TOWARDS THE DEVELOPMENT OF INTERACTIVE AND MULTIFACETED PRE-LAB EXERCISES FOR ORGANIC CHEMISTRY PRACTICAL CLASSES

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Abstract

In the Chemistry Department we are developing innovative web-based pre-laboratory exercises to enhance our students' lab learning and experience. The framework incorporates supportive information, contextual value of the experiment, multimedia resources including interactive materials, and formatively assessed questions with explanatory feedback. The interactive pre-lab exercises are designed to explain the theories and justify experimental procedures and their utility value to increase student motivation and enhance their in-person lab practice. These multimedia resources are being developed for second-year chemistry undergraduate students. The effectiveness of these pre-laboratory resources will be assessed through multiple strategies including feedback forms, module evaluation questions, inter-cohort grade comparison and semi-structured interviews via MS Teams.

Keywords: *pre-laboratory exercises, organic chemistry, undergraduate students, online resources, multimedia learning, chemical education research, cognitive load*

1. INTRODUCTION

Practical classes are an integral part of an undergraduate Chemistry degree [1–3]. They aim to support understanding of theories and concepts in students [4], and allow them to improve their practical skills, note and interpret observations and data [5], further develop social and professional skills, learn how to deal with challenges and think on the spot [4,6].

However, students may not feel comfortable and may be worried before practical sessions, as they may feel they lack practical skills [7]. Students are often also anxious about handling hazardous chemicals, using new equipment and the pressure of trying to get the 'right' result. Especially after the Covid lockdowns, during which practical sessions were limited; students were even less confident in the lab when they returned to campus. Other factors that could also contribute to these concerns include information overload [2,8], insufficient explanation of the material, worry about assessment [3], and lack of preparation [9].

1.1 The role of pre-laboratory exercises

Pre-laboratory exercises (pre-labs) can reduce some of these concerns and enhance students' experience in the lab by making the content more approachable, and familiarising students with the experiment, equipment, and procedure. These exercises usually consist of one or more short tasks that need to be completed before attending the laboratory session [3]. Pre-laboratory exercises are essential to prepare students for practical lab activities and to ensure their effective learning during the lab session itself [11–15]. They increase students' knowledge of techniques, glassware usage and assembly, safety hazards and precautions and general laboratory processes and concepts [16]. They allow for a more productive learning experience (Rollnick *et al.*, 2001) and, especially if they are available as online resources, benefit students due to unlimited access and flexibility; they can also be cost-effective [17–19]. Pre-labs can also deepen students' understanding of the material by providing context for the experiments, allowing for better retention of concepts, deeper engagement in learning and more efficient, faster completion of their lab experiment [8,10].

Pre-labs can also benefit students outside of a laboratory environment. They can increase student confidence and sense of autonomy in the lab, improving their ability to solve problems and decreasing their reliance on lab support staff and technicians for minor issues [20]. Pre-lab work gives students goals and utility value by explaining why they perform certain things in the lab, and why they should care about certain learning materials, steps, and techniques. They can also be used to put the students' work into a wider perspective, by linking the material to industrial applications and career development. This in turn can make the work more meaningful, which can further improve students' engagement with their experiments and make their lab experience more enjoyable. If the students are better prepared for their laboratory session this will improve their time management and organisational skills, they will become more productive, and can learn more within the allocated lab time [21]. There is evidence that this can improve their confidence and reduce anxiety. Pre-laboratory exercises can also benefit beginner teaching assistants, to give them an overview of the experiment and to see what they can expect from the students. They can also serve as a revision material for both students and teachers.

2. TYPES OF PRE-LAB PREPARATION MATERIAL IN CHEMISTRY

There are a number of different methods and approaches to pre-laboratory preparation. These may include reading instructions and then writing a summary of the experimental procedures (Rollnick *et al.*, 2001), answering questions related to the experiment [22], using videos and simulations [17,23] and small discussion groups [24]. Use of a variety of 'means of representation' in the form of different activity types, according to universal design for learning (UDL), can allow us to reach students with different learning needs and preferences [26]. All students benefit from having access to material presented in a range of modes from which they can select; some may engage well with detailed written instructions; some choose short videos or interactive exercises that help them visualise the equipment and experimental procedure. Their preference may also depend on the activity being taught. All videos have optional closed captions, and transcripts can be downloaded to further improve accessibility. The use of images alongside text in an online pre-lab can help students become familiar with techniques before they enter the lab, which is particularly useful for those with limited lab experience and can save time during sessions [27].

2.1 Aims

As part of this project, we aimed to enhance second year undergraduate students' lab learning in practical classes in organic chemistry through developing web-based pre-lab materials that can supplement and enhance their in-person lab practice [28]. We believe that student engagement should be an integral part of any taught module at university level [29]. In this practical module we have been working to design flexible and interactive teaching materials in collaboration with a digital learning developer. These materials, such as videos, interactive models, interactive practice exercises, and quizzes were designed to help students engage with the course and enhance their belonging and progression as new chemists.

3. OUR APPROACH

3.1 Students' involvement – students as partners

In the project we involved students, undergraduate and postgraduate, to see their perspectives and approach the material in a way that is understandable for those who should benefit from it the most, students. We treat students as partners, which does not only mean listening to what students have to say, but also taking action and involving students in decision-making [30–32].

Students are designing questions and teaching material for their peers and working on the answers that can help them to gain a broader overview and interest in the topic. They also provide a broader link to their peers through their ability to ask questions about student concerns and opinions that can then feed into the material.

We have sought students' input in re-writing experimental instructions and lab expectations, which has allowed us to make them clearer and easier for our diverse community to understand. An example of this is provided in Fig. ***1***. Use of more accessible language, clear stepwise instructions, and additional details improves their colleagues' understanding of the material and can improve their confidence in the lab. Our students also had a tremendous input in preparation of lab technique videos, interactive simulations, and the online content of the organic lab course to aid the students' learning experience and helping their colleagues with better understanding of the synthetic chemistry.

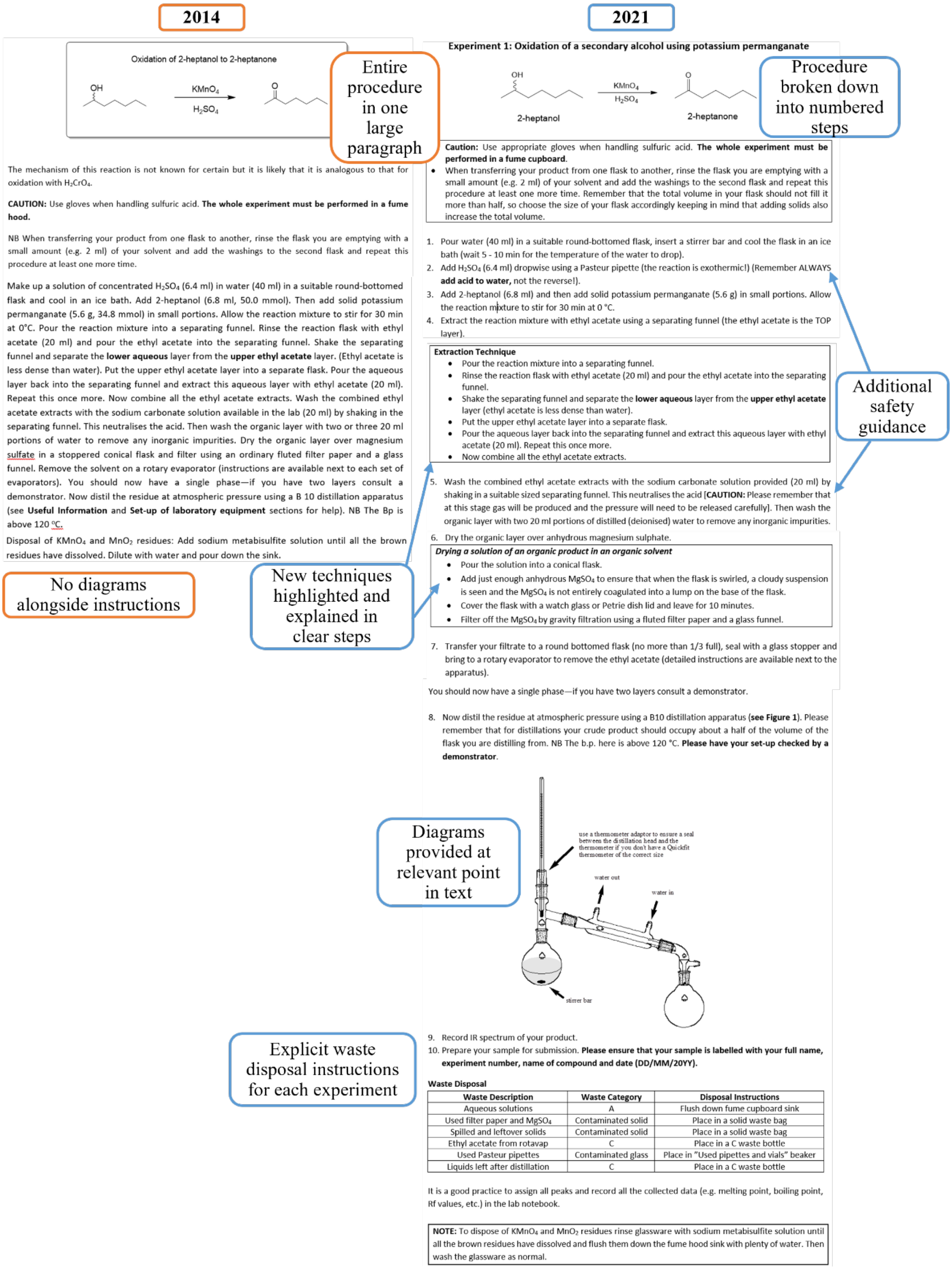

Fig. 1. A comparison of an organic lab experiment protocol from 2014 and 2021, with key improvements highlighted

3.2 Interactive learning design

Online learning materials can easily skim information at a surface level, such as through providing simple texts and lists of procedures; however, these methods fail to engage learners in deeper learning that can activate their understanding of the material and lead to better performance than merely recalling a process [33]. Since the aim of this project was to improve students' critical understanding of laboratory procedures and promote a deeper understanding of the chemistry taking place at each stage, a more practice-led and motivating approach was selected.

There are commercially available options, notably Labster, that allow for practice of lab skills in a 2D-VR (screen-based) environment. However, after review, these materials were found to be less than optimal both in terms of pedagogical approach and the lack of ability to customise them for local policies and practices. The Cognitive Theory of Multimedia Learning (CTML) [34] states that cognitive load and learning transfer can be negatively impacted by the inclusion of redundant text alongside narration, and the inclusion of extraneous content and distracting details, both of which the Labster environments include.

While research has found that Labster simulations performed as well as in-person demonstrations as pre-lab preparatory exercises for simple procedures and positively impacted student self-efficacy [35], the authors noted that further evidence is needed to ascertain efficacy for more complex experimental activities, and the specific format of the instructional material.

We first produced detailed instructions, videos and photos for our lab techniques and experiments, then employed students to provide feedback and comments on the instructions and additional material to improve their clarity and relevance. Using their suggestions, we created interactive videos and experiments using Articulate Storyline 360 and Articulate Rise. It was considered important to employ an evidence-led approach, guided by recognised educational research such as Cognitive Load Theory (CLT) [36] and multimedia learning principles [34]. CLT refers to managing the easily overwhelmed limitations of our working memory. This is achieved by reducing the extraneous load created by the presentation, structure, and interaction requirements of the material, as evidenced in Fig. ***2***.

Fig. 2. Isolated 3D model of rotary evaporator with multiple viewing angles, feature highlights and step-by-step instructions

Practical chemistry experiments demonstrate high element interactivity, in that many concepts must be understood simultaneously to gain a grasp of the overall principles and procedures that are in-scope [37]. It is expected that pre-training and simulation in this context can help to reduce element interactivity by breaking down some of these elements into discrete chunks before considering how they interact, thus reducing the intrinsic cognitive load of the learning tasks (Figure 3).

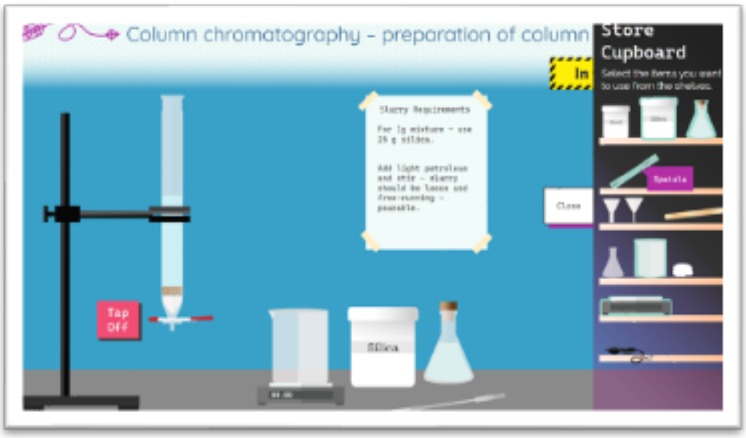

Fig. 3. Interactive experiment setup, including equipment store for students to select appropriate equipment, tips and clear instructions

Our approach was to present the experiment, equipment, and mechanism of action in a low-extraneous load environment where learners are in control of the pace, can repeat sections as desired and can receive immediate feedback on their actions (Fig. *4***Error! Reference source not found.**). We have also been fortunate to have undergraduate and postgraduate students working with us on this project. Their input has been invaluable in shaping the language, content, tips, and feedback we have incorporated, reflecting their real-world experience of questions, mistakes, and misunderstandings in our learning material.

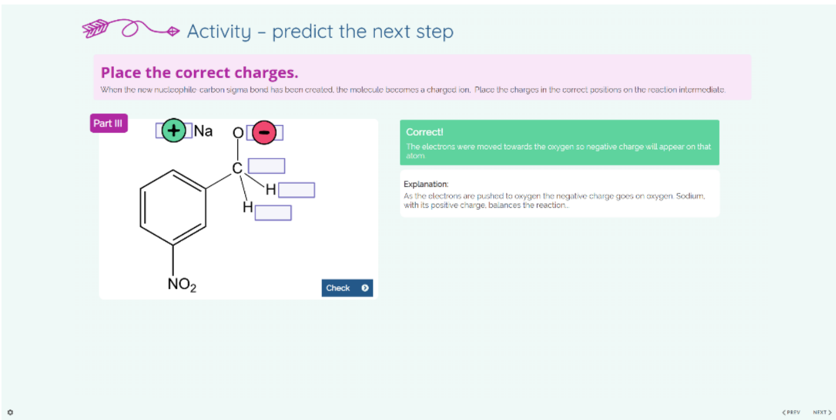

Fig. 4. Simplified drag-and-drop activity to check student understanding of the underlying chemistry, with immediate feedback

This approach will support learners to develop their domain-specific and procedural knowledge outside the high-pressure lab environment, where it can be put into practice.

3.3 A student pre-lab journey

An overview of the full lab experience from pre-labs to completion is given in Fig. *5*. Although the pre-lab exercises are recommended to be completed in a certain order, they can be accessed and viewed in any order that students prefer, as many times as required.

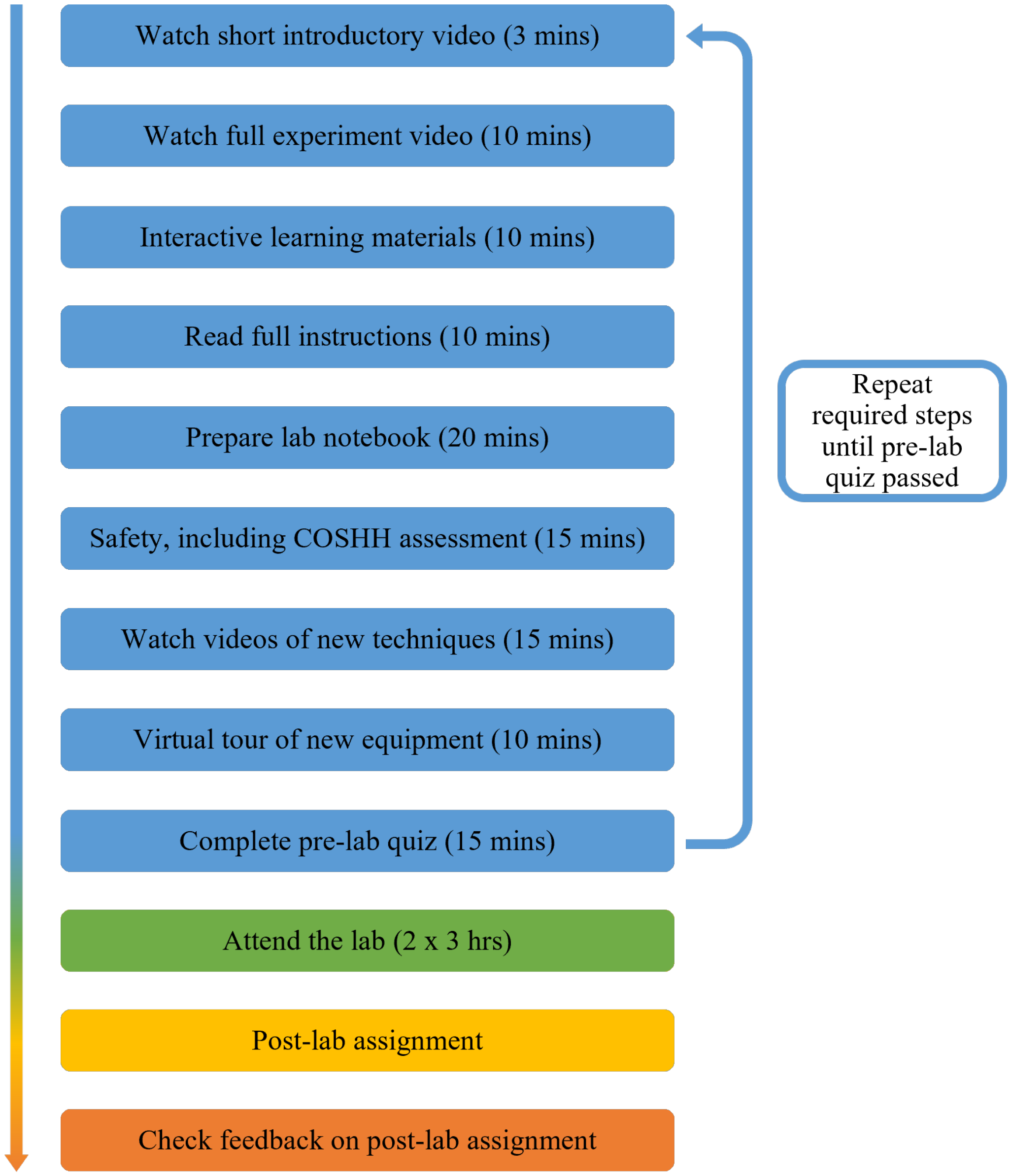

Fig. 5. A flowchart showing the student journey from beginning their pre-labs to reviewing feedback on their post-lab work

The ideal place for students to begin is with a short video introducing the experiment. This video provides a brief overview, including the preparation and pre-lab work required alongside key lab techniques, instruments and procedures covered. Our videos also show waste disposal, safety procedures and equipment setup which can help students to improve their laboratory efficiency and understanding of the methods used [17]. They also allow us to manage student expectations by clearly laying out what is required of them, the type of assessment used and the deadlines for each component. The longer demonstration video focuses on the lab activity itself, with an expert performing and narrating the full experiment. The key points are explained and presented in learner-controlled segments, so the amount of content does not overload the learner, utilising the segmenting effect [34,38]. A video may be split into sections for each key step or skills, so students can easily skip to a specific part to revise one specific technique, without having to rewatch or skim the whole video to find it. Interesting but not relevant content could be eliminated [39], providing clues and reinforcing critical thinking, whilst providing feedback that can explain key points for a beginner. Taken together, these videos can enhance students' knowledge of laboratory concepts and processes before entering the lab.

Next, students should read through the instructions for the experiment in full, to gain a general overview of the experiment. From this, they can make preparatory notes in their lab notebook [10]. These should include short summary of the procedure, drawing of the experiment setup and any other setup that will be used in the work up or purification of the product, a reaction scheme and mechanism where appropriate, worked calculations of reagents, and the theoretical yield. Through this activity students learn the importance of having a lab notebook and gain an understanding the of the procedure, glassware and reagents used in the process, helping them to be organised and well prepared for the lab [40,41]. After this, they can consider Health and Safety aspects: hazards and precautions for the chemicals, procedure, and equipment, safe working practices, and the completion of a COSHH assessment, which will be checked and signed off by a staff member before the student can perform the experiment. Key safety information (e.g., use of a particularly harmful or air-sensitive reagent, and how to safely handle this) should also be emphasised in the lab notebook, to aid memory via cognitive offloading [42]. Health and safety information is also included in the introductory, experiment and skills videos, as well as in the pre-lab quiz.

Students can also benefit from reading information related to the underlying theory of the experiment, alongside explanations for the chosen experimental approaches and procedures [9,44]. This helps students to better understand the aim of the experiment, see its relevance in real-world, and help to improve their motivation, learning and engagement with the experiment [45–47]. Searching and digesting scientific literature is also a key skill for undergraduates, and regular early practice in this will benefit them in later years when writing essays, dissertations or when working on research projects.

In the virtual tours and interactive experiment material, students can familiarise themselves with new equipment, enhance knowledge and learn through self-assembly and mistakes. This gives students an opportunity to repeatedly practice a new technique with no negative consequences (running out of time, damaging equipment etc.) as many times as needed [49]. Technique demonstration videos also use the expert modelling approach, and include bullet-point instructions supported by schemes, images, and short videos of the techniques. These are 2-3 minutes long to allow for the best engagement time [18,48]. These videos can also link instructions and theory explanations. Provision of learning outcomes and a skills list for each experiment may improve student motivation and employability, by showing students how each skill can be relevant to present and future goals, and to their personal development outside of Chemistry. This includes 'soft skills' such as time management, teamwork and problem-solving. These should allow students to see the purpose of their learning, and in return help them actively learn from the practical classes [43].

Finally, students will complete an online multiple choice pre-lab quiz after completion of the pre-lab exercises before they are permitted to come to the lab. These quizzes test the students' understanding of the experiment purpose, protocols and health and safety; the testing effect allows better retention of the learning material [50]. This is followed by clear explanations in relation to specific procedures, including key points to ensure understanding. The pass mark for the pre-lab quiz is 80%, and students can retake the quiz multiple times if they do not pass on their first attempt. Immediate explanatory feedback for each question is provided, allowing them to better understand the answers and underlying theory, as well as reducing cognitive overload [51].

4. SUMMARY AND FUTURE WORK

All experiments in the module have pre-laboratory exercises. The exercises are interactive with students responding to questions after each pre-lab work and being provided with explanatory feedback. Each activity can be tracked by using view counts build in the module site on Blackboard Learn Ultra. Interactive pre-laboratory exercises offer a valuable method of preparation for the laboratory classes, as students can access them at any time and repeat them as many times as they wish. They provide students with content, explain the context of the experiment and guide them through skills that provide utility and value not only for the experiment, but also for real-world practice, such as teamwork and organisational skills.

The project will be evaluated using a mixed-methods approach such as feedback forms, module evaluation questions and semi-structured interviews via MS Teams. The interviews will be used to assess learners' experience with the new material, their confidence to undertake lab activities, and to see how the pre-training impacted on their practical work. Students' feedback will be used to improve the products and their delivery. The pre-laboratory exercises are being tested with students to check for usability, clarity, and organisation of material. Staff and postgraduate demonstrators will also be interviewed to gather their subjective observation of student understanding, and comparison with previous cohorts.

Comparison between assessment marks for each lab experiment and historical marks will be made to assess for differences in student performance across cohorts.

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