

## Students' experiences with interactive pre-laboratory multimedia in undergraduate organic chemistry

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### Abstract

This study explores second-year undergraduate chemistry students' experiences with a co-created, interactive multimedia pre-laboratory resource designed for a complex organic synthesis experiment involving sodium borohydride reduction and column chromatography. Drawing on reflexive thematic analysis of semi-structured interviews with six participants, the research identifies key themes including interactivity and multimodality, workload management, inclusivity for diverse learners, assessment literacy, resource cohesion, and laboratory preparedness. Students reported enhanced confidence, procedural fluency, and reduced anxiety through targeted videos, animations, quizzes, simulations, and virtual tours, which provided safe rehearsal spaces and clear mechanistic explanations, though challenges arose from repetition and timing pressures. Findings confirm the value of self-contained, accessible digital content in mitigating cognitive load and supporting equity in practical chemistry education, extending prior work on pre-laboratory multimedia resources. Implications advocate selective interactivity for high-challenge tasks, layered content for varied prior knowledge, and integrated assessment guidance to optimise impact across STEM disciplines.

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## Introduction

Interactive multimedia in chemistry education has a long history: pioneering work in the 1990s established the importance of multiple linked representations and interactivity in supporting conceptual understanding (Oliver, 1996; Russell et al., 1997). Contemporary implementations now encompass a wide range of formats, including videos, animations, quizzes, simulations, and virtual 360-degree tours, delivered through institutional Virtual Learning Environments (VLEs) such as Blackboard (van Dinther et al., 2023). These resources are particularly well-suited to pre-laboratory preparation, where the multi-step nature of laboratory procedures and the complexity of underlying chemical concepts can pose significant challenges when conveyed through text or verbal instruction alone. Interactive materials offer students dynamic, multimodal routes into both procedural understanding and conceptual engagement before they enter the laboratory (Clark & Mayer, 2016; Cresswell et al., 2019; Fern & Milian, 2024; Onyeaka et al., 2023; Rodgers et al., 2019; van Dinther et al., 2023).

One important benefit of interactive materials is that they can be designed to be accessible to a diverse range of learners. For example, videos can include captions for students who are deaf, hard of hearing, or have auditory processing disorder, while visual representations can support those who experience reading challenges. These materials can also be made compatible with assistive software tools for students with disabilities (Rutledge, 2025). Interactive resources offer particular advantages for students for whom English is an additional language (EAL): they provide visual aids and subtitles to support comprehension, and allow students to revisit content as many times as needed, at their own pace and from any location (Hurix, 2023; Kay, 2012).

It is important to note, however, that these benefits are not inherent to interactive media as such. Materials designed without Universal Design for Learning (UDL) principles may inadvertently create additional cognitive or navigational obstacles, particularly for students with disabilities or those unfamiliar with a given digital interface, thereby compounding rather than reducing barriers to access (Rose & Meyer, 2002; Rutledge, 2025).

Interactive pre-laboratory materials usually include a variety of learning content such as videos, animations, quizzes, simulations, and virtual tours. These enable students to visualise and conceptualise molecular interactions and how chemical reactions happen. They also give students a safe way to practice and learn without the dangers of handling real chemicals or equipment (Clark & Mayer, 2016; Lombardi, 2007).

However, there are some challenges to using interactive materials. Not all students have sufficient internet connection speed or the right devices at home, which can make it hard for them to use these resources (Oktadio & Pardede, 2024). Creating high-quality interactive materials also takes a lot of time, skill, and money (Shallcross, 2022). Some students might get distracted when learning online, or they may find it hard to get used to new ways of learning (BRIOLight, 2021). Also, if students rely too much on digital materials, they might miss out on important hands-on skills and face-to-face communication that are learned in the real laboratory (Seery, 2020; Telefónica, 2023; ter Horst et al., 2024).

## Methodology

This follow-up study extends prior development work by the same authors (Fern & Milian, 2024) and explores students' experiences with interactive pre-laboratory materials using semi-structured interviews.

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### *Participants and Module Context*

The research was carried out in the Level 2 Practical Organic Chemistry module at Durham University, which had 168 second-year students enrolled. This module builds on first-year laboratory skills, introducing advanced synthetic chemistry techniques alongside development of teamwork, time management, and communication. Compared to the first year, experiments are more complex, laboratory time doubles, and students work more independently.

### *Development and Use of Interactive Pre-Laboratory Materials*

In the Level 2 Practical Organic Chemistry module, most experiments were supported by a pre-laboratory information package delivered via Blackboard, comprising: a brief explanation of the experiment aims, an outline of the main techniques and skills involved, short videos demonstrating key procedures, and guidance on what to include in the associated assessment tasks. While these materials provided a useful foundation, they required students to navigate between multiple separate files and links in order to assemble everything needed for each practical session.

For one later experiment in the sequence, a sodium borohydride reduction followed by column chromatography purification, the standard pre-laboratory Blackboard package was replaced by a single, self-contained interactive pre-laboratory resource. Developed through a student-staff collaboration funded by a Durham Centre for Academic Development (DCAD) Collaborative Innovation Grant, the resource was co-created with paid undergraduate and doctoral student developers who provided feedback on clarity, pitch, navigability, workload, and accessibility, directly informing revisions prior to release to the full cohort of 168 students (Fern & Milian, 2024). The resulting resource consolidated, into one package, all elements previously distributed across separate files — experiment overview, techniques, skills, and assessment expectations, alongside expanded chemistry explanations, purpose-built visualisations of Durham-specific

equipment and procedures, links to additional background material, videos, animations, quizzes, simulations, virtual tours, and fully interactive, step-by-step procedural activities (for example, building and running a chromatography column).

Accessibility was a major focus: all materials included captions and alternative text, were compatible with assistive technologies for students with disabilities, and incorporated visual and audio features to support students using English as an additional language, ensuring that all students could access and review the content as often as needed. Usability was similarly considered: recognising that students may not have previously encountered this type of interactive interface, the resource opened with a brief navigational guide outlining its structure and the function of each interactive element type, reflecting Human-Computer Interaction (HCI) principles that unfamiliar digital environments can impose extraneous cognitive load and undermine engagement before learning begins (Nielsen, 1994). The resource was made available on Blackboard prior to each laboratory session, and students were encouraged to engage with it as a core component of their preparation.

### *Ethical Considerations*

Ethical approval was granted by the Chemistry Department Ethics Committee at Durham University (CHEM-2022-10-10T20:32:32). Several context-specific considerations were addressed. As the interviewing researchers also had a teaching relationship with the cohort, steps were taken to minimise power imbalance: participation was entirely voluntary, students were clearly informed that non-participation would have no bearing on their assessment or standing, and interviews were conducted after all module grades had been confirmed. Informed consent was obtained from all participants prior to interview, and all data were anonymised at the point of transcription to protect confidentiality.

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### *Data Collection: Semi-Structured Interviews*

After the practical sessions, all students on the module were invited to take part in individual semi-structured interviews to discuss their experiences with the interactive pre-laboratory materials. This interview format allowed students to share their thoughts in detail, and interviewers could ask follow-up questions based on the students' responses. Six students volunteered for these interviews. Participant details and thematic saturation are summarised in Table 1. Saturation was assessed in accordance with Braun & Clarke's (2020) phase 4 (reviewing themes): both researchers independently confirmed that no substantively new codes were identified after the fifth interview, and the sixth interview was included to corroborate this, following recommendations for rigor in small-sample qualitative work. The interviews were conducted online, each lasting 30 to 45 minutes, and were audio-recorded and transcribed for analysis.

**Table 1** Participant Demographics and Saturation Evidence

Participant ID	Background	Approx. Performance Level
P1	UK	Mid
P2	Intl	Mid
P3	UK	Mid
P4	Intl EAL	Mid
P5	UK	High
P6	Intl	Mid

*Note: Backgrounds: Intl = international non-EAL; Intl EAL = international English as Additional Language (per student self-reports on language needs); UK = domestic. Levels from prior laboratory marks (mid: 60-65%; high: 66+%); module n=168, response ~3.6%. Saturation: no new codes after P5.*

## *Data Analysis*

Reflexive thematic analysis (Braun & Clarke, 2012, 2020) was selected as the most appropriate analytical approach for this study, given its suitability for exploratory, participant-centred research where the goal is to capture the breadth and complexity of individual experiences rather than to test a predetermined framework. Unlike template or framework analysis, Braun and Clarke's reflexive approach foregrounds researcher subjectivity as a resource rather than a threat to validity, making it particularly appropriate for a small, interpretive follow-up study of this kind (Braun & Clarke, 2020). Accordingly, an inductive approach was adopted, allowing themes to be derived directly from the data rather than being driven by pre-existing theoretical frameworks.

The two authors conducted the analysis collaboratively, working independently on initial familiarisation, open coding in NVivo, qualitative data analysis software, and theme generation before converging through iterative discussions to resolve discrepancies and refine themes.

This followed Braun and Clarke's six phases: (1) repeated reading for familiarisation; (2) generating initial codes; (3–4) searching for, reviewing, and refining themes; (5) defining and naming themes; and (6) producing the narrative with illustrative extracts. The dual-researcher process enhanced trustworthiness through investigator triangulation, reducing individual bias while preserving data richness (Nowell et al., 2017). Table 2 summarises the main themes, alongside their relative prevalence and illustrative quotes.

**Table 2** Overview of main themes and prevalence (ranked by code frequency)

Rank	Theme	Codes (n)	Example Quote
1	Interactivity and multimodality	12	It's going back to that point of actively thinking, like being forced to actively think . . . about the content at hand, so interactive . . . activities are like the best at doing that. And I would say videos are not so good like they're on the low end for like achieving that.
2	Workload and timing	9	There were 23 different sections, so maybe combining all the column chromatography ones . . . not having to go over stuff you already know how to do would probably make it easier to focus . . . and you obviously have more time to do that.
3	Inclusivity/learning needs	7	Because of the language problem and not confidence enough, I usually do the experiment like I look at the instruction and take something and look at it again and like waste a lot of time . . . the animation thing helped me to be more confident and do the experiment faster.
4	Assessment literacy	6	They [teachers] like us looking into the mechanism in the discussion and so like having some maybe prompts towards that or just like a small thing going. This mechanism is a bit challenging. Like here's a hint or something like that.

			Otherwise you just have no clue what direction to go in.
5	Single source cohesion	5	I mean, they're much more cohesive cause I did the sodium borohydride one again like last night. I just ran through it and like you just know as you noticed, everything's in one package which is kind of nice. So it's just one link for kind of everything.
6	Laboratory confidence/prep aredness	4	When I go to the lab, I can be quicker than without doing that, I know, like I need to do step one or what is step one. And I remember I did this in the online [pre-lab].

*Note: Ranks based on NVivo code counts across transcripts; total themes=6 from iterative author discussions.*

## Results

The thematic analysis of six semi-structured interviews generated a set of connected themes that describe how students experienced the new interactive multimodal pre-laboratory materials and how these resources intersected with wider features of the second-year organic laboratory course. The analysis highlighted both clear benefits (particularly around preparedness, confidence and clarity) and some tensions, notably around workload, repetition, and the limits of what pre-laboratory work can realistically address.

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### *Preparedness, confidence and stress*

Students consistently reported feeling better prepared for the sodium borohydride experiment than for earlier labs, often linking this directly to the stepwise, all-in-one guide. Several contrasted the quite scared or uncertain feelings they had before previous labs, e.g., "I was quite scared because it's so much more independent than last year", with a sense of 'this isn't my first time doing this' after completing the interactive activities and using them to make laboratory notes.

Preparedness and confidence were closely coupled: feeling well briefed on procedures and equipment translated into greater willingness to get started independently and to ask demonstrators to check work rather than approve every step. While reduced in-laboratory stress enhanced procedural confidence, this did not extend to post-laboratory assessment, see assessment literacy theme in Table 2 ("no clue what [discussion] wants"), leading into the next theme of chemistry content.

### *Interactivity, media and multimodality*

Interactivity emerged as a central strength of the materials. Students repeatedly said they "learn better doing it" than from reading or passive video and described drag-and-drop and build-the-apparatus tasks as the closest possible substitute for being in the lab. Interactive Control of Substances Hazardous to Health (COSHH) assessment and column chromatography activities were seen as particularly powerful because they demanded active decisions and provided instant feedback, rather than feeling like a "guessing game".

At the same time, students differentiated between media types. Videos were valued for showing what slurries, thin-layer chromatography (TLC) plates or separation processes should look like, but were also described as easy to drift away from, especially when long or repetitive. Photographs of the actual Durham equipment were consistently

praised, both for helping students find the right kit in crowded drawers and for matching exactly what they would see at the bench, in contrast to more stylised animations. Several students suggested that short, targeted videos and photos, combined with concise text and select interactives, offered the best balance of clarity and efficiency.

### *Chemistry and mechanisms*

The guide's treatment of the underlying organic chemistry, particularly hydride transfer and comparisons of borohydride reagents, was experienced as clear and pitched at a level that felt reassuring rather than overwhelming. Students typically spent significant time looking through textbooks, lecture notes and papers to reconstruct mechanisms and rationalise yields. By contrast, the new resource made expectations more transparent and saved time.

However, views on the amount of chemistry varied. Some students appreciated having "from the ground up" explanations that revisited assumed first-year knowledge, especially when they felt they had "missed" or forgotten earlier content. Others perceived sections (for example, theoretical versus experimental yield) as covering familiar ground in too much detail, tending to skim these in favour of more novel or challenging material. For several participants, the most valuable addition was not extra content, but explicit signalling of what level of mechanistic understanding was realistic and acceptable for the laboratory report.

### *COSHH, safety and assessment literacy*

The interactive COSHH component was widely described as helpful for turning what had previously felt like opaque or "arbitrary" scoring into a more meaningful safety task. Working through ranges of "potential for harm" and reading the reasoning behind

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different answers appeared to normalise uncertainty and gave students a more nuanced sense of what counted as an acceptable judgement rather than a single “right” number.

At the same time, there was some frustration with duplication when students completed both the interactive COSHH work and a separate formal COSHH submission or peer-review activity, which could make the overall pre-laboratory package feel like “a lot of hassle” with limited additional learning. More broadly, students pointed to a disconnect between the detailed support offered for COSHH and technique, and the relative lack of structured guidance around what constitutes a strong discussion or how to integrate mechanisms and literature in post-laboratory reports.

### *Workload, timing and motivation*

Students generally felt the materials reasonable in time commitment (often 15–45 minutes), especially when used as a refresher shortly before the laboratory, and several reported that they saved time overall by reducing confusion and questions in the session itself. The self-contained “one link” format reduced the effort of finding and assembling resources scattered across different platforms, which they described as a significant hidden workload for other experiments.

The total pre-laboratory burden remained sensitive to competing deadlines and to whether students were encountering techniques for the first time or revisiting them. Interactive elements that revisited very familiar procedures (for example, rotary evaporation or basic reflux) could feel tedious or “too slow” when repeated, especially on older devices where loading times were noticeable. Students emphasised that their willingness to engage deeply depended not only on design but also on clear framing: positioning the resource as the primary way to feel ready for an independent laboratory, rather than an extra box-ticking task, was seen as important for sustaining motivation.

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### *Inclusivity, prior knowledge and learning needs*

The materials appeared to support a range of learners, including those who described themselves as anxious, perfectionist or neurodivergent. One student with OCD and ADHD highlighted the comfort of having “everything there” in one place, from assumed first-year mechanisms to nuanced reagent comparisons, which reduced the stress of worrying that something crucial had been left out. Others noted that the combination of concise text, visuals and interactive steps helped them overcome language barriers or difficulties “imagining” procedures from written instructions alone.

At the same time, participants recognised that what counted as “enough” or “too much” background differed between students and across the year. Several suggested that allowing students to bypass sections on techniques they already felt comfortable with, and signposting which parts were essential versus optional reinforcement, would help manage cognitive load while still offering a safety net for those who needed more repetition.

### **Discussion**

This study shows that a single, self-contained interactive pre-laboratory resource can do more than simply familiarise students with techniques; it can also shape how prepared, confident and supported they feel in a busy, high-stakes organic laboratory environment. In doing so, it extends earlier work on pre-laboratory videos and multimedia (Cresswell et al., 2019; Onyeaka et al., 2023; Rodgers et al., 2019) by highlighting the value of combining multiple media types and activities within one coherent package, and by foregrounding students' own accounts of workload, anxiety and inclusivity.

### *Preparedness, confidence and affect*

Students' descriptions align closely with the intended role of pre-laboratory materials in the literature: reducing in-laboratory cognitive load so that attention can shift from "what do I do next?" to interpreting observations and troubleshooting (Clark & Mayer, 2016; Seery, 2020). In particular, the interactive apparatus builders and stepwise COSHH exercises appear to have functioned as low-risk rehearsal spaces, allowing students to practise actions and decisions before they encountered time pressure, limited demonstrator availability, and the social scrutiny of the laboratory.

The interviews also underscore an affective dimension sometimes under-emphasised in design-oriented accounts: feeling prepared and feeling confident were tightly coupled, with students explicitly linking increased preparedness to lower stress and a greater willingness to work independently. This echoes broader work on multimedia learning, which suggests that clear, well-sequenced visual and interactive supports can reduce extraneous cognitive load and free up capacity for germane processing (Clark & Mayer, 2016), but adds students' own language around "not my first time doing this" as an indicator of perceived self-efficacy. At the same time, the persistence of anxiety around post-laboratory reports suggests that pre-laboratory design alone cannot compensate for opaque assessment criteria or limited feedback opportunities (cf. Seery, 2020).

### *Interactivity, media and "doing" chemistry online*

Students' comments about different media types resonate with evaluations of pre-laboratory videos and simulations elsewhere. As in other studies, short, targeted videos were valued for showing dynamic processes and end-points (Cresswell et al., 2019; Onyeaka et al., 2023), but were experienced as relatively passive and easy to "tune out" when long or repetitive. The combination of focused video with interactive tasks for active rehearsal integrates both content types to provide an optimised learning experience.

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However, the data also serve as a caution against assuming that more interactivity is always better. Highly granular simulations, especially when combined with technical issues such as slow loading, could feel tedious or unnecessarily time-consuming, particularly when they revisited well-rehearsed techniques like rotary evaporation. This aligns with broader concerns that poorly scoped interactive technologies may introduce additional friction or distraction, rather than supporting learning (BRIOlight, 2021; Oktadio & Pardede, 2024).

The students' suggestions point towards a more selective approach: reserving rich, stepwise interactives for conceptually or procedurally demanding tasks (for example, column chromatography, Schlenk lines), and complementing them with concise videos and photographs for routine operations.

### *Chemistry, mechanisms and assessment literacy*

A striking theme in the interviews was the importance of the resource as a “single source of truth” for mechanistic explanations and expected levels of detail. Students described the hydride transfer section as clearer and more usable than typical textbook or lecture materials, and emphasised how helpful it was to be told explicitly when a mechanism was genuinely uncertain, and what level of reasoning was realistic for their stage. This aligns with arguments that multimedia resources can provide curated, discipline-specific explanations that are better aligned with local expectations than generic texts (Fern & Milian, 2024; Kay, 2012).

At the same time, our findings complicate any simple narrative of “more chemistry is better”. For some, revisiting assumed first-year content was experienced as unnecessary repetition, while for others the same material offered essential recap and reassurance. This variability is consistent with work on prior knowledge and the “expert blind spot”, in which instructors underestimate how much scaffolding students need (Kay, 2012; Seery, 2020). The interviews suggest that layering information, using tabs, optional sections and clear labels to distinguish “core” from “background”, may allow

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students to self-differentiate, while still ensuring that those who need more foundational support can access it without stigma.

### *COSHH, safety and the nature of judgement*

The interactive COSHH activity illustrates how digital materials can be used not just to deliver information, but to open up disciplinary judgement practices. Students moved from viewing COSHH scoring as a largely arbitrary exercise to seeing legitimate ranges of acceptable values, and appreciated being shown how safety decisions are reasoned rather than merely marked right or wrong as would be done with a simple quiz. This aligns with trends in laboratory education that emphasise safety as a site of higher-order thinking rather than compliance alone (Seery, 2020) and resonates with work using interactive and game-based approaches to help students internalise abstract rules and thresholds (Oktadio & Pardede, 2024).

Yet there were also concerns about duplication when COSHH-related work spanned multiple platforms and assessment formats. From a design perspective, this reinforces the need to consider the “assessment ecology” as a whole: interactive components are most likely to be perceived as valuable when they clearly complement, rather than replicate, existing tasks, and when the purpose of each activity in the learning and assessment cycle is explicit.

### *Workload, timing and motivation*

Students’ accounts of workload are finely balanced. On one hand, many perceived the resource as time-efficient, especially when compared to the effort of searching for multiple documents and sources across different systems, a finding that echoes wider concerns about “hidden” access work in digital learning environments (Fern & Milian, 2024). The “one link” design appears to reduce this access burden, and several

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students emphasised that the resource helped them use laboratory time more effectively by reducing basic procedural queries.

On the other hand, motivation emerged as a persistent constraint: even well-designed materials compete with other assessed work, and students were candid that deadlines and grade weightings shaped how thoroughly they engaged. This mirrors broader critiques of technology-enhanced learning that stress the importance of alignment between digital activities, credit, and perceived payoff (BRIOlight, 2021; Telefónica, 2023). The students' comments suggest that framing the resource explicitly as the primary route to feeling in control in the laboratory, rather than as an optional add-on or purely summative hurdle, may be just as important as the specific media choices.

### *Inclusivity, accessibility and diverse learner needs*

The findings reinforce the potential of interactive multimedia to support inclusivity, in line with work on digital accessibility and flexible pacing (Baumann & Melle, 2019; Hurix, 2023; Sloan et al., 2006). Students with declared neurodivergence and those reporting language-related challenges described the resource's combination of clear text, visuals, and repeatable interactives as particularly valuable, emphasising the comfort of having "everything there" and the ability to revisit material without judgement. This aligns with Universal Design for Learning principles, which advocate multiple means of representation and engagement, and suggests that relatively modest design choices (captions, alternative text, chunked sections) can have disproportionate benefits.

At the same time, inclusivity here is not simply a matter of adding more media. For some students, repeated interactives on familiar equipment or long sequences of small clicks were experienced as tedious, especially on older devices, and could undermine engagement. This points to the importance of co-design and iterative refinement with students, to ensure that accessibility and scaffolding do not inadvertently increase cognitive or temporal load for those who already feel confident.

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### *Limitations and implications for practice*

This study is necessarily limited by its small, self-selecting interview sample, drawn from a single institution and module, and by its focus on students who had already experienced one iteration of interactive pre-laboratory materials. The accounts are rich but cannot be taken as representative of all students, and the work does not directly link perceptions to objective measures of performance or error rates in the laboratory. Nevertheless, the depth of the thematic analysis offers a detailed picture of how particular design choices play out in practice, and where tensions and trade-offs are felt most acutely.

For practice, the findings suggest several priorities for chemistry departments and educational developers. First, investing in a small number of high-quality, self-contained and ideally reusable interactive resources for key bottleneck experiments or techniques may offer more value than attempting to “digitise everything”. Second, designing for flexible pathways, clearly marked “essentials”, optional refreshers, and layered explanations, can help accommodate diverse levels of prior knowledge without overburdening students. Third, integrating explicit assessment guidance and discussion-focused prompts into pre-laboratory materials could help bridge the current gap between procedural preparedness and post-laboratory confidence, an area that merits further investigation alongside more traditional evaluations of skill development and safety outcomes (Fern & Milian, 2024; Seery, 2020). These findings offer generalisable principles for interactive pre-laboratory design across higher education disciplines, particularly in STEM where procedural anxiety and fragmented resources are common.

Beyond chemistry, the emphasis on self-contained, interactive 'rehearsal spaces' (Table 2) addresses universal pre-practical challenges in fields like engineering, biology, and nursing simulations. For instance, modular interactives that layer core vs. optional content, supported by student comments on skimming familiar procedures, enable scalability for large cohorts with varying pre-existing knowledge. Departments could prioritise 3-5 'high-challenge' activities per module (e.g., sterile technique in

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biosciences), integrating assessment prompts to bridge procedural confidence with critical reflection, as students requested explicit guidance on discussion sections. Such targeted digital scaffolding reduces cognitive load while promoting equity, aligning with universal design for learning principles that are applicable across institutions.

The study relies solely on perceptual data without direct quantitative links to laboratory outcomes, such as time-to-task-completion, procedural error rates, or safety incident logs; this was a deliberate scope choice to prioritise rich thematic depth in a follow-up to prior development-focused work, but future iterations could integrate such metrics via pre/post comparisons.

## Conclusions

Interactive, self-contained pre-laboratory materials offer a powerful way to support second-year chemistry students in feeling prepared, confident and independent during demanding organic practical sessions. By combining targeted interactivity, clear chemistry explanations and real-world visuals in one accessible package, these resources address key barriers to effective laboratory learning, from procedural anxiety to fragmented preparation, while accommodating diverse learner needs.

The findings emphasise that success hinges not just on media richness, but on thoughtful scoping and task selection: reserving granular simulations for high-challenge tasks, layering content to match prior knowledge, and explicitly linking preparation to assessment expectations. When framed as the primary route to laboratory readiness, such materials can transform pre-laboratory work from a compliance chore into a meaningful rehearsal space, ultimately freeing up in-laboratory time for deeper chemical thinking and inquiry.

Future iterations should prioritise student co-design to refine pacing and flexibility, alongside quantitative measures of laboratory performance and safety to complement these rich experiential accounts. With targeted investment, interactive pre-laboratories

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hold clear promise for enhancing equity, efficiency, and engagement in similar chemistry curricula.

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