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A Formula for Inclusion: Dyslexia-Informed Universal Design of Chemistry Laboratories

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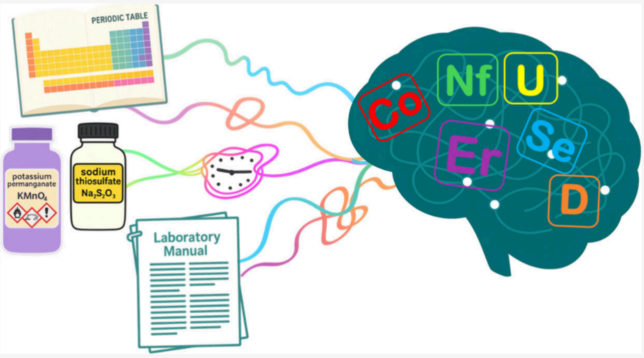

ABSTRACT: Dyslexia is one of the most prevalent Specific Learning Difficulties (SpLDs) and presents challenges that extend beyond reading and writing to include difficulties in information processing and working memory. Although dyslexia has been widely examined within education more broadly, recent reviews highlight a striking lack of chemistry education research addressing this issue, particularly within undergraduate laboratory contexts. This article reports findings from a pilot design-based study in which dyslexic undergraduate chemistry students were engaged as partners to identify discipline-specific barriers in laboratory learning and to codesign more inclusive laboratory materials and resources. Students highlighted barriers in interpreting chemical notation, following complex laboratory protocols, and processing dense textual information. In response, and informed by Universal Design for Learning (UDL) and Cognitive Load Theory (CLT), we developed and implemented targeted laboratory design strategies, including structured visual materials, dual-format chemical labeling, and scaffolded skill development within a spiral curriculum. These UDL-informed approaches demonstrate how reducing the extraneous cognitive load in undergraduate chemistry laboratories can enhance accessibility and support more inclusive laboratory participation.

KEYWORDS: *Inclusive Chemistry Education, Universal Design for Learning (UDL), Cognitive Load Theory, Dyslexia, Neurodiversity, Accessibility, Design-Based Research*

■ CHALLENGES OF LEARNING IN THE CHEMISTRY LABORATORY

Learning in a chemistry laboratory is demanding, requiring students to process and act on multiple forms of information simultaneously.[1,2] Students are often required to read and interpret written instructions, chemical notation, diagrams, and safety information while performing manual dexterity tasks under time pressure in a high-sensory environment. These activities involve moving between symbolic, submicroscopic, macroscopic, and procedural information, all of which draw on working memory and can contribute to high intrinsic cognitive load.[1,2] Laboratory protocols also typically involve multistep procedures, complex sequencing, and frequent switching between instructions, equipment, and experimental observations. When these materials are not clearly or consistently presented, they can introduce unnecessary extraneous cognitive load, limiting the working memory resources available for conceptual understanding.[3,4]

Chemistry laboratory environments present cognitive and perceptual challenges for a wide range of learners, including those with Specific Learning Difficulties (SpLDs). SpLDs encompass a diverse group of conditions, each associated with distinct learning profiles and support needs. While many of these conditions can influence how students engage with laboratory work, this section focuses specifically on dyslexia, given its prevalence in the student population and its particular relevance to the interpretation of symbolic notation, procedural instructions, and visually dense materials commonly encountered in chemistry.

These general demands apply to all learners, but they can be especially challenging for students with dyslexia, whose cognitive profiles may make certain aspects of chemistry laboratory work more difficult.[1,5−7]

■ ADDITIONAL CHALLENGES FOR DYSLEXIC LEARNERS IN THE CHEMICAL SCIENCES

Dyslexia is one of the most widely recognized Specific Learning Difficulties (SpLDs) in the United Kingdom, affecting an estimated 10−15% of the population, with around 4% being

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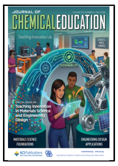

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severely affected.[8] While often simplified as a reading disorder, dyslexia is a multifaceted neurocognitive condition that influences phonological awareness, working memory, and processing speed.[5,8] Research literature increasingly characterizes it as a lifelong neurodevelopmental difference, a view reflected in UK educational policy and inclusion guidance.[9−11] Although reading may be affected, dyslexia also shapes how learners decode symbols, retain multistep information, and interpret visually dense materials.[6,11]

In chemistry, these difficulties can be particularly pronounced. Dyslexic students must interpret mixed-case chemical symbols, subscript and superscript notation, structural formulas, and technical terminology, all of which draw heavily on working memory and perceptual processing. Previous research has shown that dyslexic learners may struggle to discriminate between similar chemical symbols or nomenclature, follow complex laboratory procedures, and connect written formulas with reagent labels.[6,7,12]

Despite the prevalence of dyslexia, a recent bibliometric review by Cídlová et al. and references therein highlight a striking lack of chemical education research addressing this issue.[12] Their Web of Science search identified only 49 publications relating to dyslexia in scientific education, with only three articles explicitly focusing on chemistry. This disparity highlights a significant gap between the widespread nature of dyslexia and the evidence base forming inclusive chemistry pedagogy. This pilot study therefore collaborated with dyslexic undergraduates to identify discipline-specific barriers and to codesign inclusive laboratory resources informed by Universal Design for Learning (UDL) and Cognitive Load Theory (CLT).[1−4,13,14]

THE NEED FOR RESEARCH AND PRACTICE REFORM

The limited literature suggests two parallel needs. First, there is a research need for a deeper understanding of the discipline-specific challenges faced by dyslexic learners in chemistry, particularly in laboratory environments where cognitive load is high, in order to improve equity for these learners. Second, there is a practical need for inclusive instructional design that proactively reduces barriers, rather than relying solely on individual accommodations. Many students with dyslexia, or related neurodivergent profiles, remain undiagnosed or actively choose not to disclose, meaning that reliance on accommodations alone may leave important needs unmet.[15,16]

Research on accessibility and inclusion in STEM more broadly has highlighted the wide range of barriers experienced by disabled and neurodivergent learners, including those with physical, sensory, or attentional differences.[5] These studies provide an important backdrop for understanding the challenges faced by dyslexic students; however, relatively little work has examined how such issues manifest specifically within undergraduate chemistry. This absence of chemistry-specific dyslexia research underscores the need for studies that investigate how learners experience the demands of symbolic language, laboratory procedures, and multimodal information, which are characteristic of this discipline.

To address both of these needs, inclusive approaches must be embedded at the outset of the curriculum and resource design. By examining the barriers experienced by dyslexic chemistry students and codeveloping responsive materials based on their input, educators can create laboratory environments in which all learners, regardless of cognitive profile, can participate equitably. Dyslexia frequently co-occurs with other neurodevelopmental differences, such as attention-related or sensory processing differences, and many students experience overlapping learning challenges that do not fit neatly within a single diagnostic category.[5,17−20] In addition, a substantial proportion of students remain undiagnosed or choose not to disclose specific learning differences, meaning that laboratory cohorts are likely to include learners with a wide range of cognitive profiles.[21,22] While this study focuses explicitly on dyslexic learners and draws on the experiences of dyslexic student participants, it is not possible to separate dyslexia-related challenges from co-occurring factors within this group.[15] Rather than attempt to isolate individual conditions, this work adopts a dyslexia-informed approach to inclusive design that recognizes learner variability as a normal feature of laboratory teaching. Framing the work in this way allows the resulting design strategies to support dyslexic learners while also offering potential benefits to students with comorbid profiles and to the wider student cohort. In this paper, we use the term *barriers* to refer to features of laboratory design that may hinder equitable participation or increase unnecessary cognitive load, and *challenges* to describe students' reported experiences of navigating these features. We further distinguish between *laboratory materials* (core teaching artifacts such as laboratory manuals, in-lab worksheets, and printed procedural instructions) and *laboratory resources* (supporting items such as prelaboratory instructional videos, signage, dual-format labels, and other adjunct media) designed to enhance preparation and reduce extraneous cognitive load.

UNIVERSAL DESIGN FOR LEARNING AND COGNITIVE LOAD THEORY AS FRAMEWORKS FOR INCLUSION

Universal Design for Learning (UDL) and Cognitive Load Theory (CLT) together provide complementary theoretical frameworks for reducing barriers in chemistry laboratory teaching by accounting for learner variability and the limits of the working memory.[3,14,23,24] The UDL principles of representation, engagement, and expression provide a structured way to design resources that support this variability from the outset rather than through individual accommodations. Within chemistry laboratories, these principles align closely with established evidence on cognitive load and on the use of multiple representations.[25−27] Clear visual structure, multimodal resources, and deliberate scaffolding have all been shown to reduce unnecessary processing demands and to support students in managing the symbolic and procedural complexity of laboratory work.[1,2,27] These connections illustrate why UDL provides a relevant theoretical lens for examining and responding to the difficulties experienced by dyslexic learners in laboratory settings.

Alongside Universal Design for Learning, this work is informed by Cognitive Load Theory (CLT), which describes how learning is constrained by the limited capacity of working memory.[3,4,14] CLT distinguishes between intrinsic cognitive load, arising from the inherent complexity of the material, and extraneous cognitive load, imposed by poorly designed materials or unnecessary processing demands. In chemistry laboratories, students must often interpret written instructions, chemical notation, equipment, and safety information simultaneously, which can result in a high cognitive load. For dyslexic learners, this burden may be further increased by difficulties with dense text, symbolic representations, and inconsistent visual formats. Designing laboratory resources that reduce extraneous cognitive load through clearer layout, consistent labeling, and multimodal representations can therefore support more effective engagement with the underlying chemistry.

Together, these frameworks informed both the identification of discipline-specific barriers and the iterative development of redesigned laboratory resources. UDL provided the overarching structure for inclusive design, while CLT offered a cognitive rationale for reducing unnecessary processing demands. The codesign process ensured that these principles were grounded in the lived experiences of dyslexic students.

RESEARCH QUESTIONS

- RQ1. What discipline-specific cognitive and perceptual barriers do dyslexic chemistry undergraduates experience in undergraduate laboratory settings?
- RQ2. How can UDL-informed design principles be applied, through a dyslexia-informed codesign process, to create more accessible and inclusive laboratory materials and practices?
- RQ3. How do students perceive the clarity, usability, and inclusiveness of the redesigned laboratory materials and laboratory resources?

These questions reflect the three phases of the design-based research process: identification of barriers (RQ1), iterative resource development (RQ2), and evaluation of student perceptions (RQ3).

DESIGN-BASED RESEARCH STUDY: PARTICIPANTS, METHODS, AND ANALYSIS

Study Design

This study used a design-based research (DBR) approach to investigate the barriers experienced by dyslexic chemistry undergraduates and to iteratively develop inclusive laboratory materials informed by their feedback. Design-based research (DBR) is an interventionist methodology that seeks both to understand learning processes and to generate practical design principles through iterative cycles of analysis, development, implementation, and refinement.[28,29] It is particularly suited to complex educational environments where contextual factors shape both learning experiences and instructional design. By integrating theory-informed design with systematic reflection on practice, DBR enables the development of locally grounded yet conceptually transferable design principles.[29] DBR is appropriate when the aim is both to characterize learning challenges and to generate practical design solutions through cycles of analysis, development, implementation, and refinement. The three research questions aligned with the phases of the DBR cycle: RQ1 focused on identifying discipline-specific barriers through audit and student discussion; RQ2 guided the iterative codesign and refinement of laboratory resources; and RQ3 evaluated students' perceptions of the redesigned materials.

Participants

Throughout this paper, the phrase "student participants" refers to the 13 dyslexic undergraduates who took part in the codesign study. The project originated in routine laboratory teaching when a student was observed spending considerably longer than peers reviewing the laboratory materials before practical sessions. In conversation, the student explained difficulties interpreting chemical formulas and matching symbolic notation in the laboratory materials with the names on reagent bottles. Initial reasonable adjustments were implemented and were received positively; subsequent inquiries from other students prompted a broader exploration of inclusive design across the practical chemistry course.

Seven first-year students volunteered for the initial codesign phase (Stages 1 and 2) and contributed to the earliest iterations. After a general invitation by e-mail, two second-year and four third-year students joined, giving 13 dyslexic undergraduates in total. A broader group of 25 dyslexic students (including some but not all of the codesign participants) completed the post-redesign questionnaire in Stage 3. Ethical approval was granted by the University of Oxford Medical Sciences Interdivisional Research Ethics Committee (ref R90704/RE001), and all participants provided informed consent for anonymized use of their contributions.

Iterative Development Cycle

The DBR process comprises three stages.

Stage 1: Audit and analysis. The teaching team analyzed existing laboratory materials, reagent labels, assessment templates, and associated prelaboratory resources to identify potential sources of cognitive and perceptual load for dyslexic learners. Student participants examined these materials and identified sections that they found difficult to interpret or navigate. The review began with first-year laboratory materials (as they underpin later work) and incorporated insights from second- and third-year students who reflected on features that had previously caused confusion. This combined staff- and student-led review highlighted barriers, such as dense text, inconsistent formatting, ambiguous symbolic notation, and mismatches between laboratory materials terminology and reagent bottle labels.

Stage 2: Codesign and revision. Student participants reviewed the teaching team's draft versions of laboratory materials, reagent labels, chemical reference lists, and other supporting materials and provided feedback on clarity, organization, and usability. The teaching team revised the materials in response to this feedback; updated versions were then re-reviewed by the students. This revision−review cycle was repeated across multiple iterations to progressively refine the resources.

Stage 3: Broader evaluation. The redesigned resources were evaluated via a short questionnaire completed by a wider group of dyslexic students ($N = 25$), including, but not limited to, the 13 student participants involved in the codesign process. The questionnaire focused on the clarity, usability, and perceived usefulness of the alternative-format materials during laboratory work. Feedback from this wider group was strongly positive and informed the decision to make alternative-format resources available more broadly. In line with UDL principles, access to these materials was subsequently offered to all students as part of the standard laboratory provision rather than as case-by-case accommodations.

Data Collection

Three complementary data collection methods were used to address the research questions.

1. Audit of existing laboratory materials

   Student participants examined laboratory materials, reagent labels, assessment templates, and prelaboratory resources and highlighted passages that had previously caused confusion (for example, the relationship between potassium permanganate and $KMnO_4$).
2. Small-group discussions

   Participants took part in semistructured small-group discussions (45−60 min) that focused on specific manual excerpts and general patterns of difficulty encountered during laboratory work. These sessions elicited detailed, lived-experience descriptions that helped prioritize elements for revision.
3. Post-redesign feedback questionnaire

   After producing the revised materials, dyslexic students completed a short questionnaire consisting of five rating-scale items and three open-text prompts. Questions invited comment on clarity, readability, and usefulness and solicited suggestions for further improvement. Although modest in scale, the questionnaire provided a final round of feedback within this DBR cycle that was then acted upon.

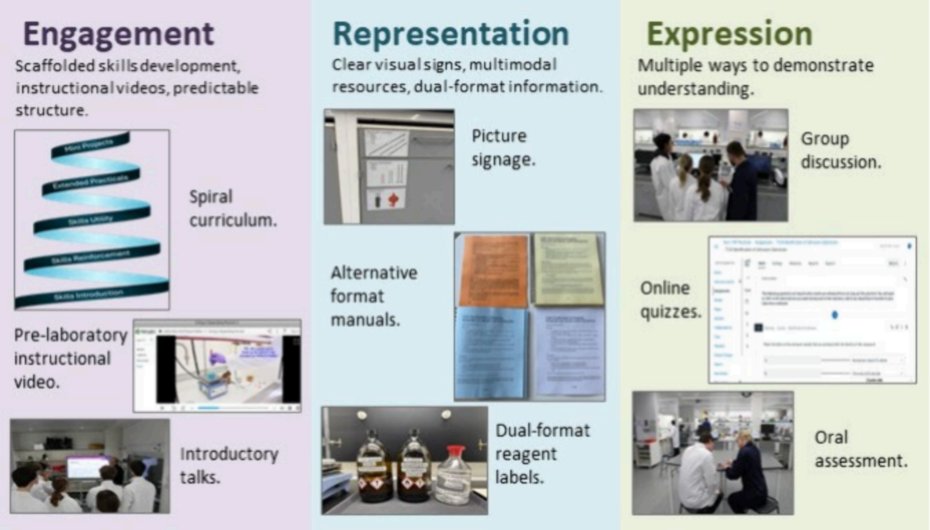

Figure 1. Application of Universal Design for Learning (UDL) principles to chemistry laboratory education. Representation includes clear visual structures, alternative-format materials, and dual-format reagent labels. Engagement includes prelaboratory instructional videos, scaffolded skill development, and introductory workshops. Expression includes flexible assessment formats, such as oral discussions and visual data representations. Together, these examples illustrate how UDL informed the design of more inclusive laboratory experiences in this study.

Safety considerations. This study involved standard undergraduate laboratory activities; no unexpected or unusually high safety hazards were encountered.

Data Analysis

Qualitative data from the laboratory materials audit and small-group discussions were analyzed using an inductive thematic approach.[30] Notes were reviewed collaboratively by the teaching team to identify recurring patterns relating to cognitive load, symbolic interpretation, and navigational difficulty. Emerging themes were refined through iterative discussion and linked back to the research questions. Questionnaire responses were summarized descriptively, and open-text comments were analyzed for recurring themes to inform final refinements of the laboratory resources. Given the exploratory and design-focused nature of this DBR study, the analysis prioritized the identification of actionable design principles rather than formal coding or statistical generalization.

Limitations

As a small exploratory study conducted with a self-selecting group of 13 dyslexic students from a single institution, the findings should be interpreted cautiously. The sample reflects a range of year groups and laboratory experiences, but it does not represent the full diversity of dyslexic learners. Power dynamics between staff and students may also have influenced how feedback was shared, although we attempted to mitigate this by using informal settings.

■ DESIGNING INCLUSIVE CHEMISTRY LABORATORIES USING UDL

The inclusive design strategies developed through the codesign process were informed by the three core principles of UDL, namely, engagement, representation, and expression.[23,24] Each will be discussed in turn, and all are summarized in Figure 1.

Examples of redesigned materials, including laboratory signage (Figure S8), chemical reference lists, reagent labels, and instructional video stills, are provided in the Supporting Information.

Engagement

Engagement relates to supporting students' motivation, confidence, and familiarity with laboratory work. Students noted that unfamiliar equipment and procedures increased cognitive load during practical sessions.[31] The value of preparation activities for supporting student confidence has been discussed in the chemistry education literature.[32,33] The practical course at Oxford is structured around a spiral curriculum model, in which foundational skills are introduced early and then revisited with increasing complexity across different laboratory iterations.[34] This approach provides repeated opportunities for consolidation and supports the development of procedural fluency over time, which students reported as particularly helpful for managing the cognitive demands of practical work.

Representation

The principle of representation guided the redesign of the laboratory materials and associated teaching materials. Student participants reported that dense text and inconsistent formatting made information difficult to locate, particularly under time pressure. In response, the laboratory materials were reformatted to improve visual organization through clearer headings, increased spacing, and the use of bullet-pointed instructions. Chemical names, formulas, and abbreviations were presented together both in the laboratory materials and on reagent labels to support movement between symbolic and physical representations (e.g., water, H_2O, and aq). An example of the original manual layout, illustrating dense text and limited navigational structure, is provided in the Supporting Information (Figure S1), alongside a sample page from the redesigned laboratory materials (Figure S2). In the laboratory materials, a detailed chemical list was provided at the start of each experiment, presenting all relevant substances alongside their chemical formulas, IUPAC names, trivial names, and any abbreviations used. An example of this format is shown in the Supporting Information (Figure S3). These approaches are consistent with research on multiple representations and symbolic processing in chemistry.[26] Examples of laboratory materials using multiple background colors are shown in the Supporting Information (Figure S4). While research on the effectiveness of colored backgrounds for reducing visual stress in dyslexic readers is mixed, with conflicting findings reported in the literature,[35−38] such adjustments are frequently specified in students' disability

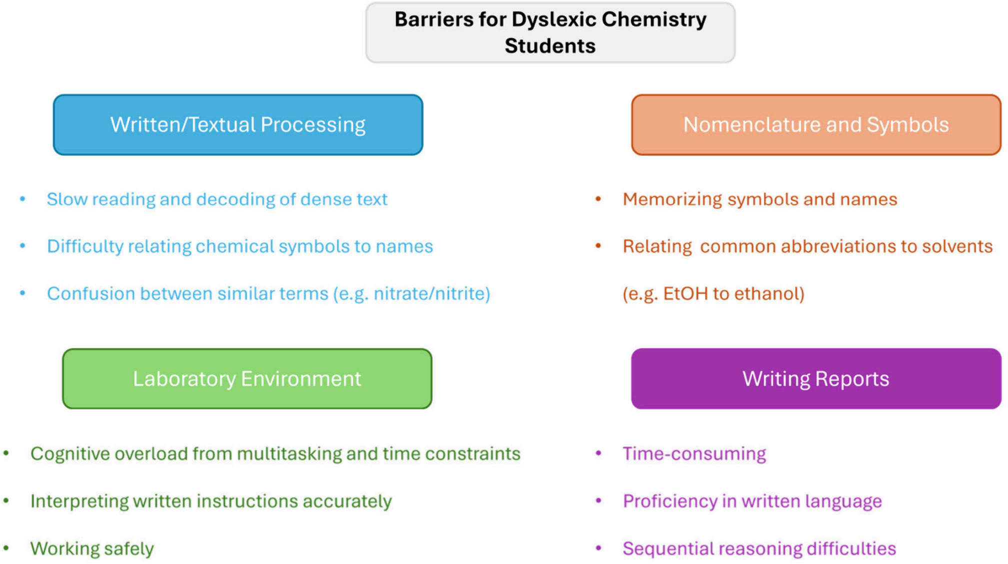

Figure 2. Key barriers identified through the initial audit and student review of laboratory materials and resources.

support plans. Where individual students report that colored backgrounds are beneficial, these formats are therefore made available on request.

Expression

Expression refers to enabling students to communicate their understanding through varied formats. Within our undergraduate practical program, a range of assessment and feedback approaches, including oral discussions, group debriefs, and visual representations of data, had already been in place prior to this study. These approaches were intended to provide flexibility in how students articulate conceptual understanding and have been discussed more broadly in the inclusive assessment literature.[39] However, evaluation work reported by Oliver indicated that the purpose, expectations, and structure of some of these assessment and feedback opportunities were not always clear to students.[31] As part of the present study, the dyslexic student participants provided targeted feedback on how these existing practices could be made more explicit and easier to navigate, for example, through clearer explanation of expectations, more structured prompts, and improved alignment between laboratory tasks and postlaboratory assessment activities.

The codesign process described in this paper therefore focused on refining and clarifying established assessment practices rather than introducing entirely new formats. Student feedback informed revisions made by the authors to the way oral discussions, debriefs, and alternative representations were framed and supported within the laboratory course. This participatory refinement aligns with the learner-centered ethos of UDL and with established models of students as partners in curriculum development.[32]

■ RESULTS

Findings Related to RQ1: Barriers Experienced by Dyslexic Learners in Chemistry Laboratories

Analysis of the laboratory materials audit and small-group discussions revealed several discipline-specific barriers that dyslexic learners encounter during laboratory work; dense blocks of text, inconsistent formatting, and visually cluttered pages make it difficult to locate key information quickly.

A recurring barrier involved translating between equivalent chemical representations across different contexts. Students described difficulty when the name or abbreviation used in the laboratory materials differed from that appearing on reagent bottles, for example, when the manual referred to "ethyl acetate", while the bottle label used an alternative systematic (ethyl ethanoate) or abbreviated form (EtOAc). Although such variations are chemically correct and reflect standard supplier labeling practices, dyslexic students reported that having to mentally reconcile multiple representations of the same substance increased cognitive load, particularly under time pressure.

Student participants also described difficulties processing multistep procedures when instructions were not clearly segmented or when the purpose of a task was not explicit. These challenges were compounded by time pressure in the laboratory, which students noted reduced confidence in and increased cognitive demand. Together, these findings reinforced the barriers identified during the initial audit phase (Figure 2), showing consistent patterns across both staff-led review and student accounts of laboratory experience.

Findings Related to RQ2: Design Principles and Iterative Refinements

Student participant feedback played a central role in guiding revisions to the laboratory materials, with the most substantial changes relating to visual layout, navigation, and preparatory support. Laboratory materials were reformatted using clearer headings, increased spacing, and bullet-pointed instructions, which students consistently reported as easier to follow. One second-year participant commented, "We love the alternative formats; I really struggle with blocks of text and having the bullet points really helps," a view echoed across the participant group.

A key aspect of the redesign was the adoption of the Aptos typeface. Aptos is a sans-serif font with open letterforms, consistent stroke widths, and generous spacing, features that align with accessibility guidance aimed at reducing visual crowding and improving legibility. Its recent adoption as the default typeface across Microsoft 365 reflects its role in accessibility-focused design initiatives within widely used

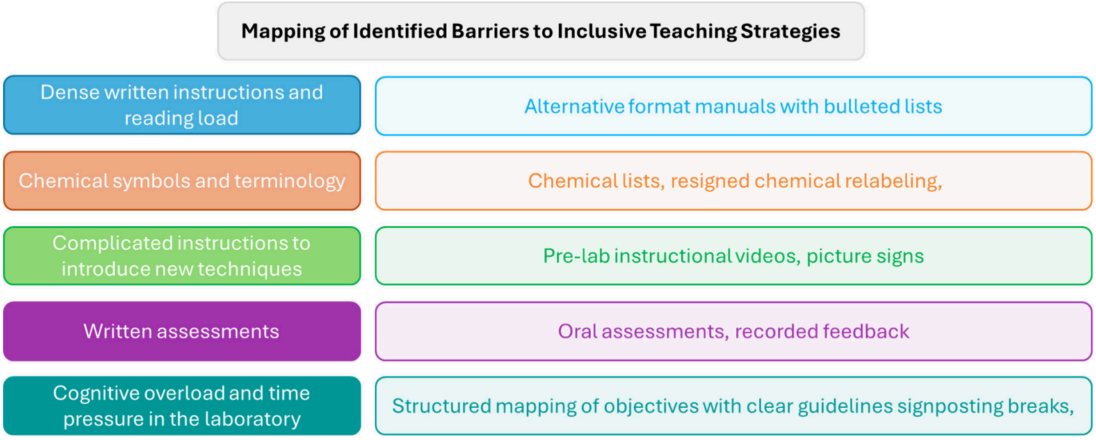

Figure 3. Summary of inclusive design changes developed through the codesign process, including revised laboratory materials layout, Aptos typeface, dual-format reagent labels, equipment signage, and prelaboratory instructional videos.

digital platforms. Although Aptos has not been formally validated as a dyslexia-friendly font, its clean visual structure supported the broader aim of reducing perceptual demands.

Chemical naming and labeling were also revised in response to student feedback. Participants described difficulty connecting the chemical formulas used in laboratory materials with the names printed on reagent bottles. To address this, reagents were relabeled to include the full name, chemical formula, and common abbreviations, and reference lists were added to each experiment. These changes improved the consistency between written and physical materials and supported navigation during practical work. Examples of the dual-format reagent labeling are provided in the Supporting Information (Figure S5).

Clear and structured preparation before entering the laboratory was identified as particularly important, especially in relation to understanding the aims of each practical session, required techniques, and safety considerations. Introductory laboratory talks for all practicals had been part of the undergraduate practical program since approximately 2018 and were intended to support student preparation. However, earlier evaluative work indicated that these talks were not always effective, with some students reporting confusion when learning objectives, safety information, and postlaboratory expectations were not made sufficiently explicit.[31]

Building on this earlier evaluation, the introductory remarks were revised to provide clearer structure and sequencing. As part of the present study, dyslexic student participants reinforced the importance of this clarity. They reported that learning objectives were not always clear at the outset of a session, that COSHH information could be difficult to interpret when chemical names were unfamiliar, and that they benefited from an explicit summary at the end of each introductory talk restating the purpose of the experiment and the requirements for completing postlaboratory tasks.

The earlier evaluation also highlighted limitations in the instructional videos previously provided via the Canvas virtual learning environment. These videos, produced by a third-party provider (LearnSci), demonstrated techniques using generic or simulated equipment rather than the actual apparatus used in the teaching laboratories, which some students found difficult to translate into practice. Similar barriers associated with nonauthentic or poorly aligned instructional videos have been reported in the chemistry education literature.[39−41]

In response, and as part of the work described in this paper, a new suite of short prelaboratory instructional videos was recorded using the actual equipment and laboratory layout encountered by students. Examples of the prelaboratory instructional videos and the platform used to access these are shown in the Supporting Information (Figures S6 and S7). These videos were made available prior to each practical session, allowing students to familiarize themselves with techniques and apparatus in advance and to revisit demonstrations as needed.

Taken together, the revised introductory talks and bespoke instructional videos reduced the need for students to decode dense written instructions while simultaneously managing unfamiliar equipment. From a UDL perspective, the approach provided multiple means of representation and engagement through spoken explanation, visual demonstration, and written summaries. From a CLT perspective, these changes primarily reduced extraneous cognitive load by clarifying task goals, aligning visual and physical representations, and supporting the sequencing of actions without increasing the intrinsic complexity of the chemistry.

Student participants reported that these changes helped them feel better prepared and less anxious when entering the laboratory, allowing them to focus more effectively on the underlying chemistry. Following this positive feedback, access to the revised introductory materials and instructional videos was extended to all students enrolled in the course, consistent with a UDL approach. The full set of design changes developed through the iterative codesign process is summarized in Figure 3.

Findings Related to RQ3: Student Perceptions of the Redesigned Materials

Questionnaire responses from dyslexic students ($N = 25$) indicated that the redesigned materials were clearer, easier to navigate, and more supportive of laboratory learning. Ratings indicated improvements in perceived readability, consistency, and confidence when using laboratory materials.

Open-text responses provided further insight into how these changes affected students' laboratory experiences. One student described the redesign as having "revolutionized my practical experience," while a third-year participant commented, "I wish I had these alternative manual formats throughout my degree; they would have made a huge difference."

Students also valued having multiple ways to prepare for laboratory sessions. In-house prelaboratory instructional videos were described as reassuring and helpful, particularly when working with unfamiliar equipment. Several students noted that being able to review procedures in advance reduced anxiety and allowed them to enter the laboratory feeling more prepared.[42]

Overall, the results show that relatively small but carefully targeted adjustments to layout, chemical nomenclature, and prelaboratory preparation can have a disproportionately positive effect on students' experiences of laboratory work. These perceptions suggest that dyslexia-informed design principles can enhance clarity and accessibility for a wide range of learners.

■ DISCUSSION

The findings of this pilot study provide insight into how dyslexic learners experience the cognitive and perceptual demands of undergraduate chemistry laboratories and how UDL-informed design approaches can reduce these barriers. Student participants described difficulties that align with established research on working memory limitations and the challenge of translating between symbolic, macroscopic, and submicroscopic representations.[1,2] These challenges are consistent with CLT, particularly the strain placed on working memory when learners are required to integrate multiple forms of information simultaneously.[3,14] The present findings extend this work by showing how these demands are intensified for dyslexic learners when information is densely presented or inconsistently formatted.

The redesign strategies developed through the codesign process correspond closely with principles for reducing extraneous cognitive load. Clearer visual structure increased spacing, and more consistent formatting reduced unnecessary processing demands, allowing dyslexic students to focus more effectively on the underlying chemical concepts.[3,14] These changes also reflect the UDL principle of representation, which emphasizes providing multiple ways of accessing information. The introduction of dual-format chemical labels and structured reference lists supports students as they translate between symbolic, verbal, and physical representations, consistent with research on multiple representations in chemistry.[26,43]

Improved laboratory preparedness emerged as another key outcome of the redesign. Revised introductory talks and bespoke instructional videos provided opportunities for students to familiarize themselves with equipment, procedures, and expectations before entering the laboratory. These strategies reduced cognitive load associated with unfamiliar tasks and align with the UDL principle of engagement, which focuses on reducing anxiety, supporting autonomy, and building learner confidence.[34,44] Student participants' reports of feeling more prepared and less overwhelmed suggest that these resources supported sustained engagement during laboratory sessions.

Although the redesigned materials were developed in response to dyslexia-specific challenges, several students noted that the changes would have been beneficial throughout their degree. This observation aligns with broader research in inclusive and neurodiversity-informed education, which shows that design approaches developed to support disabled learners often enhance learning conditions for a wider student population.[13,21,33] The findings therefore contribute to ongoing discussions around universal design in chemistry education and demonstrate the value of involving learners directly in the development and refinement of teaching resources, consistent with student-as-partner models.[32]

As a pilot study involving a small, self-selected cohort from a single institution, these findings should be interpreted with caution. Nevertheless, they provide a strong foundation for future research examining the impact of UDL-aligned laboratory design across larger cohorts and diverse institutional contexts. Further work could explore how inclusive design principles can be extended to other areas of the chemistry curriculum including assessment practices and long-term skill development.

■ CONCLUSION

This pilot study highlights the under-reported, discipline-specific challenges encountered by dyslexic learners in undergraduate chemistry laboratories and demonstrates how dyslexia-informed design approaches can help reduce these barriers. Through an iterative codesign process, dyslexic students contributed directly to the development of clearer laboratory materials, improved chemical and equipment labeling, and more structured preparatory materials. These changes were positively received and were reported to improve clarity, confidence, and engagement during practical work.

Although the study involved feedback from a relatively small cohort, the findings suggest that design decisions informed by the needs of dyslexic learners can benefit a wider student population. The approaches described here provide a foundation for further research and offer a practical model for integrating UDL principles into laboratory-based chemistry teaching.

■ ASSOCIATED CONTENT

Supporting Information

The Supporting Information is available at https://pubs.acs.org/doi/10.1021/acs.jchemed.5c01544.

Examples of original and redesigned laboratory materials, including sample manual layouts; chemical reference lists presenting names, formulas, and abbreviations; examples of alternative-format materials using colored backgrounds; dual-format reagent labels; prelaboratory instructional video stills and access platform; laboratory signage used to support navigation and equipment identification; and additional inclusive teaching aids (PDF, DOCX)

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Notes

The authors declare no competing financial interest.

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