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Frances Heaney*, Carmel Breslin, Steffi Thomas, Bernard T. Drumm, Ronan Bree, Brian Murphy, Aoife Morrin, Blánaid White, Eric Moore, Christopher Burke and Denise Rooney

From varied school science backgrounds to university: student expectations and perceptions of a UDL-aligned chemistry practical course

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Abstract: Within an overall context of supporting inclusivity and the school to university transition, this study aims to understand the second-level patterns of participation and perception of practical chemistry of first-year general chemistry students, and subsequently to gain their perception of a university practical chemistry course purposefully redesigned through the lens of UDL principles. Across two academic years all relevant students were invited to participate in two survey tools. The prior experience of first-year general chemistry students varied widely; >50 % did not participate in school senior cycle chemistry. Of those who did, methods of working and perceived value of practical work differed significantly. At the end of first year university, most students (62 %) perceived hands-on work as most beneficial to their learning of practical chemistry; of the remainder, approximately equal sized minorities perceived the pre-lab, post-lab and report writing phases as most beneficial. The finding that a substantial proportion of students feel their learning is best supported by activities outside the laboratory environment serves as a valuable reminder to educators, especially those working with large and diverse cohorts, of the importance of including well-designed pre-lab, post-lab and reporting activities in practical courses to help all students succeed.

Keywords: education in practical chemistry; EuroVariety 2025; first-year students; prior learning; universal design for learning

***Corresponding author: Frances Heaney**, Department of Chemistry, Maynooth University, Kilcock Road, Maynooth, Co. Kildare, W23 F2H6, Ireland; and Kathleen Lonsdale Institute for Human Health Research, Maynooth University, Kilcock Road, Maynooth, Co. Kildare, W23 F2H6, Ireland, E-mail: Frances.heaney@mu.ie. https://orcid.org/0000-0002-4603-0278
Carmel Breslin and Denise Rooney, Department of Chemistry, Maynooth University, Kilcock Road, Maynooth, Co. Kildare, W23 F2H6, Ireland; and Kathleen Lonsdale Institute for Human Health Research, Maynooth University, Kilcock Road, Maynooth, Co. Kildare, W23 F2H6, Ireland. https://orcid.org/0000-0002-6313-4271 (D. Rooney)
Steffi Thomas, Department of Chemistry, Maynooth University, Kilcock Road, Maynooth, Co. Kildare, W23 F2H6, Ireland
Bernard T. Drumm and Ronan Bree, Department of Life and Health Sciences, Dundalk Institute of Technology, Dublin Road, Dundalk, Co. Louth, A91 K584, Ireland
Brian Murphy, Department of Pharmaceutical Sciences and Biotechnology, Technological University of the Shannon: Midlands Midwest, Athlone, Co Westmeath, N37 HD68, Ireland
Aoife Morrin and Blánaid White, School of Chemical Sciences, Dublin City University, Dublin D09 V209, Ireland
Eric Moore and Christopher Burke, School of Chemistry, University College Cork, Cork T12 YN60, Ireland

1 Introduction

First year students arrive to university with widely different personal and academic backgrounds and potentially face challenges adapting to university life where academic and social struggles can accompany financial pressures and significant lifestyle changes. New arrivals can be unaware of the reality of a first-year STEM timetable or the academic workload and arrive ill-prepared for the social and academic independence associated with the school to university transition. First year attrition rates are causing concerns across the higher education sector. One study reported gender, age and performance at the entry point as indicators of the ease of adaption and likelihood of academic success for STEM higher education students.[1] Disengagement is widely accepted as a barrier to success. One Australian study proposes engagement involves a complex interweave of student and university factors with wellbeing nurtured through institutional choices (flexible workloads and timetables) and the development of self-efficacy through classroom practices which facilitate timely feedback, promote autonomy, and induce positive emotions.[2] A sense of belonging, feeling supported, intellectual engagement and workload stress are reported as measures of student experience,[3] further, it is known that academic mindset and experience of imposter syndrome relate to exam performance.[4] It is proposed that affective experiences and cognitive outcomes can be enhanced with educator cognizance of the diversity in their classrooms, and in the deliberate selection of appropriate pedagogical strategies.[4]

Most students entering our university have taken the established Irish Leaving Certificate. This senior cycle programme provides a broad education with some opportunity for specialisation.[5] Accordingly, academic preparedness at the school-university transition can vary widely across STEM disciplines. Institutional supports for students transitioning to university are available through the Maynooth Access Programme (MAP);[6] *Milo,* a digital resource to help build academic and wellbeing skills is available to all students. Maynooth University is also committed to supporting students through embedment of universal design for learning (UDL) principles to build a more inclusive learning environment for all.[7] UDL is a framework that supports intentional implementation of classroom strategies to create inclusive learning environments through offering multiple ways for students to access and engage with information and express their learning.[8] UDL and student centred learning (SLC), are the inclusive teaching practices most adopted in higher education settings.[9] The impact of implementing UDL concepts on academic attainment of chemistry students is generally favourably reviewed albeit it with a caution that different groups respond differently to UDL methodologies, and a caveat that continued study is required for a fuller realisation of its potential.[10] Galvin and Morgan share a perspective that UDL approaches provide valuable support for STEM educators in providing supportive, flexible and inclusive learning environments, including in the laboratory, with much progress already made on the island of Ireland and beyond.[11]

The trojan efforts made to maintain the practical component of chemistry education during the Covid-19 pandemic indicates its value to third-level educators. A quick review of the literature shows open source, in-house, and commercial resources were adopted. Pedagogic strategies included analysis of instructor provided data, virtual laboratories, remote at-home lab-in-a-box experiments, and, when permissible, hybrid lab classes with reduced numbers. Often, online background work and pre-lab assignments were incorporated.[12–21] We contributed to this space demonstrating successful adoption of a lab-centred continuous assessment framework to engage students, gather feedback and enact timely, informed improvements. More recently, we have adopted digital badges to foster engagement and promote the development and recognition of practical skills.[22,23]

Notwithstanding staff and student opinions on its educational value, the financial and resource demands associated with laboratory-based teaching mean it is appropriate that studies on the importance of laboratory work, laboratory education practices, faculty, student and demonstrator experience, and laboratory education research continue to attract attention.[24–34] Reid and Shah's foundational report places laboratory work in a space where school experience, lecture and tutorial content should also be considered. It emphasises the worth of pre-lab exercises, quality lab manuals and follow up activities to optimise learning. It also highlights the importance of clear communication of aims and objectives.[32] Seery and colleagues further offer laboratory education practitioners a succinct set of guiding principles covering all aspects of the laboratory experience from design to assessment.[33] Meanwhile, the learning outcomes and assessment of learning in the laboratory together with evidence-orientated practice and curriculum development are the focus of recent chemistry education research reviews.[24,25]

It is generally accepted that well conducted practical work can be motivating and help second-level students' understanding of scientific concepts.[35] It is also known that how students perceive their prior learning of practical chemistry relates to their preparedness for university. Furthermore, prior experience is correlated with first-year academic performance.[36] Despite the acknowledged benefits of practical work, the Royal Society of Chemistry's 2025 report indicates significant barriers remain to running practical chemistry classes in the UK and the Republic of Ireland. Insufficient time, challenging student behaviour, costs, a lack of equipment, lack of training and understaffing of science technicians are cited as impediments.[37]

2 Research questions

This study is concerned with the practical component of the education of first-year general chemistry students in a large enrolment class at one Irish University. It is framed by two research questions:

(1) What are the patterns of participation in senior cycle school chemistry and expectations for learning practical chemistry at university amongst first-year general chemistry students?

(2) How do students perceive the different phases of a first-year university general chemistry practical course purposefully redesigned with resources and classroom practices intentionally considered through the lens of UDL principles?

3 Methods

3.1 Context

General chemistry comprises two 7.5 ECTS modules taken by all first-year students (CH101, semester 1; CH102, semester 2). In each module the practical component comprises five laboratory-based experiments (wet-labs), and five workshop style activities (dry-labs) all of 3 h duration. Students occasionally performed the experiment with a partner or in a team but generally worked individually. Attendance was mandatory and recorded by instructors. In each module, assessment associated with the laboratory experiments contributed 20 % of the grade. This study considers practical chemistry education to include pre-lab, post-lab and reporting phases in addition to the experimental phase. Pre- and post-lab phases included a talk delivered by the lab demonstrator on arrival to/immediately prior to departure from the laboratory and a virtual lab activity to introduce/reinforce experimental techniques and concepts under development in the experiment. The experimental phase related to working with chemicals and equipment in the laboratory, and the reporting phase to preparation of the graded written assignment.

3.2 Student population

General chemistry sits within several four-year BSc programmes: Science, Science with Education, Biological and Biomedical Science, Biotechnology, Food Science and Human Nutrition, Physics with Astrophysics, Sport Science and Health, and Pharmaceutical and Biomedical Chemistry. Some participants ultimately major in chemistry, others in another area. This study spans academic years (AY) 2024 (320 students) and 2025 (381 students) and all students enrolled in general chemistry modules were invited to participate in this research study.

3.3 Purposeful redesign: resources and pedagogical approaches

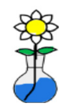
The first-year practical chemistry course was intentionally rethought with consideration of Reid and Shah's influential paper on the role of laboratory work in higher education[32] and CAST's three core UDL principles.[8] The focus was on provision of supports and implementation of classroom practices to optimize the learning experience and help all to succeed. Key aspects of the design, the pedagogical goals and the actions taken to deliver them in all phases of practical chemistry, pre-lab, in-lab, post-lab and report writing, are summarized in Tables 1–3.

The initial focus was on practices to engage and maintain student motivation, Table 1. A summary document clearly communicating information on the date, location and the focus of each laboratory session was provided to encourage the development of time management skills, and to minimize uncertainty (1.1). Virtual lab simulations were introduced as pre-lab work to alleviate worries about the laboratory environment. These educationally valuable activities[38] introduce the equipment and provide for authentic interactive practice of technical skills in a safe environment (1.2). Opportunities for engagement and reinforcement of developing practical skills were further extended through the introduction of post-lab virtual, scenario-based, problem-solving activities (1.2). To link sustainability to personal accountability, attention was drawn to sustainable laboratory practices.[39] Attractive icons were designed and regularly deployed to highlight waste management practices and responsible use of resources. Relevance was emphasized by deliberate illustration of concepts with real world examples (1.3).[40] Conscious decisions were made to encourage collaboration and integrate learning in the social domain.[24,25] At key points, laboratory time was ring-fenced for demonstrator-led discussions. Peer-to-peer learning was also promoted, for example, through an invite to "Discuss with two of your neighbours……", or to work as a team to solve a chemical puzzle (1.4). To foster self-esteem and build confidence a skills portfolio was included as a distinct post-lab reporting component for each experiment (1.5).

Opportunities for students to receive information across the different phases of practical chemistry was carefully considered, Table 2. The lab manual, recognized as a primary scaffolding resource,[32,33] was thoroughly reevaluated to ensure relevance, clarity and ease of use. To promote fluency and reduce the cognitive load associated with new vocabulary, a concise glossary of scientific and technical terms was created and prominently located at the front of the manual (2.1). Each experiment was presented in a well-structured, consistent manner with short sections dedicated to aims, objectives and learning outcomes (2.2). In addition to text, illustrations were added to help students grasp key information and support their professional development, e.g. through engagement with safety information (2.3), in choosing glassware or in visualizing technical instructions (2.4). Visual and auditory resources provided through the virtual labs platforms further extended the means by which key information was accessed.

Opportunities for expression of learning and the available supports to help students structure assignments were also reviewed, Table 3. The opportunity for immediate feedback during the simulated practice of technical skills bolstered a decision to embed virtual pre- and post-lab activities (3.1). Structured in-lab demonstrator-led discussions were deliberately introduced to create chances for verbal expression of knowledge in a social environment (3.2). Whilst preparation of a traditional lab report is accepted as an important component of undergraduate training, we agree with others that first-year students need support in reaching this goal.[30,33] For this reason, formats other than formal written reports were intentionally introduced in semester one. We designed a workbook to guide students in recording methods, experimental observations and results, and in forming conclusions. This template report was designed to limit anxiety associated with instructor expectations, build confidence, and provide variety. Depending on the experiment goals, boxes were provided for short answer questions relating to concepts, calculations and results. Graphed pages and results tables pre-populated with column headings were included as appropriate. In semester two, a formal class was held to help students build confidence in structuring a traditional report. A detailed rubric was provided, including a marking scheme and guidance on report structure and length (3.3). A skills portfolio was introduced to encourage self-reflection on how skills and strengths were developing following completion of each experiment (3.4).

Table 1: Pedagogical goals and actions taken to introduce multiple means of engagement in the different phases of practical chemistry following re-design of a first-year general chemistry lab course through the lens of universal design for learning (UDL).

<table>
<tr><th>Pedagogical Goal</th><th>Action (Primary phase of experimental work)</th></tr>
<tr><td>1.1. To minimize anxiety and promote motivation by helping students manage their time, plan and organise their work.</td><td>Design a Clear Laboratory Schedule (Pre-lab)
<table>
<tr><th>Lab Session</th><th>Dates (Wed. Thurs or Friday)</th><th>Room</th><th>Name of Session</th></tr>
</table></td></tr>
<tr><td>1.2. To support engagement with the concepts to be investigated and the experimental techniques to be employed in a low-stakes, safe environment by providing interactive virtual lab learning activities.</td><td>Introduce Virtual Lab Activities (Pre- and post-lab)
LearnSci
Labster
Incorporate pre-lab preparation activities that students can take multiple times including digital lab simulations.
Incorporate post-lab reinforcement activities.</td></tr>
<tr><td>1.3. To promote engagement and understanding of abstract concepts clarify the relevance by introducing real-world values and highlighting authentic applications.</td><td>Include Waste Management Information (In-lab)

Draw attention to personal responsibility to reduce, reuse and recycle, and the development of a culture of sustainability through repeated use of a visual cue.

Highlight Resource Management (In-lab)

Highlight opportunities for individual control of resource usage by repeated use of a visual cue.

Embed Real-World Examples (In-lab)

Emphasise the application of analytical chemistry techniques in the food and beverage industry, in one example, the focus is on colour additives, in another it is on determination of the acid content of a red wine.</td></tr>
<tr><td>1.4. To build community, promote active participation, inclusion and collaboration by introducing a supportive environment for social peer-to-peer learning.</td><td>Introduce Demonstrator-Led Discussions (In-lab)

Facilitate peer-to-peer learning and team-working activities.</td></tr>
<tr><td>1.5. To promote reflection, self-assessment, and professional development by providing a skills portfolio for each experiment.</td><td>Design a Skills Portfolio (Post-lab)
<table>
<tr><th colspan="7">Skills Portfolio</th></tr>
<tr><td>Preparation of dilute solution from a concentrate</td><td>Rate your level of confidence (circle)</td><td>1 (low)</td><td>2</td><td>3</td><td>4</td><td>5 (high)</td></tr>
<tr><td colspan="7">What did you find most challenging about the experiment?</td></tr>
<tr><td colspan="7">How will you improve your performance next time?</td></tr>
<tr><td colspan="7">Make two suggestions on how you could have done the experiment differently.</td></tr>
</table></td></tr>
</table>

Lab demonstrators spend significant face-to-face time with students. They play a pivotal role in supporting learning and it is important that they too are supported in developing their professionalism. Training emphasised the demonstrator role in facilitating executive function and building technical capacity. For example, demonstrators were asked to give guidance and feedback on student choices rather than mandate a pre-determined mobile phase for TLC analysis. Demonstrators were encouraged to help students develop planning skills, e.g. in timely population of their workbook, and in recording experimental observations and results in real-time. The training also emphasised the demonstrator's role in promoting inclusion and student engagement e.g. in facilitating in-class discussions with multiple small groups (3/4 students) rather than in one larger group involving

Table 2: Pedagogical goals and actions taken to diversify the means of representation in the different phases of practical chemistry following re-design of a first-year general chemistry lab course through the lens of universal design for learning (UDL).

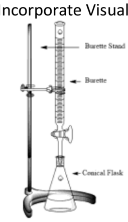
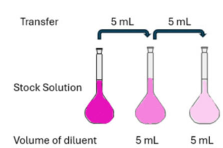
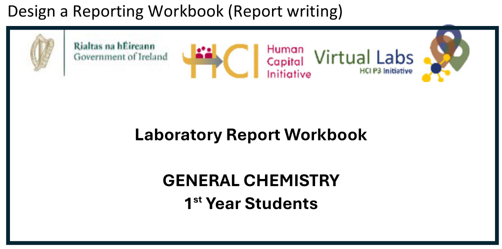
Pedagogical Goal	Action (Primary phase of experimental work)
2.1. To support students in understanding new and complex terminology by designing a resource which clarifies vocabulary and concepts.	Design a Glossary of Terms (All phases) Alphabetical list of Terms and their Definitions Accuracy: How closely the measured value of a quantity corresponds to its “true” value. Acids and Bases: According to the definition of Bronsted and Lowry:
2.2. To support learners who need clarity, structure and explicit information by designing a comprehensive, accessible lab manual with a clear and consistent style throughout.	Prepare a Well-Organised Lab Manual (All phases) Overview of the experiment Key terms associated with Experiment 1: Concepts involved with experiment: Learning outcomes of the experiment: On completion of this assignment, you should be able to: Useful resources associated with experiment:
2.3. To improve accessibility and ensure the culture of safe working practices reaches all by designing resources that provide critical safety information in more than one format.	Embed Safety Information (In-lab)  Communicate Key Safety Information and guidelines with appropriate pictograms
2.4. To support learners who value information in different formats by providing key information in visual and text formats.	Incorporate Visual Cues (In-lab)  Highlight the names of the glassware involved in experiments, e.g. titration  Use images to provide instruction and illustrate the techniques, e.g. serial dilution.
2.5. To expand the range of ways students can access information by providing alternatives to written formats.	Implement Virtual Lab Activities (Pre- and post-lab) LearnSci Labster Provide information in visual and auditory formats
2.6. To ensure clarity and accessibility, support planning and scaffold development of experimental and reporting skills by offering pre- and post-lab talks and immediate adapted responses to group and individual student queries.	Demonstrator Support at Personal and Group Level (In-lab) 

Table 3: Pedagogical goals and actions taken to enhance the means of action and expression in the different phases of practical chemistry following re-design of a first-year lab course through the lens of universal design for learning (UDL).

<table>
<tr><th>Pedagogical Goal</th><th>Action (Primary phase of experimental work)</th></tr>
<tr><td>3.1. To expand the opportunities for students to apply their knowledge by offering opportunities for formative assessment with immediate feedback within virtual labs activities which can be taken at a location of the student's choice.</td><td>Introduce Virtual Lab Activities (Pre- and post-lab).
LearnSci Deployed as a pre-lab activity that students can take multiple times.
Labster Deployed as a post-lab reinforcement activity.</td></tr>
<tr><td>3.2 To provide opportunity for verbal expression of understanding with immediate feedback in a community setting by designing the lab class with time dedicated to demonstrator led discussions.</td><td>Create Demonstrator-Led Discussion Points (In-lab)
</td></tr>
<tr><td>3.3. To build confidence and enhance motivation in approaching report writing by providing clear guidance on instructor expectation.

To afford students, across the academic year, a range of different ways to express their understanding by designing a workbook with templates for different styles of reports.</td><td>Design a Reporting Workbook (Report writing)

Rialtas na hÉireann Government of Ireland
HCI Human Capital Initiative
Virtual Labs HCI P3 Initiative
Laboratory Report Workbook
GENERAL CHEMISTRY
1st Year Students</td></tr>
<tr><td>3.4. To support planning and help students chart their progress by providing a skills portfolio for each experiment.</td><td>Design a Skills Portfolio (Report writing)
<table>
<tr><th colspan="7">Skills Portfolio</th></tr>
<tr><td>Preparation of dilute solution from a concentrate</td><td>Rate your level of confidence (circle)</td><td>1 (low)</td><td>2</td><td>3</td><td>4</td><td>5 (high)</td></tr>
<tr><td colspan="7">What did you find most challenging about the experiment?</td></tr>
<tr><td colspan="7">How will you improve your performance next time?</td></tr>
<tr><td colspan="7">Make two suggestions on how you could have done the experiment differently.</td></tr>
</table></td></tr>
</table>

their full cohort (16 students). Demonstrators were also asked to scaffold problem solving skills and to highlight links between practical work, theory concepts and the outside world. In these ways, demonstrator contributions potentially add to the quality of the student learning experience across all three core UDL principles (1.4, 2.6, 3.2).

All students purchased the lab manual and the post-lab reporting workbook. The demonstrator to student ratio was ~1:16. Digital resources included self-test quizzes, and virtual lab simulations from Labster and LearnSci. Assignment portals were provided on the course page on Moodle, our virtual learning environment, (VLE). There were no substantial changes to the module resources over the duration of this study.

3.4 Data collection and analysis

In each AY of this mixed methods study two survey instruments, hosted on onlinesurveys.ac.uk. were distributed to all enrolled students. A *prior learning* survey was posted on the CH101 course page in mid semester 1. Several papers could potentially be supported from this instrument, however, the scope of research question one determines the data relevant to this work. Here we report and analyse information on senior cycle STEM subject choice, and the subset of questions referring to school experience of frequency, ways of working, main learnings and perceived importance of practical work for reinforcing the understanding of chemistry, and expectations for learning in the practical component of first-year university chemistry.

In AY 2024 (November 2023), 166 of a possible 320 responses were obtained (52 %); in AY 2025 (October 2024), 170 of a possible 381 responses were obtained (47 %). Data from both years were combined on the basis that the two cohorts followed the same senior-school curriculum returning an overall response rate of 48% (336/701) for the *prior learning survey*. Qualitative data was examined for dominant themes.

At the end of semester 2 a *first-year university experience* survey gathered data on student perception of distinct phases of practical work. Survey items were not designed to measure UDL constructs directly but rather to measure student perception of the experience of learning with resources and practices informed by UDL principles. In both years the survey was distributed through the same VLE, Moodle, and posted on the CH102 course page. In AY 2024, 142 of 320 students responded remotely (44 %). In AY 2025, students were also given the opportunity to complete the survey during class time; 259 of a possible 381 responses were obtained (68 %). On the basis that, (i) there was no significant change to the first-year university general chemistry curriculum over the period, (ii) the same survey instrument was used each year: questions, scales and options were identical, and (iii) the same technical environment (Moodle) was used for both surveys, the asynchronous data from AY 2024 were combined with the synchronous data from AY 2025 giving an overall response rate of 57 % (401/701). No question was compulsory. Most respondents answered most quantitative questions. Response rates to qualitative questions varied more. Combined quantitative data was analyzed using Excel spreadsheets and graphically represented using GraphPad software. Qualitative data was subjected to a light thematic analysis at population level before student responses, grouped by the phase of the practical chemistry course found most beneficial, were examined for any potential alignment with the principles of UDL.

4 Results and discussion

4.1 Pre-university experience of practical chemistry

Knowing that prior learning and students' self-perception of preparedness for university chemistry correlates with first-year academic performance,[36] we were keen to understand the school senior cycle pattern of participation in chemistry amongst our first-year cohort. In our university, a minimum of one science subject is required for enrolment into the aforementioned programmes. This could be chemistry, biology, physics, agricultural science or the combined subject, Physics and Chemistry, often called "Phys-Chem". Accordingly, it cannot be assumed that all students in the class arrive with similar experiences.

Data shows biology (88.5 %) as the most popular school STEM subject followed by chemistry (48.1 %). Many students who have chemistry also have biology (72 %) or physics (10.1 %) as a second STEM subject. A small minority present three science subjects (10.7 %), Figure 1. The study also indicated a wide variation in the participatory experience of practical chemistry. A minority of students (18.2 %) had some experience of working independently, however, working in pairs (74.2 %) or small teams (62.9 %), or watching a teacher demonstration (45.9 %) were more common experiences, Figure 2a. The frequency with which experimental work was conducted ranged from almost never (8.2 %) to weekly (17.1 %) whilst fortnightly was the most common experience (43 %),

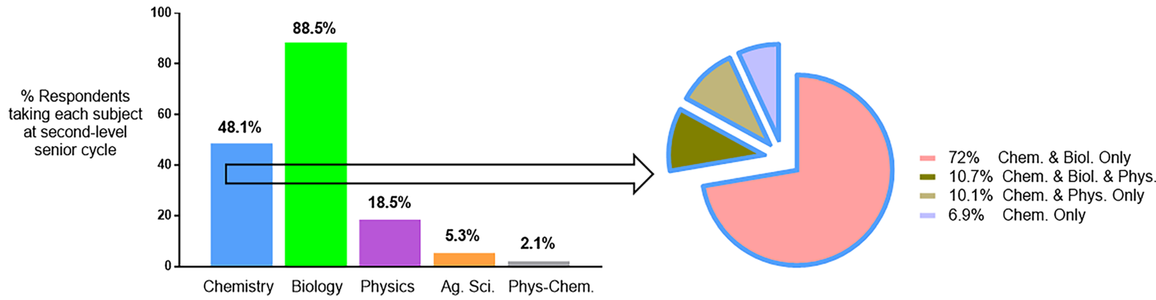


Figure 1: Participation in second-level senior-cycle STEM subjects.

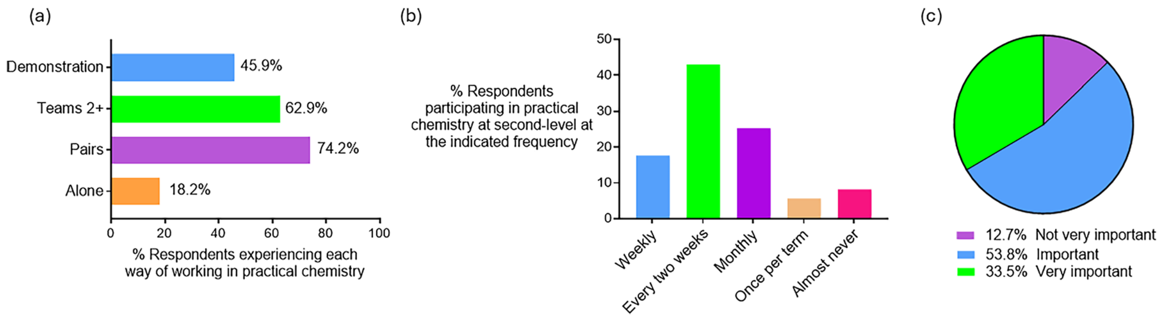


Figure 2: Patterns of participation in second-level senior-cycle practical chemistry: (a) ways of working, (b) frequency of practical work and (c) perception of importance.

Figure 2b. A small cohort perceived the experimental component of chemistry as not very important (12.7 %), however, for most it was deemed important (53.8 %) or very important (33.5 %) for their learning of the subject at school, Figure 2c.

4.2 Expectations for learning practical chemistry at university

In keeping with the large sample size, an open text question on the expectation for learning practical chemistry at university elicited a wide range of responses. Some complex replies integrated learning outcomes that could be construed as aligning with *experimental competences, conceptual learning, higher-order thinking skills, affective outcomes, and generic competences* as defined by Agustian.[41] Broad themes emerged from the student comments: motivation and expectation, safety and equipment access, social aspects of learning, and skill building, competence and relevance.

Motivation and expectation emerged as a theme with both hopes and anxieties expressed. One student reported "… *high expectations that it'll be fun as well as challenging*" and another an expectation for "*more interesting experiments with a wider range of outcomes*" or "*more understanding on what the experiment we carries out means*". Whilst one student shared a concern about workload "*I'm scared the work load will be too much*" others were hopeful of "*Being actively engagaed*". An "*I don't know*" response indicated uncertainty on what to expect. As commented by one student, "*pass so i can do other things*" suggested chemistry was not the primary academic focus.

Many responses fell within the safety and equipment access theme. Some replies focused on safe working practices and others on the environment. One responder expected the experience to "*be alot more professional and demanding*" and another hoped for "*superior equipment and technology*" or "*better equipment*". An aspiration for becoming a safe and competent experimentalist was expressed through comments including "*gain a deeper understanding of safety and experimental techniques*", "*Learn how to be safe in a lab*" and "*be fluent in all lab work*".

Responses clustering around ways of working and peer support prompted a theme on the social aspects of learning. There were expectations for individual, pair and teamwork with some wanting "*to gain more confidence with working by myself*" or "*To learn how to work more efficiently on my own*" or thinking "… *I'll have to be more independent this year*". Still others anticipated working together with more direction: "*Lots of experiment work in pairs*", "*more access to practical work and help from others*", "*To improve my Teamwork skills*".

Finally, skill building, competence and relevance emerged as a very strong theme. The hope that practical work would connect with, and help in the learning and understanding of material introduced in lectures was captured often. One representative reply anticipated that experimental work would help them "*To understand the basics of chemistry better*". One student replied, "*I want to learn how to use the equipment and see a physical visualisation of key concepts*". From others, the desire for relevance was expressed through hopes for "*Understanding why experiments are carried out*", "*learning in more detail why we're doing the experiments*" and "*That* *labs will actually be useful rather than just learning things for the sake of an exam*". Another anticipates "*more practical work that is more* clear" or "…… *practicals need more preparation*".

The themed survey responses represented diverse expectations which populated the three overlapping domains of affective, cognitive, and psychomotor learning.

4.3 Student perceptions of re-designed first-year practical chemistry course

The majority of respondents (62.3 %) found hands-on experimental work most beneficial to their learning of practical chemistry.[42] However, it is noteworthy that amongst remaining responses, pre-lab (14.5 %), post-lab (12.2 %) and report writing (10.8 %) phases were almost equally selected, (Figure 3). This finding reinforces the value of investing effort and resources in all phases of practical work to offer learning experiences that help all to succeed. Student perceptions of the learning benefits of practical work were explored by analysis of an open-ended question: "*tell us more about the specific components of practical work you find most beneficial to your learning*". Responses were initially analysed at population level and subsequently, according to the phase of the practical course found most beneficial to learning.

Emergent broad themes relating to the research questions are presented in Table 4. Learning and understanding, and the related, complementary theme of active learning emerged most prominently. Students frequently and clearly articulated the contribution of practical work to their wider learning in solidifying and reinforcing lecture content. Students perceived the *doing, being* and *seeing* of practical chemistry, as meaningfully connecting with theory and classroom teaching. Other responses clustered around related themes of resources and the value of experimentation over other formats of representation. Simulation activities were generally well received and there were helpful comments on how in-class completion of the workbook contributed to the learning environment. There were many comments on the social aspects of learning, most prominently on how demonstrators effectively supported learning in explaining *the how and the why*, in showing and helping, and in answering questions. Peer collaboration was viewed positively and whilst there was some articulation of the benefit of working alone, students were most vocal about demonstrator support. Direct comments on the affective experience were positive but not numerous. Many students valued the links to real-world settings, and the current and future benefits of skill development were also noted.

These responses suggest that, at population level, there is a perception that practical chemistry is important for learning with students feeling it helps understand concepts, gives opportunity to work with others and provides skills and competencies of value to their future selves.

Whilst the survey did not explicitly probe perceptions of UDL principles as applied in the re-design of this practical course, student quotes grouped by the phase of the practical chemistry course found most beneficial to learning, were examined for any suggestion of alignment. It could be construed that the students who reported that pre-lab work "*really helps get your mind into what will be done in the practical session ……rather than just doing it*" or who "*liked the way that the Pre-Lab work explained to me all the safety features before going into the*

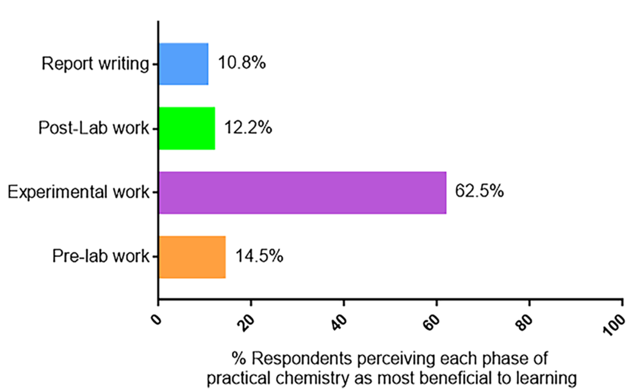


Figure 3: Student perception of the phase of practical chemistry most beneficial to learning.

Table 4: Themes identified from student feedback on the benefits of practical work.

Theme	Frequency	Supporting quotes
4.1. Learning and understanding Students see practical work impacts their learning through: – Making connections with theory – Clarifying concepts – Affording opportunities to apply concepts	151	“helped me getting a better understand of why i was doing the experiment” “helps to apply knowledge learned in lectures and solidifies information” “Clarifies concepts in a practical setting” “report writing most beneficial as it ties our lecture work and our lab work together more clearly”
4.2. Active learning Students report engagement of the mind as well as the hands and value learning from: – *doing* – *seeing* – *being*	111	“The experiment work helps me properly connect with the concept by being able to physically interact with it” “Doing the experiments helped understand what was going on and why” “The theory is never enough to actually understand something, doing it is what will” “Actually being in a lab and doing hands on learning”
4.3. Resources Students commented on their experience of the resources provided and their deployment: – Simulation activities – Visual content – Workbook	48	“lab simulations were very beneficial to understand the lab and the topics of chemistry associated” “pre lab shows videos which were really beneficial to actually see how to do certain procedures” “I thought doing the workbook in the lab as it allowed me to see where I was going wrong and how”
4.4. Reflection on modes of representation Students expressed views on different forms of representation with reference to: – Textual formats – Verbal formats – Visual formats	12	“I learn by doing and often chemistry can be hard if it’s explained and not shown.” “Reading only goes so far, actually conducting the experiments help a lot more and improves understanding” “Actually physical doing the experiment and not doing it online on a screen”
4.5. Collaboration Students experienced benefits from engagement with: – Demonstrators – Peers	44	“Working with demonstrators but also working on your own first” “the demonstrators helping and explaining” “good to have the opportunity to ask questions” “Small group demonstration” “I find working in pairs to be very beneficial, as it can be less stressful”
4.6. Affective experience Students expressed their feelings about practical work: – Personal – Environmental	9	“definitely a fun way for learning” “I enjoyed the experimental work as it added a visual aspect to experiments and reactions that really sticks and makes it easier to remember” “I liked that I could just get to work and work at my own pace” “Just doing it like. I love chemistry”
4.7. Skill development and real-world connections Students mapped their experience to: – Professional settings – Real world chemistry – Lab competencies	25	“wet lab write ups the most useful as they allowed me to make connections between the lectures and chemistry in the real world” “having the opportunity to work in the lab to enhance my laboratory skills” “Familiarised myself with glassware and equipment for future use” “Practice for future jobs”

actual lab" or found the pre-lab videos "*really beneficial to actually see how to do certain procedures*", validated the inclusion of learning activities deliberately introduced to be both engaging and varied.

Overwhelmingly positive views on hands-on experimental work centred on the impact of the laboratory environment and the *doing* of experimental work in supporting memorable learning. Students who indicated perceived benefits from seeing "*how certain things would work in the real world*", and being allowed to make "*mistakes and seeing what I had to do differently*" or "*learning how to handle chemicals in real lab environments*" capture the authenticity of the experience. These views could potentially be thought to align with principle of engagement. Views that the laboratory classes have given the "*experience to be good at the experiments in the future*", and "*skill familiarity and comfort to one day work in a lab*" are further suggestive of an engaging experience that promoted self-reflection.

The social aspect of learning in the laboratory was highlighted in many guises. Some students found the work "*fun and interesting*". Some liked working alone benefiting from "*thinking for yourself*" or finding it "*encourages learning and is very helpfu*l". For others, benefits accrued from working together. One student commented simply "*Communicating with people around*" as helpful whilst another considered "*group work helped my understanding as we all shared our knowledge*". The supportive and collaborative role of the demonstrator was widely cited. One commented on the benefit of "*being able to confide with my demonstrator*" and another noted "*caring demonstrators make understanding a lot easier*". Their contributions to "*group discussions*" and provision of "*more one to one learning*" were highlighted by different learners. Collectively, these responses could be taken to suggest the demonstrator role can be effective in promoting engagement, supporting understanding and facilitating alternative means of representation.

Students who benefited most from structured post-lab discussions provided responses that could potentially map to all three UDL principles. Some indicated these discussions helped "*develop my understanding*", "*reinforced the learning in the lab*" and were "*very realistic*". There were also views that the post-lab talk "*clearly explains and expands on the concepts explored in the experiment*" and "*helped me to complete the lab workbook questions*".

The lab simulations which were introduced to support learning across all three principles were generally, valued. One student commented that simulations were "*definitely a fun way for learning*". Students expressed benefits from being able to "*work at my own pace*" and revisiting the skills developed independently "*when i virtually go through the experiment a second time i understand it better*". Views that lab simulations "*helps me get better lab skills also it really lock your learning in with the questions it asks you throughout*" and are "*informative and helpful*" with beneficial "*explanations given through the simulations*" support the suggestion that students valued virtual lab simulations as a means of both representation and action and expression.

Structured introduction of demonstrator-led social learning and the practice of encouraging students to begin populating the workbook during laboratory time was important to those who most valued reporting. For some "*it allowed me to as(k) the demonstrator anything I was unsure of*", "*to see where I was going wrong and how*", or to better understand "*why we were doing the experiment*". For another it even prevented them from "*going home and forgetting what we did*". For one student these discussions "*contributes to active learning and better memory gain from the lab which I find beneficial when it comes to exams*". These responses could tentatively trace back to the deliberate efforts to enhance the demonstrator role through widening the means of action and expression.

Many were clear on how reporting cemented their understanding of the experiment and its connection to the learning that took place in lectures. For some, report writing promoted engagement because "*that's when you really link the theory to experimental data*" or it "*forces you to fully go back and explain what you did, results etc.*" One comment that the post-lab workbook "*reinforces that I understood what I was doing in the lab and not just following instructions*" and another that "*the questions it asks are very helpful in understanding concepts*" shows clear appreciation for the scaffolded nature of the workbook which was introduced to provide an alternative means of expressing learning.

Some students saw report writing as an opportunity for "*reflection on how and why everything was done*", to "*improves my skills" or "prepared us for final year*" suggesting that, for them, this phase of practical work promoted reflection on their professional development and potentially enhanced engagement.

5 Conclusions

This study suggests that in a country with a broad-based second-level education system prior experience of chemistry amongst students transitioning to university differs substantially, and that even for those who have taken the subject at senior cycle, the patterns of participation in practical chemistry varied widely. Our data further indicates that upon entry to university, in spite of differing backgrounds, expectations for learning practical chemistry were generally positive. The study also indicated a practical course revised through a UDL lens, was perceived as helpful for understanding concepts, providing opportunities to work with others and providing skills and competencies of future value. That most students found the experimental phase the most beneficial component of practical work was not surprising. However, the fact that, approximately equally sized minorities opted for each of the other phases (pre-lab, post-lab and reporting) is noteworthy. Thus, in this large general chemistry class, like in Atabek-Yigit and Senoz's study with science education students,[43] it is evident that one student's optimal learning moments differ from those of another. Therefore, we propose that it is essential that each phase of practical chemistry education is intentionally considered and carefully designed to support all students. Whilst our survey did not include UDL-specific questions, despite the heterogeneity of the incoming group, end-of-year supportive student comments on the value of structured pre- and post-lab work, multiple forms of engagement and enhanced demonstrator support, could be considered as endorsing the UDL practices incorporated into our revised practical chemistry course. Finally, educators from STEM subjects and beyond who are interested in institutional strategies to promote application of UDL are directed to a companion paper in this special issue by Rooney and co-workers.[44]

6 Limitations

The initiative was concerned with a single instructional context. It ran across two academic years, all enrolled students were invited as participants, consequently there is no control group, and it is not possible to conclude the effects it has had on the academic performance of the student cohort. The survey evaluated the broad student perception of the experience of learning practical chemistry; the current instrument does not directly evaluate UDL-specific implementations. A richer insight into the value of specific UDL-inspired interventions could follow from a future study which incorporated UDL-specific survey items and included more in-depth feedback from focus groups. It would also be valuable in a longer-term study to explore any impact of the course revisions on summative performance in the practical component of the course. We acknowledge that the decision to combine the 2024 and 2025 *first-year university experience* survey data despite the different distribution methods, *viz* asychronously on VLE only (2024) versus asychronously on VLE plus in-class on VLE (2025), and the different response rates, potentially pose a threat to validity. However, response-bias concerns are minimised as there were no significant changes to the first-year curriculum over the period, the technical environment was identical (VLE Moodle), responses were anonymous and the questions, scales and options were identical in both surveys. It could also be argued that any differences between the demographic captured via the predominantly synchronous survey (2025) and the remote survey (2024), reduces the bias resulting from a singular mode of collection with the combined data affording a more representative sample. As the prior experience and first-year experience surveys were not linked the data between the surveys can be compared at cohort but not at individual level. Neither does the available data permit relationships to be drawn between enrolment programme and either prior experience or first-year perceptions.

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