Extended Reality (XR) for Authentic Learning: New Frontiers in Educational Technology

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Extended Reality (XR) technologies—encompassing Virtual Reality (VR), Augmented Reality (AR), and Mixed Reality (MR)—are revolutionizing educational practices through their unique ability to create immersive, authentic learning experiences. This transformation aligns with core principles of situated cognition and legitimate peripheral participation. XR enables students to learn by doing in safe yet realistic environments where they can practice without real-world consequences. Through these technologies, learners can engage in experiences that would be impractical, impossible, or too costly to replicate in traditional educational settings. This special issue *of the Journal of Applied Instructional Design (JAID) examines the critical intersection of XR technologies with authentic learning principles, addressing the widening gap between rapid technological advancement and established instructional design practices. The collection explores how XR can bridge theoretical knowledge and practical application across educational contexts by drawing together perspectives from educational technology researchers, learning scientists, and practitioners. The contributing authors investigate three interconnected themes: the design of XR environments to support authentic learning characteristics, the unique affordances of different XR modalities, and the practical implementation challenges in educational settings. Through empirical evidence, theoretical frameworks, and practical insights, they demonstrate how XR technologies facilitate progressive skill development, create unprecedented levels of immersion and presence, and enable previously impossible learning experiences while thoughtfully addressing critical challenges in accessibility, technical implementation, pedagogical frameworks, and ethical considerations.*

Introduction

The emergence of Extended Reality (XR) technologies in education—encompassing Virtual Reality (VR), Augmented Reality (AR), and Mixed Reality (MR) (Dwivedi et al., 2022; Maas & Hughes, 2020)—has opened unprecedented opportunities for creating authentic learning experiences (Cai, 2018; Gandolfi et al., 2021; Lowell & Tagare, 2023) creating a paradigm shift in educational technology (Lowell & Yan, 2024; Radianti et al., 2020) that aligns remarkably well with the core principles of authentic learning established by seminal works in situated cognition and legitimate peripheral participation, including Lave and Wenger (1991) and Resnick (1987). With XR technologies, learners can engage in immersive experiences and environments that include realistic scenarios, virtual object manipulation, and simulated experiences that would be impractical, impossible, or too costly to replicate in traditional educational settings (Jensen & Konradsen, 2018; Lowell & Alshammari, 2018; Radianti et al., 2020). By enabling students to learn by doing, XR technologies facilitate the development of practical skills through experiential learning (Kolb & Kolb, 2009; Lowell & Ilobinso, 2023), and very importantly, these technologies create safer learning environments where students can practice and learn from mistakes without real-world consequences (Hamilton et al., 2021; Lowell & Alshammari, 2018), thereby embodying key principles of experiential learning (Kolb & Kolb, 2009) in authentic contexts.

Learning experiences with XR technologies provide unique affordances that enhance authentic learning in several key ways:

First, research syntheses have found that XR environments can be structured to support progressive skill development, enabling learners to build competence through increasingly complex authentic tasks (Hamilton et al., 2021; Radianti et al., 2020). As Dalgarno and Lee (2010) explain, this progressive development operates through multiple mechanisms: precisely controlled task complexity, systematic environmental variable management, and increasingly sophisticated feedback systems. The effectiveness of this approach is particularly evident in what Cochrane et al. (2017) term "developmental pedagogies," where technological affordances are explicitly mapped to stages of skill development, allowing for carefully calibrated learning progressions. There are many benefits of using XR technologies for progressive skill development. For example, educators can design realistic experiences with XR technologies that gradually increase task difficulty, allowing learners to build skills incrementally. As learners complete activities with XR technologies simulating real-world scenarios, they can learn to adapt to varying conditions without the risks associated with real-life experimentation. In addition, immediate and tailored feedback within the XR setting can help learners understand their performance and areas for improvement, enhancing the learning process.

Second, while completing learning tasks, XR technologies can offer unprecedented levels of immersion and presence, allowing learners to feel physically and psychologically present in educational scenarios (Dede, 2009; Markowitz et al., 2018). Before going further, it would be important to describe immersion and presence, as the perceptions of immersion and presence lead to many benefits of incorporating XR technologies in authentic learning. The term immersion is defined differently depending on the context of its usage (e.g., psychological immersion, sensory immersion, narrative immersion), and there are different levels of immersion (i.e., fully immersive, semi-immersive, non-immersive). In early literature on immersion and VR (e.g., Nash et al., 2000; Slater & Wilbur, 1997), descriptions of immersion focused on the technology’s ability to create an illusion of immersing the user in an experience. Therefore, early on, immersion was described as two different things. In 1997, Slater and Wilbur described immersion as “the extent to which the computer displays are capable of delivering an inclusive, extensive, surrounding and vivid illusion of reality to the senses of a human participant” (p. 603). In 1998, Witmer and Singer described immersion as a “psychological state characterized by perceiving oneself to be enveloped by, included in, and interacting with an environment that provides a continuous stream of stimuli and experiences" (p. 227). From these early descriptions, technology produced the perception of immersion. Immersion with XR systems depends primarily on sensory immersion. Sensory immersion is the degree to which a virtual simulation engages the range of sensory channels (e.g., sight, sound, touch) (Kim & Biocca, 2018). Thus, the level of immersion is related to the hardware and software used, and surrounding a user with images, sound, or other stimuli can lead to a perception of immersion (Freina & Ott, 2015; Lowell & Tagare, 2023). For our purposes, we will say that immersion is a characteristic of technology, and a feeling of immersion in the context of XR refers to a state where a user feels deeply engaged with a simulated experience and environment. Some researchers may describe this as being in a state of flow or complete focus in an activity (Csikszentmihalyi, 1990; Marougkas et al., 2023; Witmer & Singer, 1998). Presence, on the other hand, is a psychological experience or phenomenon. In the case of XR technologies, presence is a phenomenon where users may act and feel as if they are in the virtual world engaging in the activities they are experiencing (Kim et al., 2017). For presence to occur, involvement (or focus) in an activity within the environment and immersion are required (Witmer & Singer, 1998). We will describe presence as a user's perception of being in and interacting with an XR environment, and we will add that as immersion with XR is a result of the technology, users can increase their perceptions of immersion and thus their perception of presence by using specialized equipment and devices (e.g., VR headsets and gloves) with XR software (Lowell & Tagare, 2023).

The immersive quality of XR experiences helps bridge the gap between abstract concepts and their practical applications, making learning more concrete and experiential. Immersion helps learners tackle increasingly complex tasks in several connected ways. For instance, immersion in XR environments allows learners to offload the mental work of visualization. This frees up cognitive resources to focus on learning new skills. (Johnson-Glenberg, 2019; Parong & Mayer, 2020). The immersive environment can also present complex systems in context, allowing learners to see how different components interact together while gradually introducing new elements as learners master essential skills (Makransky & Petersen, 2021). This approach is particularly powerful for tasks requiring physical and mental understanding, as immersion allows learners to physically engage with concepts while building their comprehension of complex systems (Jensen & Konradsen, 2018). De Freitas and Oliver (2006), for example, demonstrate how varying levels of immersion can be strategically employed to support incremental skill acquisition in complex technical and professional training contexts, and Makransky and Petersen (2021) created a theoretical framework for understanding how immersion levels can be adjusted to optimize learning at different stages of skill acquisition.

Third, XR technologies enable the creation of learning environments that would be otherwise impossible or impractical in traditional educational settings. These environments can transcend physical limitations, allowing students to explore historical periods, manipulate molecular structures, practice dangerous procedures safely, or experience perspectives that would be impossible in the real world (Lowell & Alshammari, 2018; Lowell & Tagare, 2023; Southgate et al., 2019). As discussed in Lowell and Tagare (2023), the authenticity of these learning experiences is significantly influenced by both the fidelity of the virtual environment and the design of learning tasks within it. Thus, by carefully calibrating the physical, functional, psychological, and social aspects of the XR environment and the learning task(s), the integration of XR technologies in learning can create safe yet authentic learning opportunities while also enabling experiences that would be otherwise impossible or impractical in traditional educational settings (Lowell & Tagare, 2023).

The unique affordances of XR technologies for authentic learning have evolved significantly over time. We have seen remarkable advancements from early virtual environments for authentic learning to today's sophisticated XR applications. These tools now support complex interactions and provide learners with immediate feedback. Modern XR technologies now support complex interactions between people and people and virtual objects, enable collaborative learning in-person and across physical distances, and provide learners with immediate and personalized feedback (Bower et al., 2020; Radianti et al., 2020; White & Lowell, 2023). These capabilities, along with increased accessibility and improved user interfaces, position XR as a powerful tool. It has the potential to transform educational practices across disciplines and contexts.

Special Issue of JAID: Emerging Themes and Critical Questions

Extended Reality (XR) technologies offer tremendous benefits and opportunities for education. Despite their advantages, research on instructional design practices and frameworks for authentic learning with XR has not kept pace with technological advancements. This special issue of JAID addresses this gap by bringing together perspectives from educational technology researchers, learning scientists, and practitioners. These experts are actively working to realize the potential of XR in authentic learning contexts. They offer a current understanding of the design, implementation, and evaluation of authentic, immersive learning and teaching across diverse educational contexts.

Building on the foundational work in authentic learning of Brown et al. (1989) and Herrington & Oliver (2000), early applications of immersive technologies for learning as described by Dede (2009), and more recent theoretical work on immersive learning discussed by Makransky and Peterson (2021), and design of learning experiences discussed by Lowell and Tagare (2023) and Lowell and Yan (2024), this special issue of the Journal of Applied Instructional Design (JAID) explores the intersection of XR technologies with authentic learning principles. It examines how these immersive technologies can bridge the gap between theoretical knowledge and practical application in educational contexts and provides current instructional design practices and frameworks. The collected articles span theoretical analyses, empirical studies, and case reports, providing a multi-faceted examination of this important educational frontier.

In addition, the articles in this special issue address several important themes in XR-enabled authentic learning:

First, they examine how XR environments can be designed to support the essential characteristics of authentic learning, including real-world relevance, collaborative knowledge construction, and multiple perspectives (Dalgarno & Lee, 2010). Contributors explore the delicate balance between technological capability and pedagogical purpose, building on

McLellan's (1994) early vision of virtual environments for situated learning while emphasizing that successful XR implementation must be driven by sound educational principles rather than technological novelty (Hamilton et al., 2021; Lowell & Tagare, 2023; Lowell & Yan, 2024). For example, Okorie et al. (2024) investigate how XR can support critical skill development, demonstrating the technology's potential to foster collaboration, empathy, and problem-solving across different learning contexts. Oprean et al. (2024) showcase how XR can be implemented in specific educational contexts, from geoscience education to professional skills training. Cherner and Dickerson (2024) explore instructional design approaches for integrating XR technologies, proposing an expanded pedagogical model that positions students as active creators rather than passive consumers.

Second, the collection investigates the unique affordances of different XR modalities, expanding on previous instructional usage and research which has mainly focused on VR (Billinghurst, 2015; Cradit et al., 2024; Guo et al., 2021; Sivelle et al., 2024). Wu et al. (2013) and White and Lowell (2023) discuss that while VR offers full immersion for simulated environments, AR and MR provide opportunities to blend digital content with physical spaces, each presenting distinct advantages for different learning contexts and objectives. Several articles in this issue, including Oprean et al., 2024 and White et al., 2024, discuss how these varied approaches can be leveraged to create meaningful learning experiences across diverse disciplines.

Third, as discussed by Cochrane et al. (2020), the issue addresses the critical challenges of implementing XR in educational settings, including accessibility concerns, technical requirements, and the need for professional development among educators. Contributors, including Savickaite et al. (2024) and Schmidt and Glaser (2024), offer practical insights and evidence-based recommendations for overcoming these obstacles.

Looking Forward

As XR technologies evolve and become more accessible, their potential to revolutionize education grows exponentially. The research presented in this special issue demonstrates the current state of XR in education for authentic learning and points toward future directions and possibilities. As this collection of works suggests, with the powerful new affordances of XR, combined with designing for authentic experiences, we are only beginning to understand how these technologies can transform educational practices and enhance authentic learning. Emerging research, including studies in this issue, suggests that the future of XR in education lies not in technological novelty but in its capacity to create deeply personalized, accessible learning experiences. For example, Oprean et al. (2024) demonstrate how XR can be tailored to support diverse learner needs. Schmidt and Glaser's (2024) work with autistic learners underscores the importance of designing technologies that embrace individual variability. Furthermore, MacDowell et al. (2024) highlight the importance of deeply meaningful learning experiences. In addition, as discussed in Savickaite et al. (2024), integrating artificial intelligence with XR design presents promising avenues for creating more adaptive and inclusive educational technologies.

As we continue to look forward, critical challenges remain, including accessibility, technical implementation, and the need for robust pedagogical frameworks. Further, ongoing ethical concerns around data privacy and psychological safety must be addressed. Therefore, as collected works in this issue suggest, we are only beginning to understand how these technologies can fundamentally transform educational practices, creating learning experiences that are not just immersive but truly meaningful and transformative, and with great potential comes great responsibility. As educators and researchers, we must navigate the challenges of accessibility, technical implementation, and ethical considerations with care and diligence. The future of XR in education lies not in the novelty of the technology itself but in its capacity to foster genuine understanding, collaboration, and growth among learners.

We invite readers to engage with these contributions and consider how they might inform their practice and research in this rapidly evolving field. We trust that readers will find these contributions both thought-provoking and practical as they consider the role of XR in shaping the future of authentic learning. The insights presented here serve not only to advance our understanding of XR in education but also to guide future research and development in this promising field.

Let us embrace this frontier enthusiastically and cautiously, striving to unlock XR's full potential to transform education for future generations. By doing so, we can ensure that our teaching practices keep pace with technological advancements and create a more inclusive, engaging, and effective educational landscape.

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