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Extending access for all chemistry students with extended reality

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Equal access to instructor's time and attention in chemistry classes and laboratories can be a barrier experienced by students from historically excluded groups. An instructor's own biases will determine the nature of their interaction with students, and even well-meaning instructors can interact with students in slightly different ways, which might prevent certain students from having access to all the available instructional resources for the class. This is an additive problem, which may or may not be recognized in peer and student evaluations, and an issue that might escape self-reflection even in educators that are committed to diversity, inclusion, and justice. This issue conflates both actual and perceived biases, introducing a complex dynamic between instructor and student. Extended reality (XR) provides an avenue to generate materials that can be used to enhance or replace classroom instruction with a great degree of realism. In this paper we will discuss the implementation of a set of virtual reality (VR) organic chemistry labs. We will show that XR learning tools are by their very nature accessible and inclusive of a wide variety of students and will provide evidence from student reflections that shows that students from historically excluded groups find the XR content offered in our virtual reality labs more personal than in-person activities covering the same material.

KEYWORDS

virtual reality, augmented reality, extended reality, access, inclusion, organic chemistry

1 Introduction

Historically, chemistry has been a field dominated by white males. This situation was perpetuated for years due to disparities in access to quality education (Woolston, 2020; Van Dusen et al., 2022). This is evident in the underrepresentation of women in chemistry authorship (Cotton and Seiple, 2021) and gender differences in chemistry achievement and participation (National Science Foundation, National Center for Science and Engineering Statistics, 2017). Even with well-intentioned educators, inherent biases may shape interactions in ways that inadvertently limit access to course material. This subtle yet pervasive issue poses a complex dynamic between instructors and students, often manifesting through both actual and perceived differences in student-instructor interactions, including differential time and attention from instructors. Research consistently shows that students from historically marginalized groups face significant challenges in accessing equal opportunities in chemistry classes and laboratories (Kimble-Hill et al., 2020; Leopold and Smith, 2020; Neill et al., 2018). These challenges are often exacerbated by instructors' biases, which can limit students' access to instructional resources (Kimble-Hill et al., 2020). To address this, it is crucial for instructors to recognize their responsibility in supporting interactions and to implement activities such as reflective group work activities that benefit all students, especially from marginalized groups. (Leopold and Smith, 2020). Additionally, creating structured, inclusive classroom environments can help promote equitable participation (Neill et al., 2018).

Some interventions, such as growth mindset programs (Fink et al., 2018), and other supplemental programs to enhance at-risk students' academic skills and performance (Botch et al., 2007; Rath et al., 2012; Shields et al., 2012), have been shown to improve the performance of historically excluded minorities in chemistry. Small group activities, such as Peer-Lead Team Learning (PLTL) (Lewis and Lewis, 2005; Frey et al., 2018) and Process Oriented Guided Inquiry Learning (POGIL) are also known to support achievement in students from marginalized groups, particularly in large classes such as General Chemistry (Ruder and Hunnicutt, 2008; Vincent-Ruz et al., 2020).

These studies underscore the need for continued efforts to address the gender and racial disparities in the field of chemistry. However, a common feature of most supplemental chemistry achievement programs is their intensive nature (Lockie and Lanen, 1994). Providing one-on-one instruction, tutoring, or extended contact beyond what is offered in the classroom or laboratory setting imposes an extra burden on existing instructors or requires the hiring of additional instructional team members (Coletti et al., 2013). It also requires that students are motivated and available to engage with the intervention being offered at specific times/venues, and that instructors engage with all students in equitable ways. Although the intention is to be commended, many such programs do not persist due to staffing issues or limited participation, and it is our own personal experience that remedial interventions, even those with demonstrated benefits, are the first to go in lean budgetary conditions.

It is crucial to reconsider how we frame supplemental assistance in education. Labeling it as "remedial" or targeting specific groups, such as students with disabilities, can be detrimental. Adopting a positive framing approach and adhering to Universal Design for Learning (UDL) principles can enhance the accessibility and success of teaching and learning materials for all students (Brand et al., 2012; Tobin, 2021). UDL, a framework that emphasizes the design of instructional materials and activities to meet the needs of diverse learners, is particularly effective in this regard. It encourages the use of multiple means of representation, engagement, and expression, ensuring that all students can access and engage with the content. This approach is especially beneficial in online education, where it can increase student retention and engagement (Tobin, 2021). By incorporating UDL principles, educators can create a more inclusive and effective learning environment for all students. Extended reality applications can be informed by UDL principles (Parrish et al., 2021), and by their very nature make learning accessible in ways that were not previously available.

Recognizing the need for a transformative approach, many educators around the world have spent time and effort in the generation of materials that can be used to remedy such gaps. An alternative to the more traditional instructor-intensive inclusive resources is the use of pre-recorded video resources, which became prominent in many programs in the last 20 years, as the cost of creating and publishing videos decreased worldwide (Blonder et al., 2013; Box et al., 2017; Gillette et al., 2017). A logical next step was the creation of virtual and augmented reality materials to be used in chemistry courses (Dunnagan and Gallardo-Williams, 2020; Wright and Oliver-Hoyo, 2021). Such resources were widely repurposed as remote instructional materials, mostly to cover chemistry laboratory instruction during the recent COVID-19 pandemic disruption of instruction (Kelley, 2021), and have been relegated to a secondary plane in its aftermath (Link and Gallardo-Williams, 2022). This article delves into the realm of Extended Reality as a groundbreaking, and in some ways unexpected, solution to issues of unequal access. Extended reality (XR) is an umbrella term to refer to augmented reality, virtual reality, and mixed reality. XR emerges as a powerful tool to overcome the limitations of traditional classroom instruction, offering on-demand, universal immersive experiences that can enhance or even replace conventional teaching methods in certain settings. The degree of immersion in digital teaching tools within the XR realm can be highly individualized depending on the instructor and students' choices (Aguayo, 2021).

The integration of Extended Reality into education represents a paradigm shift in how we approach and deliver learning experiences. XR, encompassing both augmented and virtual reality, enables educators to create dynamic and interactive content that transcends the confines of traditional pedagogy. XR technologies have the potential to improve learning outcomes by enhancing interactivity and immersion (Logeswaran et al., 2021; Herur-Raman et al., 2021; Paye et al., 2021). In this context, we present a VR intervention: a suite of virtual reality organic chemistry labs (Dunnagan and Gallardo-Williams, 2020) to show that XR activities are by their very nature accessible and inclusive of a wide variety of students. We bring up this example and its student outcomes as part of a rapidly developing field. By addressing the crucial intersection of technology, diversity, and education, this work seeks to extend access and create a sense of belonging and community for chemistry students through the innovative use of XR tools.

2 Virtual reality: creating immersive learning environments

In 2019 we introduced a series of organic chemistry labs designed to be experienced in a fully immersive virtual environment (Dunnagan et al., 2019). These labs transcend the limitations of physical spaces, providing students with the opportunity to explore intricate reactions and phenomena in a risk-free, yet realistic setting. The immersive nature of VR not only enhances comprehension but also caters to diverse learning styles, ensuring that students from all backgrounds can actively participate and thrive in their educational journey.

When we designed the VR lab experiences, we were intentional in recruiting a diverse pool of teaching assistants, using inclusive language, and offering examples that were unbiased and appealing to all our students. Our strategy involved crafting VR laboratories that prioritized inclusivity and diversity. This encompassed curating content and leveraging the talents of several teaching assistants. Conscious efforts were made to reflect diversity in the virtual TA pool, aligning with the races, ethnicities, and gender orientations present in the Department of Chemistry at North Carolina State University. This intentional inclusivity received positive feedback from students, with 30% expressing favorable comments on the diverse virtual TA pool in course evaluations. This might appear at first sight to be a nod to diversity and inclusion initiatives; however, it goes beyond that, as it allows students to find a TA that looks like them among the pool of available instructors. While white students might have a variety of role models to choose from, the same is not true for students from marginalized backgrounds. The simple act of including diverse TAs can go a long way in creating community for these students.

To ensure a bias-free learning environment, the content of VR laboratories underwent a rigorous review process. Sourced from experienced TAs and reviewed by faculty, the scripts were scrutinized to eliminate any racially charged or gendered terms. The goal was to create a supportive and inclusive learning experience, reducing terms that may be perceived as biased. This multilayered review process contributed to the success of these realistic VR simulations in minimizing instructor bias and offering struggling students an opportunity to experience the best that the instructor has to offer.

However, when we tested the VR labs with the first group of students, we were surprised to discover in the data from historically marginalized groups in our sample population that their comments were not solely focused on the aspects of diversity and inclusion that we had included as part of the VR lab design. Instead, most of the students from historically marginalized groups also mentioned how much they appreciated the time and attention given to them by the virtual teaching assistant. These lifelike simulations appeared to mitigate instructor bias, as the material was generated independently of student presence, providing an opportunity for any student who may face challenges in a traditional setting to access the instructor's expertise under the best possible conditions.

The challenge of ensuring equitable access to support in higher education poses a significant hurdle, particularly for students from historically marginalized groups. Instructor-student interactions are greatly shaped by individual biases, creating varying levels of engagement and potentially limiting some students' ability to fully benefit from course content. This nuanced issue, frequently unnoticed in evaluations by peers and students, can persist even within faculty committed to fostering diversity and inclusion. It underscores the intricate relationship between instructor bias, student perception, and actual access to educational resources. In addressing this challenge, virtual reality (VR) emerges as a promising tool to create immersive materials that can either complement or substitute traditional classroom instruction with a high degree of realism and engagement.

The analysis of data collected from the user study evaluating our VR materials for organic chemistry laboratories also sheds light on how students interact with VR instructors. Feedback provided by students from historically excluded groups highlights the perceived impartiality of the virtual instructor, the ability to engage with course material independently, and the advantage of remote access as key desirable aspects of the VR learning experience (Dunnagan et al., 2019). During the evaluation, 23% of students from historically excluded groups expressed satisfaction with the direct attention received from the virtual Teaching Assistant (TA). The prerecorded TA interactions, designed to appear accessible and supportive, proved to be a significant factor for students, highlighting the unanticipated impact on their learning experience. One of the student reflections included the following statement:

> "I have never had a TA look me in the eye for so long and take such care to explain a concept to me. This felt very personal."

The traditional classroom setting, prone to implicit biases, can hinder the educational experience for students, especially in close-quarters interactions such as laboratory settings. Virtual reality (VR) laboratories address this challenge by providing constant, supportive availability of TAs, minimizing the likelihood of biased interactions. Moreover, the virtual TA dynamic eliminates the potential for intimidation, a common concern in in-person labs (Dunn et al., 2023), leading to positive feedback from students who have not perceived the virtual instructor as intimidating or impatient.

Conscious efforts were made to reflect diversity in the virtual TA pool, aligning with the races, ethnicities, and gender orientations present in the Department of Chemistry at North Carolina State University. This intentional inclusivity received positive feedback from students, with 30% expressing favorable comments on the diverse virtual TA pool in course evaluations. This might appear at first sight to be a nod to diversity and inclusion initiatives, however it goes beyond that, allowing students to find a TA that looks like them among the pool of available instructors. While white students might have a variety of role models to choose from, the same is not true for students from marginalized backgrounds. The simple act of including diverse TAs can go a long way in creating community for these students.

In addition to the perceived impartiality of the instructor and the diversity of available instructors, students appreciated the ability to engage independently with the material and the convenience of remote access. Student comments, often shared during open microphone portions of interviews, were candid and personal, providing valuable insights into the overall positive impact of the VR learning experience. We had ample opportunity to test the usefulness of the VR lab experiences during the COVID-19 pandemic disruption, and found the online labs to be a suitable substitute for the in-person experience (Dunnagan and Gallardo-Williams, 2020).

In the summer of 2020, we used the Meaningful Learning in the Laboratory Instrument (MLLI) (Galloway and Bretz, 2015) to gauge students' cognitive and affective expectations before the virtual lab course and their experiences with virtual reality upon course completion. Students who participated in virtual reality laboratories reported more positive affective experiences than anticipated, expressing minimal frustration or confusion during the laboratory sessions (Williams et al., 2022).

Our exploration not only showcases the technical aspects of the VR organic chemistry lab experiences but also emphasizes their inherent accessibility and inclusivity. The crux of our discussion revolves around best practices for engaging students in introductory organic chemistry lab courses, with a particular emphasis on reaching those from historically marginalized groups. Through compelling evidence drawn from student reflections, we make the point that XR content fosters a more personalized and inclusive learning environment compared to traditional in-person activities covering the same material for some students.

In addressing the diverse needs of students, a hybrid approach combining both in-person and virtual experiences emerges as a favorable compromise, a trend that is currently seen in the health science education field (Pottle, 2019). This strategy accommodates the preference for in-person laboratory sessions while embracing the inclusive advantages not only for students from historically excluded minorities, but for any student experiencing attendance constraints like pregnancy or military deployment, or even students with unique safety considerations. Since chemistry is a laboratory-based discipline, and laboratory instruction is central to its mission (Seery, 2020), enhancing laboratory offerings with XR options might open the field to students that traditionally would not be able to participate.

3 Conclusion

In conclusion, this article highlights the current advances and future directions of an XR project in chemistry education. The presented VR intervention demonstrates the potential to overcome barriers related to unequal access and biased interactions. By fostering inclusivity and accessibility, XR can contribute to creating a more equitable and engaging learning environment for all chemistry students. The most impactful part of this work relates to an unintended outcome: Providing all students with equal access to the instructor's attention and all the resources available in an online environment. As we continue to explore and refine XR applications, the goal is to pave the way for a transformative shift in how chemistry education is delivered and experienced.

Looking forward, the integration of XR in chemistry education holds significant promise. The success of our VR intervention suggests that these technologies can address longstanding issues of unequal access and biased interactions in traditional classroom settings. Future research should explore the scalability of XR interventions and their long-term impact on student success, particularly for historically excluded minorities. Additionally, efforts should be made to integrate XR seamlessly into curricula, ensuring sustained benefits beyond temporary disruptions like the COVID-19 pandemic.

Data availability statement

The original contributions presented in the study are included in the article/supplementary material, further inquiries can be directed to the corresponding author/s.

Ethics statement

The studies involving humans were approved by the North Carolina State University Institutional Review Board. The studies were conducted in accordance with the local legislation and institutional requirements. The participants provided their written informed consent to participate in this study.

Author contributions

MG-W: Conceptualization, Data curation, Formal analysis, Funding acquisition, Investigation, Methodology, Project administration, Resources, Supervision, Writing – original draft, Writing – review & editing. CD: Conceptualization, Investigation, Project administration, Writing – review & editing.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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