Co-created pre-training for undergraduate chemistry students through Interactive Chemistry Experiments (ICEs)

L. Milian (Chemistry), N Fern (Digital Learning Team), Beth Henderson (3rd year PhD Chemistry student), Charles Tkaczyk (2nd year PhD Chemistry student)

Objective

The development of a set of interactive learning materials to support novice chemistry students in preparing for a complex and time-consuming experiment. Initially developed for the module 'Practical Chemistry 2 Organic', encompassing 160 students per year, it could also be used across the wider undergraduate chemistry curriculum since it is a common experiment. Durham has no similar interactive teaching materials for Chemistry; this project provides a useful test case for developing future virtual experiment resources.

The project aims are:

- To develop an interactive version of the sodium borohydride reduction experiment and lab familiarisation materials
- To utilise DCAD's existing software and tools to full effect, assessing their suitability for future virtual experiment development
- To evaluate the impact of the interactive materials on the student experience and educational outcomes

Background

Led by staff from Chemistry and DCAD, and supported by student co-creators, the ICE project seeks to better prepare students for a time-consuming and complex experiment by providing them with an interactive resource that will allow them to rehearse experiment procedures and chemical processes and introduce them to unfamiliar equipment and environments. The need for this type of pre-training has been made clear by the COVID-19 pandemic. Our lab capacity is currently halved, so it is important that students can maximise their efficiency and make the most of the lab time they have allocated.

Students are often concerned about lab sessions due to a lack of practical skills, which can in some cases manifest as extreme anxiety when faced with lab work (Kolil, Muthupalani & Achuthan 2020). The pandemic has led to reduced and limited practical sessions, and students are even less confident in the lab now that they are returning to campus, with current second year students suffering from severe restrictions on their first-year experience. It is hoped that this resource will improve student preparedness and confidence to complete this experiment, with the added benefit of being a fall-back position in the event of further disruptions to face-to-face teaching.

This academic year, a prototype of the first interactive virtual experiment will be produced, tested and introduced. Students will be able to simulate this experiment at their own pace and in their own environment to enhance preparation. The virtual experiment comprises an interactive, structured experiment flow, with students able to move elements on their screens, and access explanations and contextual information. They will be able to perform the virtual experiment more than once and progress and improve using feedback provided.

Rationale

The use of multimedia instruction and simulation for chemistry teaching is not new, but is now gaining more attention, with evidence that it can improve student's self-efficacy and decrease anxiety concerning practical chemistry experiments when used as a pre-training intervention (Kolil, Muthupalani & Achuthan 2020) and can effectively supplement student skills in chemistry (Bortnik, Stozhko, Pervukhina, *et al.* 2017). While commercial packages exist, they can be prohibitively expensive, and are not always the best solution. Many such products suffer from being designed from a technological but not pedagogically aware perspective.

The Labster virtual laboratory material was reviewed prior to this project and while it was a polished product, it presented several problems from an educational efficacy and quality perspective. Labster does not score highly when considered in relation to cognitive load. It was felt to be visually complex with many extraneous elements, including background music, visual clutter, artificially generated voice overs and complex navigation. In particular, the material suffers from 'redundancy', in that the voiceover reads the same text that is on the screen for learners to read. Mayer (2021 p.198) has found through multiple research studies that "adding onscreen text that is identical to narration tends to hurt student understanding". Mayer also argues against the use of 'seductive details', since these serve to distract learners from what is relevant to learning, despite being interesting or entertaining for the learner.

It was considered important to employ an effective, but less stimulating and more focused methodology for this simulation experience, guided by recognised educational research such as cognitive load theory (CLT), multimedia learning principles (Clark & Mayer 2011) and educational psychology.

CLT refers to managing the limitations of our working memory, which is easily overwhelmed, by reducing the extraneous load created by how teaching is presented, structured and interacted with, and seeking to optimise the processing of intrinsic cognitive load presented by the material to be learned (Lovell 2020). The lab environment is noisy, busy, and full of different kinds of equipment. Our approach is to maintain fidelity where necessary, but 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 feedback on their actions. In this way, learners will be supported to develop their domain-specific and procedural knowledge outside of the high-pressure lab environment where it can be put into practice.

Practical chemistry experiments demonstrate high element interactivity, in that many concepts must be understood simultaneously in order to gain a grasp of the overall principles and procedures that are in-scope (Sweller 2010). 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.

While much of the initial planning for the interactive experiment has been completed, the challenge has been unpicking and structuring the material in a coherent way for a novice to understand independently. Students and Demonstrator staff were brought on board at an early stage to complement the academic input, and have been very useful in spotting gaps, providing context, and identifying common misunderstandings and mistakes. The funding provided by this grant will further support and accelerate this input.

Project Outline

Key deliverables and milestones

Project Plan 2021/22	D	J	F	M	A	M	J	J	A	S	O	N	D
Task 1: co-creation													
Task 2: review of content													
Task 3: Development													
Task 4: Usability testing													
Task 5: Revisions													
Deliverable 1: Prototype deployment													
Task 6: Evaluation													

Task 7: Content revision/redevelopment													
Task 8: Dissemination													

Tasks:

1. Cocreation with student developer and PhD students - finalise structure, script and format of interactive experiment (LM, NF, SD, SI, BH, CT)
2. Student developer reviews content needs and provides sense check, identifies weak points and feedback needs (SD, SI)
3. Development of interactive experiment (NF)
4. Usability testing and accessibility checks (NF, SI)
5. Revision prior to prototype roll-out (SD, NF)
6. Evaluation of prototype (LM, NF, SI)
7. Revision of content & further development (LM, NF, SD, BH, CT)
8. Dissemination of findings (LM, NF)

Deliverables:

1. Deployment of interactive experiment prototype (NF)

Project Team

The project management group meets regularly (at least monthly) and have oversight of the project as a whole. They are:

- Litka Milian, Assistant Professor, Department of Chemistry. Litka is responsible for managing the student input into the project, and for the provision of content and expertise related to the subject matter.
- Nicola Fern, Digital Learning Developer, DCAD – Nicola has worked at Durham University since 2020 and has previously worked in digital learning development within the NHS. She has a MA in Digital Technologies, Communication and Education from Manchester University, and was recently awarded AFHEA. Nicola is the developer responsible for the technical production, testing and deployment of the interactive assets.
- Beth Henderson, 3rd year PhD Chemistry student/Demonstrator
- Charles Tkaczyk, 2nd year PhD Chemistry student/Demonstrator

We have also had input from Sarah Belfield, 3rd year chemistry undergraduate student.

We will use funding from this grant to employ students to fulfil Student Developer & Student Interviewer roles. This will enable an enhanced level of co-creation, enable the project to meet its delivery targets and avoid relying on the understandably limited goodwill input from unpaid students.

The student co-creators are responsible for providing student-perspective input into the content, feedback and format of the interactive assets, and to help to ensure that the educational content is accessible to students of differing abilities.

Budget

Spending is largely expected to fund student time for the project, data collection/analysis and dissemination of the project. All student time is costed at Grade 4 (£10.78/hr). The hours will be split between two undergraduate students.

Much of the development time will be done over the December/January period. This comprises:

December 1st-17th & January 10th-31st

This gives us 3 weeks of term time working and 1 week of up to 20 hours during holiday time. Given two students working on the project, this equates to 36 hours termtime work, and 40 hours holiday time work (76 hours total). This may be adjusted/spread out more as required, as the PhD students may also do extra work within this budget. The work in this period will entail content development and revision and usability testing.

March 1st – 18th & Easter break

During March and April, as part of an iterative development approach, feedback from the think-aloud usability testing will be combined with input from the quick response forms provided for immediate feedback after students access the prototype to redevelop content where necessary. We have allowed for 3 weeks of term time work at 6 hours each per student (36 hrs total), plus 2 weeks at 20 hours per student during the Easter break (80 hours total) – for a total of 112 hours for this period.

Revision and further development to feed into a final version of the product for use in the next academic year will continue over the Summer, excluding May as this is the exam period. One student will be doing the interviews and analysis so only one student is costed for the 82 hours of development time remaining, which will be spread out across June and July as necessary.

Student Training: 28 hours = £301.84
Student Interviewer time: 20 hours = £215.60; Analysis/coding: 40 hours = £431.20 – Transcription will be done using built-in MS Teams transcription functionality and session recording.
Interview incentives: £400 (£20 per participant)
Student Developer time: 98 hrs termtime (to be worked across the duration of the project) @ 6 per week (£1,056.44), 172 hrs non-termtime (£1854.16)
Demonstrator consultancy: £431.20
Association for Learning Technology Conference 2022: £265 per participant (Day Rate) – 1 student attendee

Total: £4955.44

Evaluation Plan

We will use a mixed methods approach in evaluating this project:

1. Prototypes of the product will be tested using a think-aloud protocol with a sample of students to assess usability and gain understanding of user's cognitive processes.
2. Immediate feedback will be gathered from students using the prototype via a quick feedback form. This will be used to improve the prototype on an iterative basis.
3. The Student Interviewer will be trained to undertake semi-structured MS-Teams-based interviews with participants to assess their experience with the interactive material, their confidence to undertake lab activities, and how the pre-training impacted on their practical work.
4. We will compare the assessment marks for the lab report for this experiment, which comprises the summative assessment for this module, with historical marks to detect any differences in student performance.
5. We will interview experienced academic staff and Postgraduate demonstrators about their subjective observations of students' understanding during practical lab sessions, and how this compares with previous cohorts.

Impact Plan

The aim of the ICE project is to improve student confidence and preparedness to complete the Sodium Borohydride Reduction experiment in the lab environment. Should it prove successful, this approach could be rolled out to further experiments within the department, and could indicate the potential for the principles more broadly with the Faculty or the University.

We propose to disseminate the outputs of the project on a different number of levels:

1. We will disseminate the project internally via Scholarship of Teaching and Learning Forum,

departmental staff development days and Learning & Teaching events, as well as through DCAD fora such as the Digital Learning Newsletter and the DCAD blog.

2. We will disseminate the results of the project via the Three Rivers Conference and ALT-C.
3. We will produce a journal article on the University's adoption of interactive technologies for science at undergraduate level for submission to ALT's 'Research in Learning Technology'.

References

Bortnik, B., Stozhko, N., Pervukhina, I., Tchernysheva, A., et al. (2017) Effect of virtual analytical chemistry laboratory on enhancing student research skills and practices. *Research in Learning Technology*. [Online] 25. Available at: doi:10.25304/rlt.v25.1968 (Accessed: 2 November 2021).

Clark, R.C. and Mayer, R.E. (2011) *E-learning and the science of instruction : proven guidelines for consumers and designers of multimedia learning*. 3rd ed. San Francisco, CA, Pfeiffer.

Kolil, V.K., Muthupalani, S. and Achuthan, K. (2020) Virtual experimental platforms in chemistry laboratory education and its impact on experimental self-efficacy. *International journal of educational technology in higher education*. [Online] 17 (1). Available at: doi:10.1186/s41239-020-00204-3.

Lovell, O. (2020) *Sweller's Cognitive Load Theory in Action*. John Catt Educational.

Mayer, R.E. (2021) *Multimedia learning*. Third edition. Cambridge, United Kingdom, Cambridge University Press.

Sweller, J. (2010) Cognitive load theory: Recent theoretical advances. In: Jan L. Plass (ed.). *Cognitive load theory , (pp*. New York, NY, US, Cambridge University Press, vii. pp. 29–47.

Durham University
Department of Chemistry

Department of Chemistry
Science Laboratories,
South Road,
Durham, DH1 3LE.

Professor Karl Coleman CSci CChem FRSC
Head of Department

May 24, 2022

To Whom It May Concern:

Re: Head of Department Support Letter for the application 'Pre-training for undergraduate chemistry students through Interactive Chemistry Experiments (ICEs)'

I am writing to give my strongest support to the application of Dr Litka Milian (Chemistry), in partnership with Nicola Fern from the Digital Learning Team, for a DCAD Collaborative Innovation Grant to support undergraduate chemistry students through interactive practical experiments.

Chemistry is a practical subject and we spend a lot of time with students developing their practical skills. Recently, and especially with Covid, we have noticed that students are coming to study chemistry with very little practical experience, so this application is very timely in addressing this issue. It is often apparent, and as outlined in the application, students lack confidence before practical sessions as they feel they lack necessary skills. The same issue is felt with our Level 2 and 3 students who have received limited practical sessions due to lockdowns or Covid restrictions.

The development of interactive visual learning materials to support chemistry students in preparing for a practical class is very exciting and will be a huge learning benefit. The interactive experiments will help students visualize complex experimental work before they are exposed to the laboratory setting allowing them to gain confidence before trying things for real. This will have the added benefit of saving staff which is very limited in a laboratory setting; demonstrator staff maybe looking after 10 or more students at any one time. The ability of the student to vary the inputs and observe the impact without worrying about any dangerous effects of these changes will be extremely useful.

The project has had student input as a core feature from the beginning, and this type of learner-centric development and co-creation of material will result in an effective suite of learning material that is closer to the student's experience, knowledge and needs as a result.

The COVID-19 pandemic has exposed the Chemistry Department's lack of online pedagogic tools and pre-training material to maximise the efficacy of student lab time. Litka's project is hugely innovative for Durham's ability to take this forward, and if the project is a success we have ambitions to expand the roll out of this type of resource.

If the application is successful, it will be used as a stepping stone to develop more virtual experiments and this will have a positive impact on all aspects of practical chemistry in the Chemistry Department.

In summary, this is an innovative and interesting, timely and exciting application that has the potential to change the way we deliver practical chemistry in the Department and it has my full and unreserved support.

I you would like any further information please do not hesitate to contact me.

Yours sincerely,

Prof Karl Coleman

Head of Department

Department of Chemistry