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Developing interactive multimedia learning materials for chemistry pre-lab training

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Abstract This article is a progress update on a project investigating the impact of embedding interactive pre-lab materials into the preparation resources for 2nd year undergraduate students in an organic chemistry practical module. Materials were developed as part of a collaborative innovation grant that embedded students as collaborators in the development process. Resulting activities included a mixture of multimedia and active learning exercises, including animations, quizzes, videos, interactive simulations and 3D and 360-degree tours. Prototype evaluation results were used to refine the final version prior to release. A full evaluation is being carried out, and final results will be reported in a future article.

Keywords: *Interactive materials, practical chemistry, pre-lab resources, undergraduate teaching, digital learning, learning technologies, interactive media*

Introduction

The impact of the COVID-19 pandemic was felt throughout higher education, leading to swift changes in how education was delivered and accelerating the adoption of technology (Holme, 2020; Bozkurt, Karakaya, Turk, Karakaya, & Castellanos-Reyes, 2022; Mojica & Upmacis, 2022).

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Our students also changed; their educational experiences during this time were very different from previous cohorts, and this is especially true in practical subjects such as chemistry (Simmons & Mistry, 2023). Limited or no access to lab facilities, equipment, and procedures for both A-Level and undergraduate students led to a reduction in their confidence and self-efficacy in these environments (Kelley, 2021). Where lab time was possible, local procedures were altered to minimise contact between students, save time and reduce movement around the lab. During this period, students were not expected to select and prepare equipment for experiments. Higher levels of anxiety are common concerning lab practicals (Kolil, Muthupalani, & Achuthan, 2020; Petillion & McNeil, 2021) and this was also noted in anecdotal conversations with students in our department. This led us to reflect on how we might improve the lab experience of students whose educational experience was disrupted by the pandemic and those who will follow them.

As an initial measure during the pandemic, we implemented video demonstrations of experiments. These videos were designed to support students to develop their laboratory skills by providing them with a clear example of practice, and useful tips to make the most of their constrained lab experience (Stieff, Werner, Fink, & Meador, 2018; Rose et al., 2019; Altowaiji et al., 2021; Petillion & McNeil, 2021; Díez-Pascual & Jurado-Sánchez, 2022).

The videos created ranged from 5 to 20 minutes in length, showcasing a demonstrator conducting an experiment with close-up shots and narrations with subtitles. While the videos highlighted crucial segments of the experiments, some students watched them without fully grasping the content. As a result, they encountered difficulties in recalling the significance of certain techniques, like adding specific solvents or cleaning equipment. Existing research has indicated that solely relying on video demonstrations may not adequately facilitate students' complete understanding and retention of the material. (Kozhevnikov, Hegarty, & Mayer, 2002; Mayer, 2021; Petillion & McNeil, 2021).

To expand on this resource, we searched for more engaging and interactive materials. While existing interactive lab resources were available, they were often costly and overwhelming, with an excessive amount of information (Ali, Ullah, & Khan, 2022). Recognising the need for an improved experience for students, we drew from the lessons learned during the pandemic and acknowledged the shortcomings of the materials developed during an emergency. We collaborated closely with our students; together, we developed our own set of interactive resources, precisely adapted to meet their expectations and accommodate their specific needs. To ensure the relevance and engagement of students, we selected one of their favourite experiments, containing a range of practical skills essential for their growth as proficient chemists.

We had two primary objectives in creating these interactive materials: firstly, to better prepare students for their practical in-person sessions, and secondly, to provide them with more engaging multimedia content. This approach aimed to enhance their overall learning experience and enable them to maximise the benefits of their practical laboratory sessions. Interactive materials have been proven to increase student engagement and their ability to effectively complete laboratory tasks in their hands-on activities (Hmelo-Silver, Duncan & Chinn, 2007; Naujokaitienė, Tamoliūnė, Volungevičienė, & Duart, 2020).

To increase our ability to engage students as collaborators on this project, we bid for a Collaborative Innovation Grant from DCAD (Durham Centre for Academic Development). This funding, aimed at supporting projects to enhance student success and foster student involvement in pedagogic design, allowed us to employ student developers, with both undergraduate and doctoral students recruited to the project. Our student collaborators helped us to refine our material outline and assisted in the creation of the learning materials. This update paper details the initial project outputs and prototype evaluation. A full evaluation of this project, including the results of the final evaluation, will be covered in a future paper.

Literature Review

Pre-lab preparation materials

Students can find laboratory practicals cognitively demanding due to the busy and competitive nature of the lab and the complex procedures they must undertake. This can lead to them focusing on completing tasks as quickly as possible at the expense of engaging with the experimental procedure to develop their lab skills and understanding (Bretz, Fay, Bruck, & Towns, 2013; DeKorver & Towns, 2015), thus impacting on how much they learn while in the lab. DeKorver and Towns (2015) describe how this approach is influenced by a desire to complete tasks early and achieve a good grade, and results in an inability to link the lab practicals with theoretical concepts; they observed some interesting behaviour from their participants. Students declined opportunities to practice practical skills due to lack of existing competence, or took shortcuts rather than refining their technique – thus avoiding learning opportunities that would help them develop those very skills. An overreliance on surface-level learning techniques in pre-lab study, such as memorisation, further distances students from meaningful learning, pursuing the path of least cognitive effort (Bretz et al., 2013).

Most pre-lab preparation material focuses on the how and the what of the experiment – the protocol to follow – rather than the reasons for each step and the nuances of the techniques used (DeKorver & Towns, 2015; Verstege, Lamot, Vincken, & Diederen, 2022). This encourages students to focus on the same aspects during the session; this can then lead to problems articulating the conclusions their experiment arrived at - a separation of the procedural and motor skills from the cognitive skills of understanding the chemistry at play (DeKorver & Towns, 2015). While teaching staff have been found to possess clear goals across a variety of domains (cognitive, affective and psychomotor), organic chemistry staff in particular can focus on cognitive and psychomotor skills over affective skills such as relating learning to real-world contexts, collaboration and increasing student motivation (Bretz et al., 2013). This lack of emphasis on elements linked to student experience of learning could further push them towards a disconnected and surface-level approach to learning these skills, harming self-efficacy and confidence as well as less success in their academic career.

Online learning materials

Lab-based chemistry practicals are complex, with a high level of element interactivity (Sweller, 1994); many concepts must be understood to grasp the overall principles and practical steps involved in a given experiment. This leads to a high level of intrinsic cognitive load, which can overwhelm working memory and prevent effective learning (Sweller, 1994, 2010; Paas, Renkl, & Sweller, 2003). To overcome this, online pre-lab preparation resources can draw on techniques adapted from learning science research into human cognitive processes (Mutlu-Bayraktar, Cosgun, & Altan, 2019), for example, Cognitive Load Theory (Sweller, 1994), the Cognitive Theory of Multimedia Learning (Mayer, 2021) and Dual Coding Theory (Clark & Paivio, 1991).

Techniques flowing from this research, such as Mayer's multimedia learning principles, allow us to organise, scaffold and present material to students in such a way that the intrinsic or essential load is managed (Mayer, 2021). Reducing unnecessary extraneous load can free up students' cognitive processing and maximise the productive use of cognitive resources (Mayer, 2021). This increases the availability of cognitive processing for integrating new material with existing knowledge to build a mental model and link practical techniques with the underlying chemistry.

Development overview

An initial outline for the learning materials was formulated to consolidate the pre-lab materials into a comprehensive guide for the designated experiment (sodium borohydride reduction). Second-year undergraduate chemistry students typically complete this experiment during a six-hour lab session. Each student in the cohort completes the experiment individually within their assigned lab period, with approximately 80 students working concurrently in the lab.

Figure 1: A sample image from the 3D tour of the rotary evaporator

Our student developers were tasked with revising and refining the learning content to tailor it appropriately for second-year chemistry students, ensuring it was accessible and suitable for their academic level.

This input was invaluable and included advising on and testing the development of multimedia and interactive components. As part of their involvement, they directly built sections of the materials themselves using Articulate Rise web-based e-learning authoring tools[1]. The tools included in Rise enable material to be segmented and organised in different ways, such as with accordions, tab interactions, and note cards. Small interactive tasks were also used, such as quiz questions, sorting tasks and step-by-step guides.

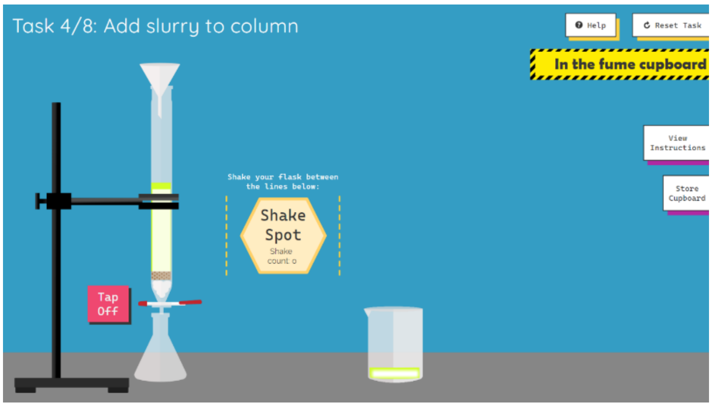

***Figure 2**: Example from the interactive column building activities.*

The animations, graphics, videos and interactive simulations included in the in-depth guide were created by the project team and include videos of specific phenomena, such as the 'snowstorm' effect observed when mixing silica into the solvent used, and the separation of liquids using a separatory funnel. Many illustrations, activities and short animations were prepared to go alongside the text elements of the script.

The interactive activities created include:

[1] Articulate web site: https://articulate.com/

- A COSHH (Control of Substances Hazardous to Health Regulations) assessment that reflects uncertainty, with correct answers indicating a range rather than a single answer
- A 'set-up' builder interaction for the reaction stage
- A 360-degree tour of the laboratory
- A 3D model tour and usage instructions for the rotary evaporator (see Figure 1)
- A multi-stage simulation of the column building exercise (see Figure 2)

Most of the materials were designed and developed between January and September 2022. At this point, an initial prototype was prepared for use in Semester 1 (October 2022). This included:

- The column chromatography section of the in-depth guide (including the lab tour)
- The 3D model and tour of the rotary evaporator

An initial evaluation survey for the prototype materials was completed by 40 students. Students were asked questions related to the usefulness of different pre-lab preparation materials and improvements that could be made to them. The main purpose of this survey was to identify problems with the sample materials that were tested and ways of improving the materials for the full release and evaluation. The open-ended question responses were reviewed and coded in NVIVO to identify and group comments that referenced positive and negative sentiments, problems experienced with the material, and potential improvements.

A majority of students agreed that the interactive materials as a whole had helped in their pre-lab preparation, with 14 out of 40 reporting that they felt it had prepared them very well, and 21 that it had prepared them somewhat well. A summary of responses to some key questions is included in Table 1.

Table 1: Summary responses to key questions

Questions	Yes	No

Were the instructions in the interactive material clear?	39	1
Do you think using interactive materials helped you improve your competence to undertake the lab activities?	35	5
Do you think using interactive materials helped you improve your confidence to undertake the lab activities?	39	1
Did you experience any problems with the interactive materials?	5	35
Would you recommend that your colleagues use the interactive materials to help them prepare before the lab session?	35	5

The primary issue identified in relation to the most interactive parts of the material was that it was at times slow to load and respond and that it was felt to be too long and complex. From this analysis, we identified some improvements such as streamlining and simplifying some elements, and further segmenting the more complex activities. These improvements and the rest of the materials were completed in time for the full pilot in March 2023.

Evaluation methodology

A mixed methods approach was selected for the final evaluation to assess both the overall perceived impact of the material and to explore further the experiences and attitudes of the students. The survey assesses student perceptions of the learning artefacts, the usefulness of the different pre-learning activities and the types of activity included within them. The survey also addresses perceptions of clarity, structure, and functionality. The qualitative element provides in-depth and rich insight into the experiences the students had with the material.

Semi-structured interviews have been conducted to gather data on the effectiveness of the interactive pre-lab materials. This type of interview is a specific form of conversation where knowledge is created through interaction between the interviewer and the respondent. According to the interpretive paradigm, knowledge is the result of multiple ‘truths’ emerging from the narratives of individuals situated in the same context (Kvale & Brinkmann, 2009). Semi-structured interviews allow for a flexible and open-ended approach to gathering information, allowing participants to share their perspectives and experiences (Miles & Huberman, 1994). These interviews have been used successfully in previous research to explore the effectiveness of educational interventions (Charmaz, 2006; Tavakol & Sandars, 2014). The interviews are being coded and analysed using thematic analysis (Braun & Clarke, 2012).

The Organic Chemistry module is designed not only to enhance practical laboratory skills but also to foster crucial transferable skills such as time management, teamwork, and effective communication. The practical activities in this module build upon the skills learned in the first-year General Practical Chemistry practical module. In the second year, the practical module involves more extensive experiments, twice the amount of lab time compared to the first year, and a greater emphasis on independent work.

The materials developed were rolled out to the full cohort of students in this module, which was a part of the 2022-23 academic curriculum for second-year students and has a total of 168 students enrolled. After the practical sessions were completed, students were invited to complete a follow-up survey (n=46, representing 27% of the cohort), while a subset of volunteers participated in semi-structured interviews (n=6). The analysis of these findings will be reported in a future article.

Conclusion

The initial feedback suggests that interactive pre-lab resources have the potential to enhance student preparation and confidence for practical lab sessions. Most students found them to be effective in preparing them for the experiment. The prototype evaluation enabled us to proactively address the problems students had with our initial materials and improve the likelihood of the final products to meet their needs and improve their pre-lab experience.

The feedback from the prototype is consistent with prior research which has found that interactive learning activities can improve student engagement and performance in hands-on activities (Hmelo-Silver et al., 2007). The use of interactive pre-lab resources can provide students with a more engaging way of learning and help them to better understand the equipment and procedures involved in the experiment. However, we have to ensure that the resources are not too long or difficult to interact with, as this can negatively impact student motivation and attention.

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