preparation

Preparation for the teaching laboratory was discussed by all three interview groups. Participants S6 and S4 indicated that they require their students to undertake preparatory activities to scaffold them for success within the teaching laboratory.

In the in-person interview group six participants mentioned preparation during their interviews, with some students referencing preparation more than once. Two students cited preparation as an aim for the teaching laboratory, suggesting that it is important to them. A range of preparatory activities were identified by the students, however the most common was to read the laboratory script or documentation which is a more passive activity.

In the online interview group, six out of seven participants referenced preparation within the discussion of actions that they undertake to achieve success, suggesting that students understand that preparation for the teaching laboratory is important. Again, reading the laboratory script or documentation is the most common preparatory activity, but what is less clear is the depth with which these students are reading the document, with participant 3_3 seeming to indicate that they skim-read the document and only read in more depth if a technique is unfamiliar.

Further investigation into student preparation for the teaching laboratory is warranted, as it is an element of the laboratory experience that staff have little opportunity to observe. Students are indicating that they are preparing, however this is in contrast with the prevalent literature suggesting that students often enter the teaching laboratory underprepared (Moffatt, 1994). A possible explanation is that a selection bias has resulted in only motivated students have participated in these interviews, skewing the apparent preparedness of the students. Alternatively, the preparation that students are undertaking may not be scaffolding their learning and instead supporting a more outcomes-focused approach often described as cooking or cookbook chemistry (Bertram et al., 2014), (Gallet, 1998), (Venkatachelam & Rudolph, 1974).

Peer influence

Peer influence has been discussed by two staff participants and 4 student participants in the in-person interviews. Students described comparing themselves to their peers, measuring how effective they had been in the teaching laboratory by comparing the speed and quality of their work to others in their class. The staff comments from participants S4 and S6 on peer influence as student motivation reflect this, with participant S6 indicating that students can experience negative emotions within the teaching laboratory due to this comparison.

Students have also indicated that they obtain support from their peers, which is reflected in comments from participant S2 on students seeking support from their peers, and also where participant S6 indicated that misconceptions can propagate from student to student, suggesting that students are sharing information, albeit incorrect information, within the teaching laboratory as a form of peer support.

Stress

It is important to note that the researcher was a working academic within the Chemistry team at Nottingham Trent University prior to these interviews and is open about having a disability. This may have resulted in students being more open about discussing mental health or disability related concepts than they would with a different researcher.

Participant S6 indicated that they think that the students can panic within the teaching laboratory and that the Superlab is an intimidating environment.

In the in-person interviews two participants directly stated that they experienced anxiety or stress within the teaching laboratory and that managing this stress and remaining calm is an aim for them, and another student made humorous remarks suggesting that students can feel panic within the teaching laboratory. An additional student who stated that they have an anxiety disorder, indicated that the teaching laboratory does increase their levels of anxiety, however they indicated that all experiences in university increase their anxiety levels and therefore this cannot be attributed directly to laboratory related anxiety.

In the online interviews, four participants cited that anxiety or stress are a motivating factor for them when making decisions, and two students indicated that managing stress or remaining calm is an aim for them within the teaching laboratory. This is a marked increase in the number of students reporting stress relating to the teaching laboratory. In such small numbers of interviews, it would be over-reaching to suggest an increase in the stress levels of students, however given that stress has been cited by so many participants across both cohorts of interviews, it bears further investigation. Stress assessment tools have been developed (Lesage et al., 2012) (Denovan et al., 2019) and could possibly be implemented in the teaching laboratory to assess student stress levels. It would however be important to risk assess this prior to implementation to avoid subjecting stressed students to more stress by requiring them to complete additional tasks.

Miller and Lang (2016) suggest a variety of design approaches to reduce stress within the teaching laboratory, including the implementation of technology to improve accessibility for students with disabilities.

Impact of technology on student learning in the teaching laboratory

These interviews were an opportunity for students to identify the impact of technology on their learning in the teaching laboratory. Students did identify some advantages and some challenges; however, the impact is often identified as occurring on students' operation in the teaching laboratory rather than their learning. Relying on what a participant chose to not talk about is not ideal for drawing conclusions, but omission can be an indicator of an absence of a phenomenon - it is possible that these students have not identified a substantial impact on their learning from the presence of technology in the teaching laboratory precisely because they do not perceive a substantial impact.

In an interview situated in the technology enhanced Superlab, or online with specific strands of questioning relating to technology, students much more strongly emphasise the laboratory component of the environment and staff and peer interactions as having an impact on their learning. It is important to note that these students are unlikely to have experienced traditional paper-based laboratories, having had most of their laboratory experiences within the Superlab, or in other teaching laboratories at NTU with tablets available.

This is supported by staff comments that indicate the challenges of students engaging within the teaching laboratory and literature that indicate that the teaching laboratory is already a complex learning environment. Staff members have noted that there are elements of impact on the student learning experience, and the difference in stances is important to investigate further in the future.

5. Contributions to knowledge and further work

5.1 Contribution to knowledge

5.1.1 Development of methodology and tools

This study has involved the development of a novel tool for measuring the digital usage of technology by undergraduate students that can be implemented large-scale to represent student's usage. The design of this tool is such that it can be updated with new technologies as they emerge, allowing it to remain relevant in relation to current practice.

This study also allowed for the implementation of the SLEI in a context it has not previously been implemented, a technology enhanced interdisciplinary teaching laboratory in higher education. This data shows that there is a statistically significant difference between two scales used within this tool for the different levels of study investigated, with data indicating a difference in the actual experiences of students' use of technology and integration of their teaching laboratory experiences in first and final years. New students in year 1 indicated a higher level of use of technology in their teaching laboratory studies, and a higher level of integration between their studies within and external to the teaching laboratory environment, however this tool does not allow for investigation into the cause of this difference.

The approach to investigating the purpose, aims and motivations of students within the teaching laboratory and the staff counterparts is novel. Typically, research is undertaken either with staff or students, and the researcher has been unable to locate any examples of staff and students from the same institution in a similar timeframe being investigated to allow for cross-comparison as is presented in this study.

5.1.2 Technology Enhanced Teaching Laboratory

This study shines a spotlight on the technology enhanced teaching laboratory environment, identifying that it is indeed a challenging environment for students to learn in. However, statements from staff and students appear to indicate that the impact of the use of technology is minimal and typically mitigated by student actions, and the challenges arise from time pressures, and the inherent complexity of the teaching laboratory environment as an environment. Although the introduction of the technology may lead to an increase in cognitive load, the students are already managing high cognitive load tasks and perhaps do not perceive an addition to this load in the form of technology. The challenges to learning appear to be more linked to the nature of the laboratory, rather than the addition of technology enhancements, which is consistent with current research indicating that the teaching laboratory is a complex place, both for staff and students, and requires careful consideration and design (Seery et al. 2024).

Effective familiarization sessions, swift resolution of technical problems and further development of the technology present within the Superlab is recommended to allow staff members to take full advantage of the technology without having to compromise their personal teaching philosophies and aims. A particular development that staff would view as beneficial is the introduction of an appropriate Electronic Laboratory Notebook system to overcome the challenges relating to data recording.

5.1.3 Pre-laboratory preparation

Carnduff and Reid (2003) undertook a review of pre-laboratory exercises in the Higher Education sector, highlighting a wide variety of exercises undertaken by students prior to entering the teaching laboratory environment that were asserted to support learning within the teaching laboratory by reducing the cognitive load that learners experience (Reid and Shah 2007) in the complex learning environment of the teaching laboratory (Seery et al. 2019). Pre-laboratory exercises have been advocated as a way of improving preparation of students (Rollnick et al. 2001) with students actively using learning materials provided in a time-linked or “just-in-time” manner in relation to the laboratory both before and after the laboratory to manage their cognitive load while working within the teaching laboratory (Agustian and Seery 2017)

Reid and Shah note, in particular, that the development of technology within teaching has provided the capacity for variety and development within the realm of pre-laboratory exercises. To further explore this, a study was undertaken by this author in collaboration with co-researchers to examine the pre-laboratory practice in the Higher Education STEM sector more widely (Rayment et al. 2022). This study explored the type of pre-laboratory exercises being undertaken across 30 UK HE institutions, covering 88 modules. The study identified a very wide range of activities designed by staff for pre-laboratory provision and barriers to the uptake and implementation of pre-laboratory exercises (Appendix 7). The types of exercises undertaken within Bioscience based courses varied by level, whereas Chemistry based courses were more likely to undertake more fewer types exercises such as reading the provided experimental protocol or undertake calculations.

In a similar way, technology has facilitated the development of flipped learning, a decentralised learning model where students take ownership of their own learning through the inversion of the dissemination of information (Seery 2015). Flipped learning (also termed the flipped classroom model) has been developed over the last two decades and is well described in the literature (Bishop and Verleger 2013; Eppard and Rochdi 2017) and has been documented to reduce the cognitive load in students studying an engineering course (Karaca and Ocak 2017).

Given the same pedagogic basis and structure of preparing learners for a learning experience with a preparatory exercise, and decentralising learning from the formal university environment, it is reasonable to categorise Pre-laboratory exercises as a type of flipped learning. Accepting that pre-laboratory exercises are a laboratory-based flipped learning exercise, a flipped learning framework such as that proposed by (Eppard and Rochdi 2017) to develop pre-laboratory exercises would assist students in using the teaching laboratory to facilitate their learning more effectively.

Pre-laboratory exercises and flipped learning have both been illustrated to be methods of engaging learners, decreasing cognitive load and they should be regarded a method of managing cognitive load in a complex learning environment such as the technology enhanced learning laboratory.

A particular comment from a student highlights the importance of laboratory instruction as a contextual phenomenon. Participant 1_5 in the online interviews indicated that sometimes an instruction can be viewed prior to the teaching laboratory session and not make much sense, but undertaking the action in the experiment provides context and makes sense of the instructions. This should be considered when developing both pre-laboratory and laboratory instructional materials.

5.1.4 Implications for practitioners

A. Pre-laboratory preparation

Students are often overloaded in the laboratory, to set them up for success, prepare them for the laboratory environment. A pre-laboratory exercise is advisable and can take many forms. The aim of this exercise should be to prepare the student for the experiment they are doing by familiarising them with the aim of the experiment, and any new equipment they are likely to be using.

This pre-laboratory exercise can take many forms, as dictated by the learning needs of the students and the content of the material. As for flipped learning, it is possible that this learning can be required, and failure to complete can delay starting their experiments. Students should be reminded that this exercise is for their benefit and will assist them in entering the laboratory effectively. The pre-laboratory exercise is a scaffold to the later scientific method used by researchers, where a researcher will explore relevant literature and methods before entering the laboratory to undertake an experiment. Pre-laboratory exercises can cover a variety of concepts; however, it is important that they do link clearly to the laboratory content of the related session. This preparation could also help to reduce anxiety, highlight potentially inaccessible situations allowing students to request support (e.g. colour-blind students and colour changes) and increase confidence as they start to recognise familiar elements in the laboratory.

B. Instructional materials

At the earliest levels of study, streamline instructional documentation – ensure that the students can easily find the different steps of the physical process of the experiment either through clear formatting or separation of theory and directions to mitigate the likelihood of cognitive overload.

Ensure that instructions are clear at lower levels and avoid jargon where possible. Providing a reference chart of different pieces of equipment or a glossary of terms (Royal Society of Chemistry (RSC) 2016) may be beneficial to students who have less experience in a laboratory setting than their peers and would overcome the embarrassment that some students have expressed regarding asking for help with questions perceived as too simple.

At lower levels, ensure that students do not succumb to time pressure, and understand that a null result or a failed experiment is still a result. Students have regularly expressed that there is a concern that they will not finish the experiment in time and that impacts negatively on their ability to take time to learn.

Instructional materials for the teaching laboratory exist within the context of the teaching laboratory, providing materials in a just-in-time manner may assist students in understanding the context for the instructions they are provided with.

C. Reflection and critical thinking

Encouraging thought and reflection by building in time for this, which can take many forms. Examples from staff and student interviews are included below.

- Staff prompting thought by questioning
- Whole class or small group discussion opportunities such as the example given in the interviews of peer comparison of products at the end of the experiment, and discussion regarding the differences.
- Planned self-reflective time-periods during down-time in the experimental process, prompted by questions in the laboratory instructions. An example would be "While your solution is under reflux, consider the following question: What would happen if this reflux was undertaken at a lower temperature?"

Additionally, it would be possible to encourage reflection outside the laboratory using a well-designed post-laboratory activity with reflection prompts.

Literature suggests that this reflection is something students struggle with or even actively avoid, and that is reinforced by the statements made in the interviews in this study. As such, it is critical that educators reinforce this crucial developmental activity with students.

D. Student skill recognition

When in the laboratory, students appear to often focus on a single laboratory session. This can result in students either failing to appreciate or articulate the broader non-technical skills they develop throughout the course, which are highly desired by employers (HE Professional Team 2023). It is important to remind students that the laboratory does not only foster physical laboratory technique, but also a much wider variety of skills, and encouraging students to reflect on their skill development at various points throughout their course would be an ideal way of doing this. Possible methods include:

- A skills portfolio (Bhattacharya and Hartnett 2007) can be used to prompt critical reflection of development throughout a module or course.
- Skills competency checklists or assessments can be effective for highlighting technical skills and fostering confidence (Wright et al. 2018), (Sánchez Carracedo et al. 2018) as well as evidence for future employability. However, checklists can have drawbacks as they may omit some best practices, for example McKinley et al. (2008) indicate that in a medical setting, an audit of checklists often omitted infection control or safety elements, which would be concerning in a laboratory setting.
- Students could be required to reflect on their skills at periods throughout their course in comparison to a graduate skills framework. (Swingler et al. 2019)
- Explicit links between teaching and assessment materials to benchmark statements and accreditation documents from governing bodies. (QAA 2022) (Royal Society of Chemistry 2022).

These methods would work towards ensuring that the students view the laboratory as situated within their course as well as valuable for all students, even those who no longer intend to pursue a chemistry-based career after Higher Education studies conclude.

To support students in identifying these skills, it may be suitable to employ a curriculum review to identify where these skills are taught as learning objectives within the laboratory courses. This could also reduce allow the exploration of less product-focussed teaching styles to reduce the cookbook chemistry style student focus on “making the product”.

E. Introduction of technology

When introducing technology into an environment, it is important to understand that the technology is being introduced into a context. Although students may already be using technology extensively, they may not be using it in a manner that is appropriate to support their learning or appropriate for the environment. To ensure digital skills equality and reduce the likelihood of negative impact on learning, it is important to implement technology following good practice guidelines (Stringer et al. 2019) (Scott et al. 2017), summarized below.

- Introduce technology to solve an identified need, led by pedagogy and learning outcomes.
- Provide guidance regarding how technology is to be used in context.
- Provide basic training on all required elements of operation.
- Provide troubleshooting guides for when technology fails.
- Have redundancy plans in place for common technological failures.

5.2 Further work

Further development of the Digital History Survey is recommended that would broaden the scope, potentially including self-assessed digital literacy. It would be useful to compare the self-assessed digital usage through the Digital History Survey to an observed activity to validate the level of digital usage or skill that the students are indicating to ensure the tool is sufficiently robust before further implementation.

A practice-based study of the implementation of the laboratory learning taxonomy would allow further investigation of student’s cognitive gains in the teaching laboratory. Given the achieving style of approach detailed by many students aligning with their outcomes-focussed actions in the teaching laboratory, it would be interesting if this could be paired with investigation into students’ approach to the laboratory in relation to Biggs’ and Moore’s categories of approach to learning(1993).

Investigation into pre-laboratory preparation undertaken by students is a key avenue for research relating to the teaching laboratory, as literature indicates that familiarity is key for reducing cognitive load, and the teaching laboratory regardless of the presence of technology is a complex learning environment with high cognitive load tasks. This research could be challenging as preparation is often undertaken away from institution-controlled environments; however, an online platform would be capable of tracking usage and engagement, and students could identify the types of tasks undertaken during their preparatory periods. A study encompassing the staff approaches to pre- and post-laboratory preparation has already been undertaken as part of this study and the associated publication is available as appendix 5. (Rayment et al., 2022).

Given the prevalence of comments relating to stress, anxiety, and panic, which are known to affect a student's capacity to learn, a targeted study relating to investigating this phenomenon in the Superlab is warranted. This study could be paired with a comparative study in one of NTU's teaching laboratories that are not paperless to further investigate the impact of the paperless procedures on student's approaches to learning which is one of the themes arising from this study from a staff perspective.

An unanticipated complexity of this study is the non-homogeneity of the teaching laboratory, with a great deal of variation within a single subject-specific laboratory course delivered by one staff member. It may be possible to undertake comparisons of perceived motivations, aims and purposes of the teaching laboratory in a more targeted manner, selecting a single teaching laboratory session that is delivered several times a year, and undertaking interviews with the participants. The reason this was not undertaken as part of this study was a logistical one, this would restrict the number of participants available for recruitment and put time restrictions on the interview windows which could result in lower response rates, however it may be more feasible in larger scale courses, or perhaps in other educational settings with more standardised curricula.

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Appendix 1: Digital qualification data from Digital History Survey

Combined		
Digital Qualifications	**2014/15 new**	**2014/15 returning**
n	**155**	**88**
GCSE IT - Grade C or above	90	50
IT Key Skills Level 2 - Pass grade	22	14
IT Key Skills Level 3 - Pass grade	13	4
IT A-Level - Grade C or above	6	4
European Computer Driving License (ECDL) - Pass grade	4	2
No relevant IT qualification	31	15
Other relevant qualification	13	15
Digital Qualifications	**2015/16 new**	**2015/16 graduating**
n	**77**	**8**
GCSE IT - Grade C or above	39	5
IT Key Skills Level 2 - Pass grade	7	3
IT Key Skills Level 3 - Pass grade	2	1
IT A-Level - Grade C or above	0	0
European Computer Driving License (ECDL) - Pass grade	3	0
No relevant IT qualification	18	1
Other relevant qualification	11	0
Digital Qualifications	**2016/17 new**	**2016/17 graduating**
n	**68**	**8**
GCSE IT - Grade C or above	31	6
IT Key Skills Level 2 - Pass grade	7	0
IT Key Skills Level 3 - Pass grade	6	1
IT A-Level - Grade C or above	1	1
European Computer Driving License (ECDL) - Pass grade	2	0
No relevant IT qualification	22	0
Other relevant qualification	8	1
Digital Qualifications	**2017/18 new**	**2017/18 graduating**
n	**54**	**7**
GCSE IT - Grade C or above	25	2
IT Key Skills Level 2 - Pass grade	7	1
IT Key Skills Level 3 - Pass grade	2	1
IT A-Level - Grade C or above	1	0
European Computer Driving License (ECDL) - Pass grade	2	0
No relevant IT qualification	17	1
Other relevant qualification	5	3

Appendix 2: Familiar operating systems of students from Digital History Survey

	Familiar Operating System	2014/15 new	2014/15 returning
	n	**155**	**88**
PC	**Microsoft**	128	69
	Apple	12	7
	Linux	1	0
	I don't know	14	12
Tablet	**Microsoft**	22	11
	Apple	74	39
	Android	33	21
	I have never used this device	7	3
	I don't know	17	13
	Other	1	1
Phone	**Microsoft**	12	2
	Apple	88	45
	Android	38	36
	I have never used this device	3	0
	I don't know	12	4
	Other	2	1

	Familiar Operating System	2015/16 new	2015/16 graduating
	n	**77**	**8**
PC	Microsoft	63	7
	Apple	13	1
	Linux	0	0
	I don't know	0	0
	Empty or void response	1	0
Tablet	Microsoft	16	2
	Apple	41	3
	Android	14	2
	I have never used this device	3	1
	I don't know	2	0
	Other	0	0
	Empty or void response	1	0
Phone	Microsoft	4	0
	Apple	39	4
	Android	32	4
	I have never used this device	0	0
	I don't know	0	0
	Other	0	0
	Empty or void response	2	0

	Familiar Operating System	2016/17 new	2016/17 graduating
	n	**68**	**8**
PC	Microsoft	54	8
	Apple	12	0
	Linux	1	0
	I don't know	0	0
	Empty or void response	1	0
Tablet	Microsoft	11	4
	Apple	37	1
	Android	14	1
	I have never used this device	2	0
	I don't know	4	1
	Other	0	0
	Empty or void response	0	1
Phone	Microsoft	0	0
	Apple	43	1
	Android	25	4
	I have never used this device	0	3
	I don't know	0	1
	Other	0	0

	Familiar Operating System	2017/18 new	2017/18 graduating
	n	**54**	**7**
PC	**Microsoft**	45	6
	Apple	9	1
	Linux	0	0
	I don't know	0	0
	Empty or void response	0	0
Tablet	**Microsoft**	8	0
	Apple	24	5
	Android	18	2
	I have never used this device	1	0
	I don't know	3	0
	Other	0	0
	Empty or void response	0	0
Phone	**Microsoft**	0	0
	Apple	28	3
	Android	26	4
	I have never used this device	0	0
	I don't know	0	0
	Other	0	0

Appendix 3: Number of items of technology used by students.

Data sourced from Digital History Survey.

Combined			
Ownership of technology and internet access		**2014/15 new**	**2014/15 returning**
	n	**155**	**88**
Smart phone		149	86
Other mobile phone (not smart phone)		8	4
iPod or mp3 player		123	61
Tablet		81	44
Laptop or Netbook		143	78
Digital Camera		91	55
Video Camera		43	24
Webcam		89	46
Digital Audio Recorder		48	19
Assistive Technology		11	2
Access to internet at residence		153	85
Access to internet at work		13	8
Access to internet at university		143	84
No internet access location specified			1

No of items of technology used		**2014/15 new**	**2014/15 returning**
	n	**155**	**88**
	0	0	1
	1	1	1
	2	8	9
	3	20	12
	4	21	24
	5	29	23
	6	24	21
	7	18	15
	8	12	6
	9	0	1
	10	0	0

Combined			
Ownership of technology and internet access		**2015/16 new**	**2015/16 graduating**
	n	**77**	**8**
Smart phone		76	8

Other mobile phone (not smart phone)	4	0
iPod or mp3 player	49	6
Tablet	40	4
Laptop or Netbook	71	8
Digital Camera	35	4
Video Camera	10	2
Webcam	24	2
Digital Audio Recorder	9	1
Assistive Technology	0	0
Access to internet at residence	73	8
Access to internet at work	9	0
Access to internet at university	72	8
No internet access location specified	1	0

No of items of technology used	**2015/16 new**	**2015/16 graduating**
n	**77**	**8**
0	1	0
1	3	0
2	14	1
3	13	1
4	14	2
5	14	2
6	9	2
7	5	0
8	3	0
9	1	0
10	0	0

Combined

Ownership of technology and internet access	**2016/17 new**	**2016/17 graduating**
n	**68**	**8**
Smart phone	67	8
Other mobile phone (not smart phone)	6	0
iPod or mp3 player	41	5
Tablet	36	4
Laptop or Netbook	57	8
Digital Camera	34	4
Video Camera	17	5

Webcam	23	4
Digital Audio Recorder	16	4
Assistive Technology	4	0
Access to internet at residence	67	8
Access to internet at work	8	1
Access to internet at university	70	8
No internet access location specified	0	0

No of items of technology used	**2016/17 new**	**2016/17 graduating**
n	**68**	**8**
0	0	0
1	3	0
2	11	2
3	12	3
4	14	0
5	11	0
6	6	1
7	7	3
8	4	1
9	2	0
10	0	0

Combined

Ownership of technology and internet access	**2017/18 new**	**2017/18 graduating**
n	**54**	**7**
Smart phone	53	7
Other mobile phone (not smart phone)	2	0
iPod or mp3 player	30	5
Tablet	20	1
Laptop or Netbook	45	5
Digital Camera	19	4
Video Camera	11	2
Webcam	20	4
Digital Audio Recorder	10	2
Assistive Technology	3	1
Access to internet at residence	51	7
Access to internet at work	38	0
Access to internet at university	18	7
No internet access location specified	34	0

No of items of technology used	2017/18 new	2017/18 graduating
n	**54**	**7**
0	1	0
1	4	0
2	9	2
3	12	0
4	10	2
5	7	0
6	3	2
7	3	1
8	4	0
9	1	0
10	0	0

Appendix 4: Final version of Digital History Survey

Digital History Survey 2015

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.

Page 1

Digital History Survey 2015

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 [ ]

Page 2

Digital History Survey 2015

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.

*Please select your legal gender:

- Male
- Female
- 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

Digital History Survey 2015

Information about you

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

- [ ] Autstic 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

Page 4

Digital History Survey 2015

Information about you

***Please select your course area:**

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

Page 5

Digital History Survey 2015

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)

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Note – this page was replicated for each of the teams in Science and Technology.

Digital History Survey 2015

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)

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Digital History Survey 2015

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

Digital History Survey 2015

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

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

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)

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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 my personal and social life, I do the following:
(Please select all that apply.)

- ☐ 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

Digital History Survey 2015

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.

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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
Co-create resources or work with a peer online.	○	○	○	○	○	○
Create graphs using a spreadsheet (e.g. Excel)	○	○	○	○	○	○
Download, save and open files.	○	○	○	○	○	○
Insert images, tables and graphs into word processed files or presentations. (e.g. MS Word, Powerpoint)	○	○	○	○	○	○
Interact with staff or students online (e.g. email, discussion boards)	○	○	○	○	○	○
Produce professional diagrams using drawing packages (e.g. ChemDraw or BioDraw)	○	○	○	○	○	○
Put information into a pre-made form, downloaded from the internet. (A proforma / template)	○	○	○	○	○	○
Use a Virtual Learning Environment (e.g. NOW, WebCT, Moodle)	○	○	○	○	○	○
Use cloud storage (e.g. Dropbox.com, NOW MyFiles, iCloud, SkyDrive)	○	○	○	○	○	○
Use formulae to manipulate data a spreadsheet (e.g. Excel)	○	○	○	○	○	○

Digital History Survey 2015

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.	○	○	○

Technology and learning.

Do you think technology has a positive or negative effect on your learning? Please explain your thoughts.

Appendix 5: Final version Modified SLEI and attitude tool

SLEI 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 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 forall 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 themain 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 forall 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 forall 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. In our laboratory sessions, we are asked to design our own experiment to explore a topic

	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. Within a laboratory session, students follow different procedures or use different samples to investigate the same idea.

	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 6: Example coding structure for interviews.

ID	Quotes	Keywords/phrases identified	Narrow Code	Broad code / Theme
2	"It's to apply theoretical knowledge in a practical sense and to build up their practical skills"	apply theoretical knowledge	Apply Theory	Learning Chemistry
		build up practical skills	practical skills	Practical/ Manipulative Skills
	"it helps in their understanding of what's being taught theoretically, so they have a kinaesthetic approach to umm.. to actual learning as well but also they need those physical skills to be able to operate in a lab environment safely basically"	understanding what's being taught theoretically	Understanding	Learning Chemistry
		operate in a lab environment safely	Safety	Practical/ Manipulative Skills
	I: ok so, in an ideal world, would you always have students coming in with some theoretical knowledge? P: not always. It's sometimes that doesn't occur because… the order in which they have lectures, so a lot of the practicals encompass usually a whole wide range of knowledge across that particular module and of course that module is being taught throughout the year. So at the start of the year we tend to try to give them the basic skills that they would need in the lab, but some of the more in-depth knowledge of say, instrumentation they don't learn until later on.	Lecture / lab link - does not always need to be chronological - linking theory	Chronology of learning	Other comments
		basic skills that they would need in the lab	practical skills	Practical/ Manipulative Skills
		in-depth knowledge instrumentation in the context of use	Understanding (Instrumentation)	Practical/ Manipulative Skills
	P: But, saying at the same time they are working in the lab and they are using those basic skills but, umm… they're not … they possibly don't understand how the instruments work quite so much, so you're trying to explain that as you go as well. So it is not just a session where they are engaging in an activity that they follow on a piece of paper like a recipe. It should be more an activity where they are actually learning as they go, umm… and possibly asking the demonstrator and supervisor questions of things they don't understand. I: ok, so there's like a knowledge seeking aspect during the lab as well? P: yes, there should be , yeah	explain as you go… actually learning as they go asking … questions knowledge-seeking, engagement	Active learning	Learning Chemistry

ID	Quotes	Keywords/phrases identified	Narrow Code	Broad code / Theme
4	So, mainly it's getting some practical skills.	practical skills	practical skills	Practical/Manipulative Skills
	getting the basic techniques…	basic techniques	practical skills	Practical/Manipulative Skills
	Understanding observation	observation	lab skills	Laboratory skills
	and err.. being able to recall everything, and also just get used to being in the lab and having to do all the different experiments	recall	Remembering	Learning Chemistry
		get used to being in the lab	comfort/familiarity	Familiarity
	I: do you mean manipulative skills? or do you mean sort of data handling skills that go with the lab? P: I think it's both, you can't really distinct [distinguish?] from one of them, so it depends obviously on which approach you're talking about, or which modules you're talking about or which type of chemistry, effectively.	you can't really distinct from one of them.	holistic nature of lab skills & practical skills	Practical/Manipulative Skills Lab skills
		Which approach… which modules … which type of chemistry.	variation in approach and skills by module	Practical/Manipulative Skills
	P: But I think it's both of them because I many kind of ways you'll have to have the lab setting where you actually do the experiment and you know how to handle the glassware, the uhh… health and safety of it as well.	do the experiment handle the glassware health and safety	Safety	Practical/Manipulative Skills (Safety)
	On being asked about general chemistry vs subject specific labs: P: no, I think it's a bit different. So, for example, the... well the techniques are completely different P: Uhh… the approach to weighing, or… that's different as well. P: the approach to preparing solutions would be quite similar in some sense but when you do analytical chemistry you need to be a bit more umm.. precise, to say the least P: the type of techniques, I think the analytical side of it is more using the machines themselves and actually getting used to handling the machine, getting confidence in that as well	Techniques are different	practical skills	Practical/Manipulative Skills
		Precise	Precision	Practical/Manipulative Skills
		Using the machines Getting used to handling the machine	Practical skills (Instrumentation)	Practical/Manipulative Skills
		Getting confidence	comfort/familiarity	Familiarity
	P: and then having to deal with the data, so I think that's where you've got the split, really, between them	Data handling	lab skills	Lab skills

ID	Quotes	Keywords/phrases identified	Narrow Code	Broad code / Theme
5	P: To show there's a real use for the theory in the lectures. It's kind of like a three stage thing, where you get first stage is introduction to the material, so that's your lectures. This is where you're showing what you're supposed to know. And then a lot of the times, you show them what you know, you don't know it, that's the point, new stuff. And then stuff like tutorials , and kinda l… question based things, can you logically apply those theories… P: to a problem, and then the lab is that final thing where you apply it to a real life situation trying to make something.	to show there's a real use for the theory in the lectures.. showing what you're supposed to know	Learning Chemistry (recall / reminder)	Learning Chemistry
		Logically apply those theories…	Learning chemistry (Apply)	Learning Chemistry
		Apply it to a real life problem	Learning chemistry (Apply)	Learning Chemistry

ID	Quotes	Keywords/phrases identified	Narrow Code	Broad code / Theme
6	P: (indistinct) Well… Chemistry, especially, is just a largely practical subject. A lot of the skills you want to get out of it are practical ones, if you are going to have a career in chemistry, at least to start off with… the skills you need, about half of them are probably practical-based. And there's no other way, really, to learn those skills other than to practice them. Not just once, but preferably repeatedly for the skills like weighing, pipetting, measuring, titrating, refluxing – all of those things you would need to do on a daily basis as a chemist.	largely practical subject A lot of the skills… are practical ones.	practical skills	Practical/Manipulative Skills
		Career in chemistry … about half of them are probably practical based no other way to learn them than practice Repeatedly	Skills for career, Repetition learning of practical skills	Practical/Manipulative Skills
	P: You need to learn them. And also, I think for students who are more practical-minded, it's a good link to the theory to see it actually happening in practice. I think it's one of the great things about Chemistry is that most… things you learn about you could do in practice. Even in a teaching lab. Umm… So it's sort of another way of learning.	good link to the theory to see it actually happening in practice	Theoretical learning in practice, illustrative learning	Learning Chemistry
	I: Ok, in the actual world, how do you think it happens? P: I think they piece it together bit by bit. And occasionally you'll get somebody in a lab who goes "Oh, like how we learned back in the lecture!" or you'll get somebody in a lecture who goes "Oh, we did that in a lab!" because you don't always manage to get the timing right because of timetabling and lecturer constraints of who's teaching what when, but I think the best designed experiments are ones where there's practical learning and also some theory reinforcement. And not just feeling comfortable with chemicals and having an idea of timescales and what… the fact that things don't always work the first time. That kind of thing is equally as valuable, learning to plan an experiment	participant mimics students making a "penny drop" moment where they make the link. Theory reinforcement	Reinforcement learning	Learning Chemistry
		Practical learning	practical skills	Practical/Manipulative Skills
		feeling comfortable with chemicals	comfort/familiarity	Familiarity
	P: Umm… so I'm definitely of the school of thought that you shouldn't just always let them run off a script because then the come to do their first research project or job, and they just don't know where to begin! P: But you've got to step that up from the beginning. At the beginning they've got to have clear scaffolding so they know what.. they.. how to learn to use the lab and	simplified - importance of scaffolding.	Scaffolding - teaching design	Other comments
		how to learn to use the lab and .. Use everything in the lab	practical skills	Practical/Manipulative Skills

	how to use everything in the lab, and then they can start to use that knowledge and put it together to make a plan. **Participant 6 continues overleaf.**	put it together to make a plan	Planning, applying knowledge	Lab skills
	I: So if you were to design a first year lab and a third year lab, how might you do that differently? P: Well, first year you'd probably have step-by-step instructions, and some supporting information like… it will say even down to the level of like "turn on your hotplate, the button on the right is the temperature and the button on the left is the stirring" or something like that. IF everybody's hotplate is the same. But y'know really in detail stuff for first years because they have not seen this stuff before and they're not going to be able to do anything. And also you have to have the demonstration, a lot more demonstration for first years and that has to be built in to your plan and hopefully have them all doing the same thing, so they can all kind of work through it together?	step-by-step instructions supporting information demonstrations	provision of information / instructions in relation to operation	Practical/Manipulative Skills
	P: Yeah. Whereas once it comes to third year you want there to be an element of individuality where they have to plan a bit what they're doing and work out why, what's the best way to do it, why they want to do it in the first place, would be the best. I: so you're going from just "doing the thing and achieving a goal" to "why are you doing the thing" and the critical reasoning P: Yeah. So I personally don't teach any uhh.. purely coursework 3rd year labs, I only teach project at 3rd year. So that is obviously completely different to a first year lab. But if I was designing a 3rd year.. a taught 3rd year lab I'd probably still make it very much more like a project. Like give them a problem, some equipment and the outline procedure, but maybe more like how you'd find it in a paper or… P: An SOP rather than how you'd find it first year, so like not "switch on your hotplate, turn the temperature to this." It'd be more like "reflux in this solvent" and then they'd have to work out what's the boiling point of the solvent, and all of that kind of thing, which they'd hopefully know from building up.	element of individuality, what they're doing … work out why… what's the best way to do it completely different to a first year lab	decision making - Planning variation in approach by level	Lab skills Other comments
	I: So... so your view is that the reason we teach in labs is primarily to train people to be chemists? P: Yes, like I say, I think it helps with theory and practical chemistry. Probably those	helps with theory	Theoretical learning Teaching Design	Learning Chemistry

	are transferable skills as well, the sort of.. planning a project, umm.. or planning an approach to something that you're going to do practically is probably something you could do in a lot of different careers and relating theory to practice as well	Practical Chemistry	Practical skills	Practical/Manipulative Skills
		transferrable skills, planning,	Planning	Transferrable skills
		relating theory to practice	Linking knowledge	Learning Chemistry (Applying Theory)

ID	Quotes	Keywords/phrases identified	Narrow Code	Broad code / Theme
7	So one... one of the key things is to train students to have the practical skills… P: umm... (pause) that they may need in employment or further study or whatever… P: I think another one is to demonstrate the theory of chemistry, so chemistry is a meaningless subject, to me, unless you actually do something P: so sitting in a lecture theatre isn't actually doing... doing chemistry. So you have to put it into practice, and so, yeah that's all part of... part of the subject.	Practical skills	Practical skills	Practical/Manipulative Skills
		need in employment or further study	Careers	Practical/Manipulative Skills
		you have to put it into practice	Apply Theory	Learning Chemistry (Applying Theory)
	On "Doing Chemistry" P: It doesn't have to be in a lab… I: yeah? P: it can be computationally or, or, or whatever... but yeah…	reinforces prior statement, applying theory can happen outside of Lab.	Apply Theory	Learning Chemistry (Applying Theory)

Appendix 7: Pre- and post-laboratory study

Statement of contribution.

The pre- and post-laboratory survey tool development was undertaken in collaboration between J Evans, S Rayment with advice from K Moss. Data collection and analysis for the UK-wide HE survey was a collaborative effort between J Evans and S Rayment. Preliminary data from this study was presented at ViCE PHEC conference in 2016 by J Evans (Moss et al. 2016a; Moss et al. 2016b). S Rayment composed the paper included below and is the solo contributor to the video development case study element of this paper.

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

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ABSTRACT

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

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

Introduction

Learning in laboratories

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

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

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

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

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

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

Prelabs

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

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

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

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

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

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

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

Methodology

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

Pre-laboratory practice in UK higher education institutions

Study design

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

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

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

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

Participants – study 1 (UK-wide HE survey)

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

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

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

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

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

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

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

Institutional context

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

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

Participants

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

Study design

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

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

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

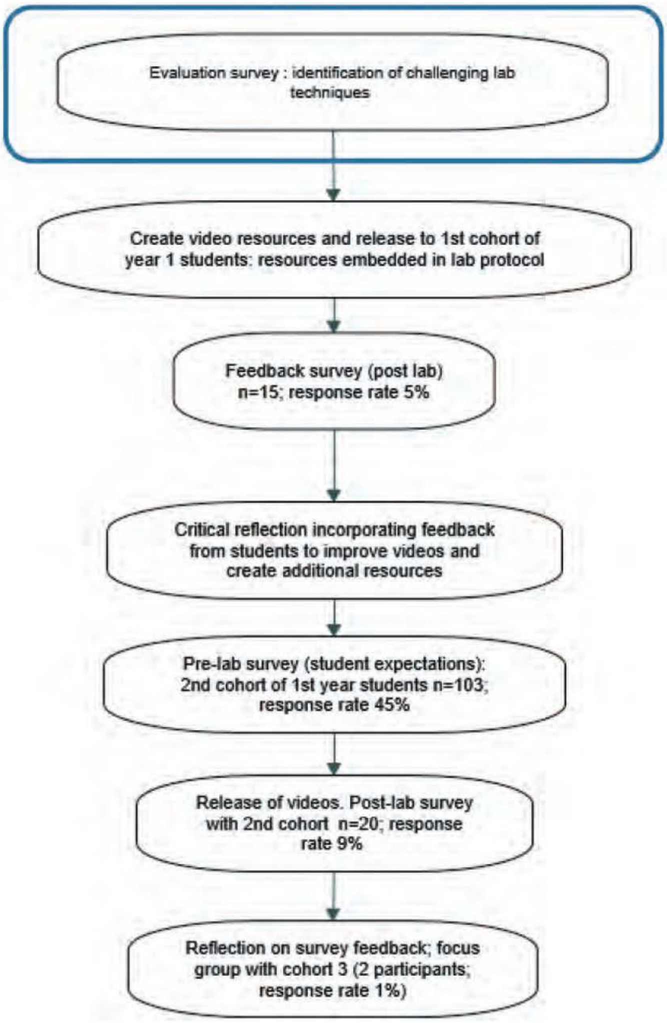


Figure 1. A schematic diagram of the development of the video case study methodology showing the survey tools used, reflective cycles and number of participants and response rates at each stage. The study highlighted in the box preceded the current study but provided information that was used in its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

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

This was then used in a subsequent cycle where videos for core laboratory techniques were produced, and a similar reflection cycle completed with a second cohort of first year students. These videos focussed on making dilutions, spectrophotometry and fundamental aspects of microscopy 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).

(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.

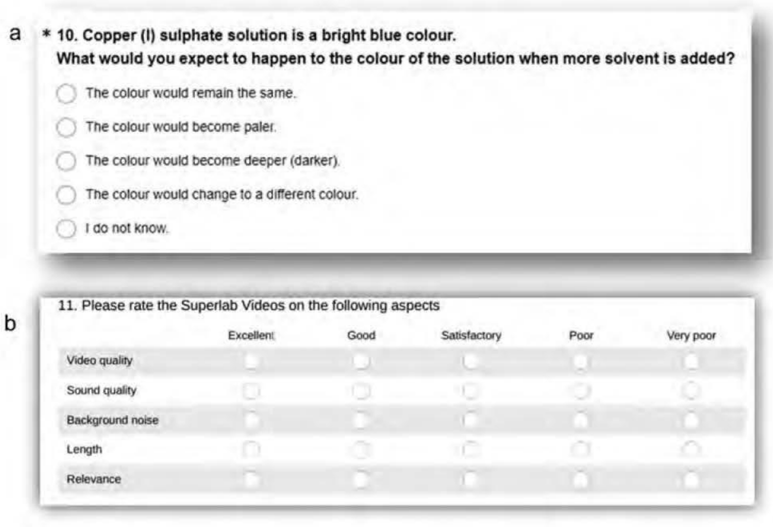
Survey design

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.

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%)

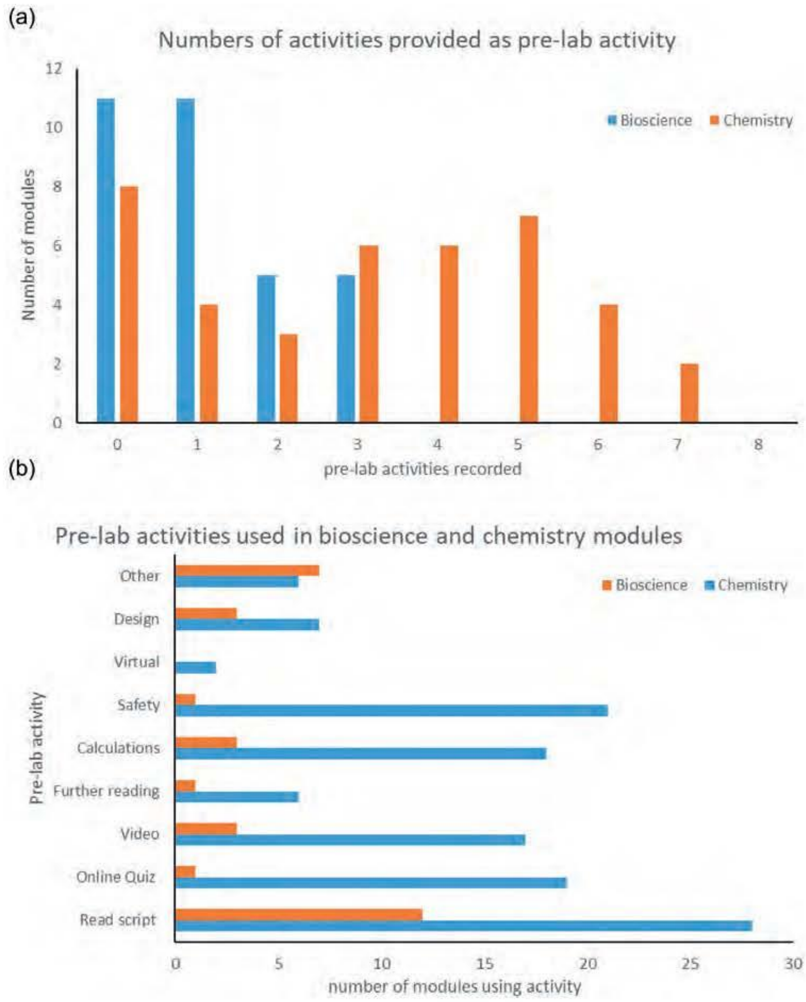


Figure 3. Data from the survey of UK HE institutions showing (a) a comparison of the number of pre-laboratory activities used in bioscience and chemistry modules. (b) a comparison of the number of bioscience and chemistry modules using different types of pre-laboratory activities.

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.

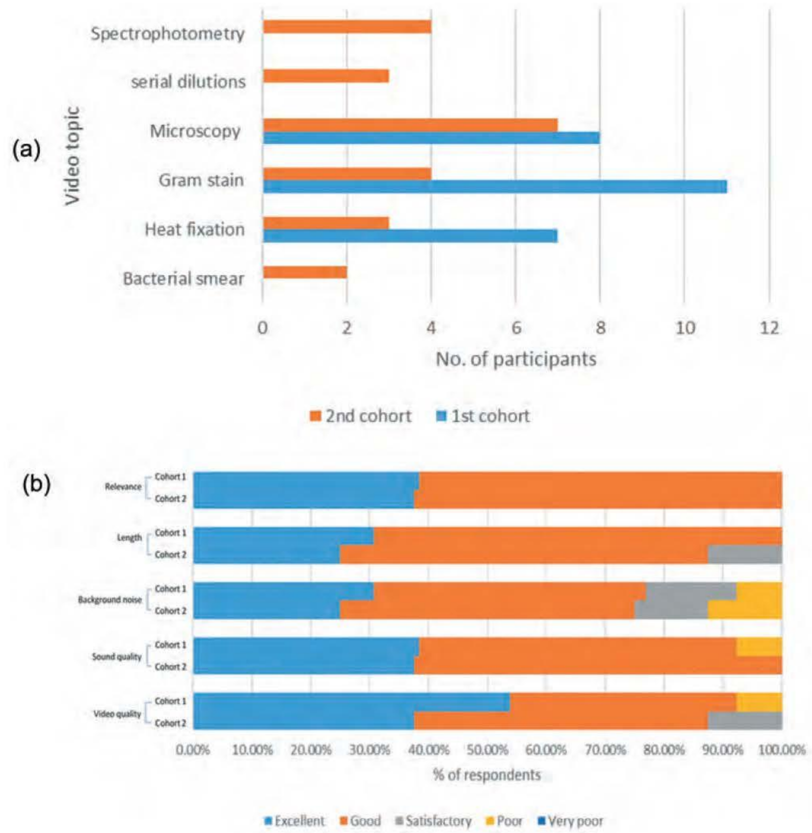


Figure 4. Case study survey data for both cohort 1 and cohort 2 showing the number of participants using different videos (a) and the participant responses for quality and relevance of the resources (b).

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.

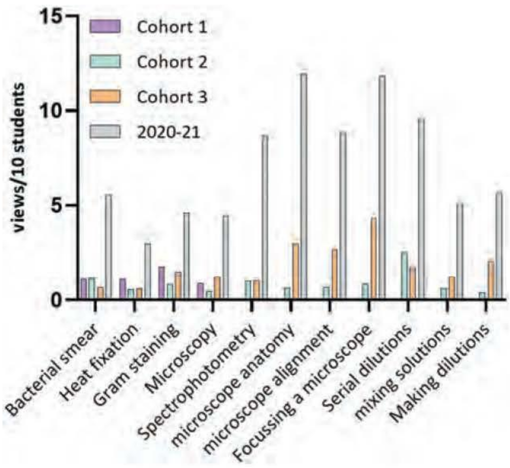


Figure 5. YouTube analytics showing the number of views that each video received over the course of the study (cohorts 1–3) compared to usage so far in the current academic year (2020–2021). views are expressed as views per 10 students within a cohort to standardise the data to account for differing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

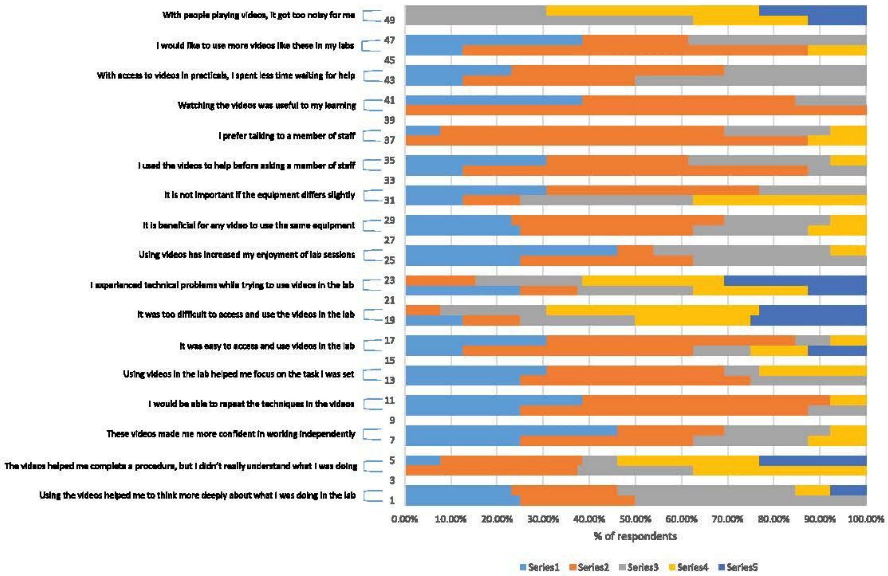


Figure 6. Representation of Likert-like scale data (participants were asked to what extent they agreed or disagreed with the statements provided) for the 1st and 2nd cohorts. Positive and negatively worded statements were included, with some addressing use of the videos within a laboratory setting, with 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 highlighted that encountering material multiple times helped them to remember it and that using videos helped them with information synthesis.

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

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

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

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

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

Discussion

Pre-lab activities in biosciences

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

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

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

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

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

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

Student experience of using videos

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

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

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

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

Managing expectations and enhancing student engagement

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

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

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

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

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

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

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

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

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

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

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