

Augmented and Virtual Reality Authoring: A Study of Educators

Qing Li
Towson University, USA
E-Mail: li@towson.edu
ORCID: 0000-0002-4518-278X

Christine See
Towson University, USA
E-Mail: csee@students.towson.edu
ORCID: 0009-0008-2162-9840

Lynn Nichols
Towson University, USA
E-Mail: lnichols@students.towson.edu
ORCID: 0000-0002-5379-564X

Ruddhi Wadadekar
Towson University, USA
E-Mail: rwadade1@students.towson.edu
ORCID: 0009-0004-0741-0026

Trudy Sullivan
Towson University, USA
E-Mail: tsullivan@students.towson.edu

Abstract: This study reports a collaborative self-study of five educators' experiences of teaching and learning augmented, virtual, and mixed reality (XR hereafter) in education. Specifically, it aims to examine educators' beliefs about XR applications and the design considerations when they are engaged in authoring educational XR applications. The analysis of data showed that the educators put the learning outcomes at the forefront of their design of XR applications. When considering the topics for XR applications, educators tended to focus on content customized to their local contexts. Important design

considerations also included curriculum and instructional design, equity, safety and other topics.

Résumé : Cette étude présente une auto-évaluation collaborative des expériences de cinq enseignants en matière d'enseignement et d'apprentissage de la réalité augmentée, virtuelle et mixte (ci-après XR) dans l'éducation. Plus précisément, elle vise à examiner les croyances des enseignants sur les applications XR et les considérations de conception lorsqu'ils sont engagés dans la création d'applications XR éducatives. L'analyse des données a montré que les enseignants placent les résultats d'apprentissage au premier plan de leur conception d'applications XR. Lorsqu'ils envisagent les sujets des applications XR, les enseignants ont tendance à se concentrer sur le contenu adapté à leur contexte local. Les considérations de conception importantes incluent également le programme et la conception pédagogique, l'équité, la sécurité et d'autres sujets. (Note: This French abstract was translated using Google Translate).

Keywords: AR/VR applications, learning design, beliefs, teacher authoring, engagement

Introduction

The rapid advancement of technology has brought a renewed interest in using immersive technology in education. Augmented reality (AR), virtual reality (VR), and mixed reality (MR) are examples of the emerging tools that can offer rich opportunities to enhance learning and teaching (Liu et al., 2017). In this study, extended/cross reality (XR) is used to include AR, VR, and MR. A literature review of the existing work shows that VR and AR can help promote constructivist learning (Bani-Salameh et al., 2017). Additional benefits of XR include, but not limited to, providing more exploration options for learners (Correia et al., 2016), improving learner performances (Chang et al., 2019), and increasing learner motivation (Bacca Acosta et al., 2014).

In fact, XR is considered as the fourth transformational wave of innovation in technologies into the society after the previous three waves, namely computers, the internet, and mobile devices

(Mystakidis et al., 2021). The digital literacy of educators, including teachers — that is, their competency in integrating emerging technologies — is critical for them to adopt best practices in teaching, improve their professional career, and most importantly prepare students to be competent future citizens in society and workplace (Michos & Hernández-Leo, 2020).

Although XR is not new, research on educational applications of these tools have been patchy, lacking empirical studies (Liu et al., 2017). Even fewer studies have focused on teachers with respect to XR. In addition, XR technology has improved drastically in recent years, making it much easier and more affordable to be used in educational settings. Evidently, efforts to help teachers integrate XR technologies in education is scarce (Mystakidis et al., 2021). This study, therefore, aims to bridge this gap by studying practice educators' thoughts and experiences.

In this paper, five educators conducted a collaborative self-study that examined themselves, including their own actions and beliefs (Pinnegar & Hamilton, 2009) while teaching and learning XR in education. Specifically, the following research questions guide this research:

1. What are teachers' beliefs about XR in education?
2. What are the design considerations when educators engaged in XR application authoring experiences?
3. What are lessons learned?

Theoretical Framework

Enactivism, an emerging philosophical view, provides the theoretical grounding for this paper. Behaviorism, cognitivism and constructivism are the most prevailing theoretical perspectives in educational technology and related fields. Though looking very differently, these dominant theories in fact share similar assumptions (Davis et al., 2008). One of such similarities is the clear separation of mind and body (Davis & Sumara, 2002). Such Cartesian or dualistic view of mind and body is very popular. In such view, mental and

physical are two different and separable phenomena. While such beliefs are dominant in the field of education, it has been convincingly argued that they have shortcomings that may undermine educational practices (Davis & Sumara, 2002; Li et al., 2010). Thus, enactivism is proposed as a promising theoretical paradigm that offers a more encompassing framework than the current predominant perspectives.

At the core, enactivism stresses five interconnected ideas: autonomy, sense making, emergence, embodiment, and experience (Di Paolo et al., 2010). In this view, doing plays a central role for it is, rather than just the vehicle of, learning (Varela & Maturana, 1992). That is, cognition is grounded in action. The rich embodied experiences offered by XR through the illusion of body ownership and even body transfer, thus afford an ideal playing field for enactivist research. Enactivism also emphasizes on the inseparability of mind, body, and environment and considers that each of the three components carries equal weight rather than one subordinate the other (Proulx, 2004). Educator learning-through-designing/building thus offers a perfect breeding ground for enactivist research for it allowing the connection between learning to their environment, which included their teaching practices, personal beliefs, background as both educators and learners, and more. In this environment, the learners are asked to design and develop XR applications aiming at specific instructional topics. It is assumed that the educator-created XR applications would embody the cognitive processes of the designers (in this case, the educators) and the processes intended for students to apply when their XR applications are exploited.

Related Literature

Teacher Beliefs

Teacher beliefs related to XR highlight its encouraging and positive role in supporting student learning. Teachers believe that tools like XR can provide student-centered (Yildirim et al., 2020), experiential and inquiry-based learning (Cheng, 2022) through immersive and novel experiences that increase motivation and engagement (Cooper et al., 2019). It gives students autonomy and

teachers flexibility to observe student progress and be a facilitator in the classroom (Yildirim et al., 2020). XR can offer students unique opportunities and access to learning that would otherwise be unavailable or impossible to recreate (Cheng, 2022; Yildirim et al., 2020). For example, exploring distant places (Yildirim et al., 2020) and abstract concepts (Cheng, 2022), manipulating objects (Cooper et al., 2019), conducting experiments, and engaging in potentially dangerous situations (Seckin Kapucu et al., 2021). Thus, the literature shows that teachers believe the integration of ET has the potential to improve student learning through the creation of hands-on and student-centered experiences.

Despite the positive aspects of incorporating XR into teaching, teacher negative beliefs can hinder teachers' acceptance and intention to use AR/VR. These included a lack of technical knowledge (Bower et al., 2020), low self-efficacy (Cooper et al., 2019), low confidence in using ET (Yildirim et al., 2020), concerns about safety and monitoring students during AR/VR use (Yildirim et al., 2020). The time it takes for students to acclimate to new technologies, along with the potential for distraction, can make teachers hesitant to use XR (Seckin Kapucu et al., 2021). Perceived difficulties in managing the technology (Cooper et al., 2019) and anticipating technical problems (Cheng, 2022) negatively impacted teachers' beliefs and intentions to use XR. Teachers noticed that VR sensation required students to take breaks (Cheng, 2022). They worried that students' feelings of isolation from peers would decrease the time students collaborate (Yildirim et al., 2020). It is clear from the literature that if schools adopt XR, there must be teacher buy-in, institutional support (O'Shea & Curry-Corcoran, 2013), and stakeholder awareness of the benefits and barriers to integrating XR in the classroom (Seckin Kapucu et al., 2021).

Learning by Doing/Design

Learning by doing/design is not a new idea. Proponents of this approach have looked at its application in AR and VR to help teachers acquire needed skills. Abundant research (e.g., Buchner & Hofmann, 2022; Li et al., 2013) has shown that learning-through-building can be an effective means to help teachers gain the needed knowledge and skills to effectively integrating technology into classrooms. Teachers

who designed AR/VR experiences reported positive changes in their beliefs and attitudes toward using these technologies with students (Han & Patterson, 2020). They shared a better understanding of AR/VR and increased technical knowledge due to the design process allowing teachers to reflect on their skills, capabilities, and knowledge (Han & Patterson, 2020). The perceived benefits of learning how to design AR/VR included experiencing the successful use of the technology (Han & Patterson, 2020) and transferring acquired design skills to students (O'Shea & Curry-Corco, 2013).

For example, Han and Patterson (2020) explored the process of teacher learning through the design and implementation of technology-enhanced learning using virtual reality (VR) in an elementary school in South Korea. The study examined the teachers' learning through the design process and enactment of a VR-enhanced curriculum unit. Focusing on the external domain of resources and information about using VR, the personal domain about using VR, beliefs, and attitudes, the domain of practice of design and implementation of VR curriculum, and the domain of consequence of student outcomes and teacher outcomes. The results showed that the teachers learned about VR setup, curriculum alignment with VR content, and pedagogical strategies to use VR to enhance student learning. Teachers learned to redesign lessons incorporating VR technology to enhance student learning.

Another study (Buchner & Hofmann, 2022) compared the effectiveness of two different Synthesis of Qualitative Data (SQD)-based learning designs for in-service teachers' training on augmented and virtual reality. The study included a total of 45 in-service teachers who were divided into two groups. The first group was given an opportunity to design their own AR content, while the second group only explored the current environment. The findings suggested that designing their own AR content increased the teachers' confidence and willingness to integrate AR into their teaching practices. The results also indicated that the Will-Skill-Tool model (WST) predicted the teachers' use of technology, with a positive attitude and belief toward integration of technology, teacher readiness, and self-perceived confidence to use it. Overall, this study suggests that designing one's own AR content is a more effective method for

teacher training than merely exploring the current environment. The study by Doğan et al. (2022) explored learning through design in 3D multi-user virtual environments. Forty university students were tasked with designing a 3D MUVE using OpenSimulator software over one semester. Adopting a quasi-experimental design, the results showed that providing continuous feedback, clear and realistic goals, and adjusting challenge levels can lead to autotelic (i.e. intrinsically motivating) experiences in students.

Although teachers experienced positive benefits, they also reported barriers to designing AR/VR learning experiences. Design considerations reflected the need to ensure a clear purpose and expectations of the AR/VR experience, and any game elements used should match the lesson's goal (Lyk et al., 2019; Patterson & Han, 2019). Teachers suggested using a needs assessment to understand students' prior experiences with AR/VR, conducting a trial run of their design, and considering the set-up of the physical learning space (Patterson & Han, 2019). In the design process, teachers encountered challenges, including a lack of design experience and technical problems (Patterson & Han, 2019). Teachers reported insufficient technical knowledge, difficulties with programs such as Unity, and a lack of time to learn (Seckin Kapucu et al., 2021). They stated that they needed adequate ET design training through teacher preparation programs (Eutsler & Long, 2021) and applied professional development (Seckin Kapucu et al., 2021). Hence, teachers encountered second-order barriers when designing AR/VR.

In sum, the existing literature focused on teachers' intention to use these AR/VR with students (Bower et al., 2020; Eutsler & Long, 2021). These studies often relied on the evaluation of usability, ease of use, and usefulness as a measure of teacher intention to use AR/VR in their classrooms (Cooper et al., 2019). The limited studies on practicing educators focused on short-term training experiences or professional development sessions targeting STEM subjects (e.g., Bower et al., 2020; Cheng, 2022). Additionally, studies on teacher design mainly linked design to redesigning or enhancing their current lessons and curriculum using AR/VR rather than XR design (e.g., Eutsler & Long, 2021; Han & Patterson, 2020). The current study thus aims to bridge the gap by exploring beliefs and experiences of

educators who teach different contents and levels of education through XR design and development.

Methods

Framed in a qualitative, naturalistic research perspective (Creswell, 1998), this case study reports five educators' learning experiences focusing on XR design and learning. As a widely adopted research methodology, it provides a great tool to deepen our understanding of educational practitioners' experiences and thinking. The case was a graduate course taught by the first author in a university setting. The theoretical proposition, enactivism, guided the data collection and helped shape our focus on certain data rather than other irrelevant data as enactivism stresses that "when we analyze data, we not only observe, but modify what we turn our attention to as we make aspects of the data emerge through our reading at the same time, this changes us" (Maheux & Proulx, 2015, p. 212).

The case study design fits well with the enactivist viewpoint because both share the goal to conduct transformative research (Creswell, 1998). Further, case study approach provides a perfect methodology for enactivism because both regarding researchers and objects, such as the educators, being researched are interconnected and such connections are essential (Maheux & Proulx, 2015). Thus, the researchers and our participants, i.e., the practicing educators, co-emerged as we are observing, exploring, reflecting designing and building. The importance of doing from the enactivism viewpoint guided our attention to focus on the educators' act and different learning activities. Case study stresses that "the quality and utility of the research not based on its reproducibility but on whether the meanings generated by the researcher, or the reader are valued. Thus a personal valuing of the work is expected" (Stake, 1995, p. 135), which further fits into the enactivist view as enactivism assumes reality is inseparable from the perceiver, thus our perception and the reality are dependent on each other. In this paper, thus, multiple perspectives were taken (e.g., multiple ways to collect data, different researchers investigating the same data) which also help triangulate

data (Gay et al., 2011). Pseudonyms were used in this paper with participants selecting their own.

The Context and Participants

The context of this study was a seven-week graduate course aiming to provide students with a foundational understanding of XR technologies in education. The course was offered as a hybrid course, with two face-to-face sessions and the rest were offered online asynchronously. In the course, students were asked to review essential concepts, explore XR and examine examples of how XR has been exploited to bring about challenges in people.

Considering that many people would have limited experience interacting with XR tools, students were asked to explore various XR environments, and experiment with different XR technologies, such as VR headsets (e.g., Lenovo, Oculus). They then chose one XR tool either to evaluate based on what they believed to be the most appropriate criteria, or to integrate into a lesson plan/training module to teach specific content.

A key aspect of this course was the adoption of learning by designing/building. Students were asked to apply learning design and XR design principles to design and develop their own XR applications. Through such design and building process, students gain deeper understanding of the fundamental ideas, theories and design principles of XR in education. Since students enrolled in this course often had limited programming background, scaffolding XR development practices were intentionally built into the weekly exercises.

This course encourages educators to be reflective in their evaluation of AR/VR environments. For example, both self- and peer-evaluations were incorporated into the process. An iterative design approach was also employed integrating peer and instructor feedback-revising loop. Following their design creation of an AR/VR experience, educators in this course determine the usefulness of the designed products through testing and discussion.

The participants consisted of five practicing educators and were involved in the XR course. Amongst them, four were graduate students enrolled in a doctor program and the fifth one was the course instructor. Two of the students were enrolled in the course, while the other two served as graduate assistants helping with the course. Amongst the 4 doctoral students, three were K-12 school teachers (one was teaching at the elementary level, while two were high school teachers) and the fourth one worked in a higher education institution.

Data and Analysis

The data collected included: assignments completed by the enrolled educators for the course which also included their online communications and digital projects, researchers' notes and reflective journals. While this study focused on online interactions and reflective journals, other data provided the context information of this study and allowed triangulation of the results. A thematic analysis was used to analyze the data. Adopting a three-step process, the analysis started with open coding (Corbin & Strauss, 1990) of all written artifacts. In this phase, each researcher independently coded recurring and salient themes. The second phase discussing each other's results and later comparing these naturally emerging themes with the literature related to XR education. Such processes allowed us to examine the summarized data and create general categories from the full dataset. A matrix of merged themes was developed to support the overall interpretation of the data. In the third phase, we used matrices and other displays to further condense the data and draw comparisons (Miles & Huberman, 1994). Grouping the data under different codes allowed us to identify patterns and emergent themes. In such iterative process, a constant comparative approach (Corbin & Strauss, 1990a) was adopted to generate, refine, and recreate themes and codes (Miles & Huberman, 1994). Specific strategies were adopted to ensure reliability and accuracy, including data collection from multiple sources, independent analysis of data, and cross checking and discussion by all researchers (Yin, 2014). Further, the theoretical grounding shaped the data collection and analysis, and helped guiding presentation of the findings (Sibbald et al., 2021). The researchers discussed all the themes, with particular attention being paid to the ones with disagreement. The

discrepancies were articulated, debated, and revised until an agreement was reached.

Results

Beliefs

Using XR to solve authentic problems was at the center of all educators' consideration related to XR application in education. They believed that the immersive nature of XR could provide an ideal environment to situate learners in real world scenarios while promoting intrinsic motivation. This was best represented by Radha's articulation about how XR to be applied in firefighter training:

This AR game is for students taking the Aerial Apparatus Driver/Operator course... Students in this course must learn how to drive and operate a heavy vehicle carrying long ladders and other equipment. A driver (in the front) and an operator (in the back) both drive this truck, so their coordination is crucial...They must navigate through an actual building on fire, search for the victims, communicate with their peers about the victims, search for safe passages, and report to the leader. [In this game] students can turn and move as if in an actual burn building (real-world settings)...this application aims to deliver a physiological immersion for students. [Radha]

Experiential learning was also favored as XR allowing visualization of abstract concepts and object manipulation. The educators discussed how content, particularly the abstract ones, could be experienced and lead to enhanced understanding of concepts. For example, Emery explained how XR could be integrated into her psychology course to enhance learner understanding:

I think students truly seeing the structure of the organs will add a more realistic meaning to the content and allow students to engage deeper and really simulate the magnitude these various areas of function of the brain have. Students get a better understanding of the content if they could manipulate

a VR brain and see real-life side effects that could take place.
[Emery]

The cost related to XR application, both positive and negative perspectives, were shared. On the one hand, the educators believed that XR could provide a cost-effective way for content learning and skill building.

Using a simulation to train firefighters in driving a firetruck is convenient, as it takes a lot of resources and planning to procure a fire truck. With the increasing fuel cost, simulated activities are cost-effective. It also helps reduce the pollution and the cost of other fire extinguishing resources. [Radha]

On the other hand, some worried that XR technologies were likely still too costly for K-12 education, and thus may perpetuate inequality:

It seems as though many AR/VR products are quite costly (Oculus headsets, Co-Spaces subscriptions, etc.). [Violet]

XR was perceived as a useful means to help confidence building and decreasing apprehension. For example, Radha acknowledged how fire-fighter trainees could benefit from XR simulations: “Before entering an actual fire building, they can practice this activity until they become confident.” Violet discussed how XR could help “reduce anxiety surrounding learning mistakes”.

Design Considerations

What were considered the most important aspects when designing an XR environment or applications for education? Apparently, the educators treated learning outcomes as the most significant aspect. Here the learning outcomes related directly to the intended educational content and objectives for which the XR application was designed for. They agreed that the ultimate goal of any XR educational application should be to promote learning. Their discussions, both online and in person, reflected this recurring theme. During an in-person meeting, the educators had a vibrant conversation about XR as a useful means of delivering content for

learners to experience. They emphasized that learning outcomes should always be at the forefront of XR design consideration and go beyond entertainment.

The most important aspects to consider when designing an educational AR/VR application is whether the technology is enhancing learning. Too often, technology is used to make learning more engaging, however, it does not reinforce or teach content in a meaningful way. When incorporating [XR] into instruction, the technology should complement learning goals and enhance mastery for students. [Violet]

There is always a fear of these technologies becoming entertainment rather than educational tools for students [Radha].

Different philosophical and pedagogical perspectives guided the XR design. Constructivism was a popular framework employed.

This simulated activity falls under a constructivist classroom design, which is a teaching style in which students can engage in the content through student-led assignments or projects that promotes them using creativity to construct a deeper understanding of the content. [Emery]

Some adopted situated learning and embodied cognition when designing, as demonstrated by Violet's design document of her VR game to teach computer science (CS).

This game relies on situated learning and embodied cognition to increase student understanding of computer science and computational thinking. Research demonstrates that students who have acted out a scenario have better recall of the concepts learned within that embodied experience (Dede et al., 2017). The expectation is that because students are creating the code and then experiencing the robot act out the code, they will have an embodied experience to reflect on when they are coding at later times.

Other theoretical perspectives like backwards design also helped the educators when designing their own XR applications.

This project is developed utilizing Backwards Design. In keeping with this method, objectives were selected first, then the summative activities were designed, then formative and smaller summative activities were created. [Radha]

The educators followed curriculum and instructional design principles to create their XR applications, keeping in mind various perspectives ranging from context, resources, to accessibility, to user-friendliness. For example, Radha's design document specified six critical perspectives, namely: audience, technology and resources, cost, accessibility, and ease of use/navigation. During an in-person meeting, the educators reflected on the type of learning content that could be effectively delivered through XR technologies, such as history and culture. Such discussion inspired them to further examine design principles and how instructional design could be applied to XR integration. For example, the topic of how to best present learning objectives, whether through an XR environment or teacher presentation, was perceived as an important design decision, and thus deserving careful consideration. Effective strategies for content delivery such as using good graphics and a realistic scale of objects were also explored.

When designing XR applications, educators tended to focus on content customized to their local contexts. In this course, students were encouraged to find real clients. All the educators turned to the people around them, either their own students or colleagues, whom they knew best about. They designed XR applications according to the specific target groups, content knowledge, specific XR genre and strategies. For example, as an instructional designer, Radha was interested in designing XR simulations for firefighter education. Targeting students of a firefighter rescue training course, she described how the students must:

...navigate through an actual building on fire, search for the victims, communicate with their peers about the victims, search for safe passages, and report to the leaders. The

students must use the building map and communication signals while navigating through the building. While doing this exercise, the students will be fully equipped with a PPE kit, helmet, gloves, boots, and other required equipment. [Radha]

Radha's argument for the using of XR was powerful: "when it comes to training emergency responders, there are limitations to creating simulated exercises, such as a real fire and rescue exercise." She envisioned an XR integrated course to help firefighters learn content and build confidence in a cost-effective fashion.

Ethics and wellness considerations were regarded vital to address potential risks and ensure the wellbeing of learners. The educators depicted how we should prioritize ethical practices, including safeguarding user data and privacy, avoiding discriminatory content, and promoting inclusive experiences. Such discussions also included recognizing the possible impact of XR on mental and physical health of learners by incorporating appropriate measures to mitigate any adverse effects.

While using the gaming application, students should not be harmed due to the equipment, poor design, cybersickness, etc. Disclaimers, warnings, and waivers must be included to avoid real-world mishaps. [Radha]

Equity was autonomously brought up multiple times and by different educators, often connected to a larger social context. Diversity in terms of language, culture, ability, etc. were all examined with the aim of cultivating an inclusive learning environment.

Extended reality could be used to better promote equitable response in the field. For example, firefighters in simulation could be approached by people speaking a variety of languages and the simulation could allow firefighters to practice understanding and responding to various requests. I'm not sure if firefighters are under scrutiny like the police force for disproportionate responses to certain racial demographic groups, but in the event that there is racial disparity in response, simulations could help firefighters

practice more equitable responses. I think this is a great idea and hope that the police force will consider using similar simulations to promote equity within their organization. [Violet]

Making sure students with disabilities have the ability to manipulate the environment to fit their needs, such as closed captioning, motor skills assistance, etc. [Emery]

The educators also urged for careful consideration of additional benefits of XR beyond cognitive gain, such as social development, mental health, etc.

There would be real benefit to scaffolding immersive firefighter rescue experiences to gradually increase from using only the visual to adding physical heat and realistic audio... this may ultimately desensitize firefighters to extreme situations and reduce post-traumatic stress disorder following intense rescues and experiences. [Violet]

Cultural immersion can be achieved using ARVR technology. Sometimes, reading and seeing something is not enough until you experience it. [Emery]

Safety was also perceived as an important aspect for XR application. On the one hand, educators depicted how XR could offer a safe environment for learners to practice needed skills “in a safe space where danger does not exist but can be simulated while gaining practice and experience” [Emery], or help reduce possible emotional issues associated to learning as demonstrated by Violet’s comment above regarding PTSD.

On the flip side, educators were fully aware of potential issues related to safety and student wellness. They stressed the importance for XR integration to recognize such safety related regulations and practices, including any possible harmful effects and behaviors, physically and beyond.

While using the gaming application, students should not be harmed due to the equipment, poor design, cybersickness, etc. [Violet]

Disclaimers, warnings, and waivers must be included to avoid real-world mishaps. [Radha]

During an in-person meeting, the educators experienced various XR tools such as Oculus and Lenovo headsets. The observation notes showed the need for each person to take breaks because of motion sickness during complete immersion in VR. This led to a dynamic discussion of various topics related to safety. For instance, one topic discussed was that factors minimizing movement and pacing with breaks could provide users with relief from possible motion sickness and other unsteady feelings, therefore demand careful consideration for XR design. Another idea was that when learners are immersed in VR environments, it is critical to remind users to sit down and utilize chairs that swivel, thus allowing learners to look around instead of moving around to avoid possible mishaps.

Lessons Learned

Several key insights emerged when considering the lesson learned from the course design and implementation in the context of XR application authoring experiences. Firstly, when a learning through doing approach was adopted, an iterative design process needed to be embraced. Differentiation with ample options was an important strategy to ensure successful implementation. Both the course design and the learners' artifacts reflected these ideas. In this course, the learners had opportunities to share their initial ideas and draft plans, receiving feedback from both peers and the instructor, and revising and refining their products. They also had the freedom to choose the outcome, software template, etc. to create their final products. Some learners adopted such an approach, as reflected below:

Components of Rapid Prototyping were also included in an iterative approach to designing and refining the game. [Radha's design document]

Another lesson learned was the need for face-to-face interactions where various XR tools could be explored. Teachers needed exposure to a variety of XR tools, which would be challenging to realize at home or even in K-12 schools, to gain comprehensive understanding of how each tool could be best utilized and for what specific purposes. Additionally, the opportunities to meet face to face to experience firsthand the XR tools, to observe each other using such tools, and to discuss related topics were priceless. The educators articulated how their learning was greatly enhanced through such experiences, which would be difficult, if not impossible, through online exchanges only.

It is important to go into the lab to use and experience the technologies so that we understood how they worked and how we might implement them in our projects [researcher journal].

Building my own game in Unity reinforced my belief that teachers need explicit, in-person instruction to find success in coding experiences. [Violet]

A third lesson learned related to technological needs, both the need for adequate technical infrastructure and the skills to use those tools. During the course, Emery could not download the authoring tools provided due to tech limitations on her end. Even though she had the option and chose to use other tools, she was nonetheless frustrated: “I found the class super interesting and the content overall something I am going to use in the future but developing it myself was just awful, which is completely unlike me.”

Others were able to implement their projects, yet still highlighted how coding such projects was time consuming and required some programming background, as exemplified by Violet’s reflection: “The amount of time spent on editing this project would not normally be feasible for most teachers, especially those without any kind of a coding background. To address these challenges, we need more professional development surrounding AR/VR for teachers, however, getting teachers to participate would be a huge challenge in itself as many teachers self-select as not ‘tech-savvy’.”

Discussion

Everyone probably agrees that AR VR are powerful tools that can potentially transform education. The question of how to best utilize such tools to enhance learning remains to be answered. This study focused on educators' experiences and thoughts and several results from the data analysis are worthy of discussion.

This study presents uniqueness as it considers the beliefs of educators who teach different contents and levels of education. It involves educators engaging in a graduate course that asks participants to consider previous research in design considerations, such as best practices, theory, learning principles, and ethics. Through the design process, it invites educators to examine issues and questions about AR/VR design and its use in education. Educators use development tools like Unity and/or Adobe Aero, scarcely cited in other studies, in their AR/VR product creation.

In this study, the educators have learned XR systematically through examining theoretical groundings and exploring best practices, allowing the unification of ethical and educational aspects in their authentic designing process. As argued by Lee and Hu-Au (2021), considering ethical practices and effective learning in concert is vital for XR integration in education in order to help students grow to their fullest potential. The experience during the course has enabled the educators to fully understand the importance of equity and wellness. When designing their own XR applications, they attend to multiple perspectives related to these topics including ethics, inclusion, and safety. Their design of XR systems thus involves a conscious decision concerning different ways to promote equity and wellness of students. While we understand that teachers would not typically have chance to create their own XR applications due to practical reasons, the process of designing and developing such products, as demonstrated in this study, has helped educators deepen their understanding of educational applications of XR. It is worth noting that equity and wellbeing topics were autonomously brought up before the ideas were introduced formally. This led the instructor to organically bring it to the subsequent reflective practices and deep discussions. Such ideas were later integrated into the

educators' design and development processes when authoring their own XR application. Such experience has resulted in an enhanced understanding of the concepts and how theories connect with practices. This endorses the learning-by-doing approach and substantiates enactivism about how cognition is embodied. Emery's challenges such as her inability to download the software, have resulted in her strong emotional response about XR development. It is a good attest of enactivism emphasizing that "learning is fully embodied and fundamentally affective" (Maiese, 2017, p. 197).

A finding of this study is that the educators' XR design has been grounded in sound theories. This is not surprising since various educational theories were examined at the beginning of the course. The XR authoring process, thus, afforded the educators a good opportunity to apply the theories to their design and development. This, however, is contrasted to previous studies that only about one in three XR use cases follow learning theories (Stanney et al., 2023). Since educational theory guided XR applications have been observed as more effective than unstructured XR learning (Khan et al., 2019), it is critical that we stress the importance of theoretical grounding when XR integration is practiced.

This study shows that learning outcomes are placed at the center when educators design educational XR applications, confirming previous research (Meccawy, 2022) that putting educators in charge of designing helps assure pedagogical alignment so that learning would not be lost. At the same time, the educators tend to customize their XR design to local context. This is in accordance with enactivism which views our body, mind, and the environment are inseparable. As such, our actions, such as perceiving, creating, etc. are all influenced by our experiences and cognition. Thus, it is not surprising that the educators have chosen to address a relevant and timely instructional problem using an actual client, applying their context, and establishing goals for the design of their AR/VR experience.

Cost associated with XR is an interesting theme that has been discussed both positively and negatively. While noting that XR can provide a cost-effective means to enhance learning, the educators realize the relatively high cost of XR can cause inequality, thus

exacerbating disparities of haves and have-nots. Although more and more families are starting to purchase XR technologies, these families only constitute a relatively small percentage of households. Even for those who have the tools, it is very likely that they own limited types of XR tools. Thus, it is important to consider how schools can provide equitable access to such powerful tools for all students and their teachers for appropriate integration so that the great potential of these tools can be best harnessed.

In this study, the educators put safety as a top priority, while highlighting XR's ability to provide safe spaces for practicing skills without real-world risks and even helping with emotional struggles. They also regard issues like fair access and data security as critical factors for XR integration. As discussed in previous research (Dodds, 2021), how to ensure XR experiences available to everyone, protecting users' privacy, etc. are ongoing challenges we face. It calls for collaboration among educators, learners, and developers to shape XR into a positive and effective tool for education.

Conclusions

XR is gaining more and more attention in various fields, including education. The increased use and the great potential of XR technologies call for deep understanding of best practices for the development and utilization of XR instructional content. It is also imperative to prepare our teachers to gain solid understanding of the best integration of such tools. This study contributes to existing literature by exploring practicing educators' experiences and thoughts while engaging in authentic XR applications' design and development processes. As demonstrated in this work, XR authoring forced the learners into a situation where they must apply the knowledge learned during the course, and go through cycles of trying, making mistakes, reflecting, modifying, refining. Such a process makes learning personalized and authentic, thus leading to heightened motivation and knowledge retention. The lesson learned from the work can enhance our understanding of how to best help practitioners develop to effectively integrate XR into teaching and learning.

It is important to note that immersive learning and XR are not passing fads. Rather, they are significant developments that call for active educators' engagement. From an enactivist perspective, learning occurs through active, embodied action within dynamic settings. XR technologies offer unprecedented opportunities by expanding the contexts in which learners can engage in embodied experiments, whether in virtually or augmented setting. As such, XR holds great potential when learners, in this case educators, are actively involved in the design and development process. Ultimately, it is the responsibility of our society, including the researchers, educators, designers, and policy makers to ensure this powerful technology is used responsibly, with enactive principles of learning offering one useful lens for supporting authentic, embodied knowledge building so that our students can benefit the most from it.

References

- Bacca, J., Baldiris, S., Fabregat, R., Graf, S., & Kinshuk, K. (2014). Augmented reality trends in education: a systematic review of research and applications. *Journal of Educational Technology & Society*, 17(4), 133-149.
- Bani-Salameh, H., Al-Gharaibeh, J., Jeffery, C. L., & Al-Sharif, Z. A. (2017). Collaborative education in a virtual learning environment. *International Journal of Business Information Systems*, 25(4), 474-489. <http://doi.org/10.1504/IJBIS.2017.085172>
- Bower, M., DeWitt, D., & Lai, J. WM (2020). Reasons associated with preservice teachers' intention to use immersive virtual reality in education. *British Journal of Educational Technology*, 51(6), 2214–2232.
- Buchner, J., & Hofmann, M. (2022). The more the better? Comparing two SQD-based learning designs in a teacher training on augmented and virtual reality. *International Journal of Educational Technology in Higher Education*, 19(24). <https://doi.org/10.1186/s41239-022-00329-7>
- Chang, Y. S., Hu, K. J., Chiang, C. W., & Lugmayr, A. (2019). Applying mobile augmented reality (AR) to teach interior design

- students in layout plans: evaluation of learning effectiveness based on the ARCS model of learning motivation theory. *Sensors*, 20(1), 105-126. <http://doi.org/10.3390/s20010105>
- Cheng, K.H. (2022). Teachers' perceptions of exploiting immersive virtual field trips for learning in primary education. *Journal of Research on Technology in Education*, 54(3), 438–455. <https://doi-org.proxy-tu.researchport.umd.edu/10.1080/15391523.2021.1876576>
- Cooper, G., Park, H., Nasr, Z., Thong, L. P., Johnson, R. (2019). Using virtual reality in the classroom: preservice teachers' perceptions of its use as a teaching and learning tool. *Educational Media International*, 56(1), 1–13.
- Corbin, J., & Strauss, A. (1990). Grounded theory research: Procedures, canons, and evaluative criteria. *Qualitative Sociology*, 13(1), 3-21. <https://doi.org/10.1007/BF00988593>
- Correia, A., Fonseca, B., Paredes, H., Martins, P., & Morgado, L. (2016). Computer-simulated 3D virtual environments in collaborative learning and training: meta-review, refinement, and roadmap. *Handbook on 3D3C Platforms*, 403-440. http://doi.org/10.1007/978-3-319-22041-3_15
- Creswell, J. (1998). *Qualitative Inquiry and Research Design; Choosing Among Five Traditions*. Sage Publications.
- Davis, B., & Sumara, D. (2002). Constructivist discourses and the field of education: Problems and possibilities. *Educational Theory*, 52(4), 409-428. <http://doi.org/10.1111/j.1741-5446.2002.00409.x>
- Davis, B., Sumara, D., & Luce-Kapler, R. (2008). *Engaging Minds: Changing Teaching in Complex Times* (2nd ed.). Erlbaum.
- Dede, C. J., Jacobson, J., & Richards, J. (2017). Introduction: Virtual, augmented, and mixed realities in education. In *Virtual, augmented, and mixed realities in education* (pp. 1-16). Singapore: Springer Singapore.
- Di Paolo, E., Rohde, M., & De Jaegher, H. (2010). Horizons for the enactive mind: Values, social interaction, and play. In J. Stewart, O. Gapenne, E. Paolo (eds.). *Enaction: Towards a new paradigm for cognitive science*. The MIT Press. <https://doi.org/10.7551/mitpress/8629.003.0003>
- Dodds, H. E. (2021). Immersive learning environments: designing XR into higher education. In J. E. Stefaniak, S. Conklin, B.

- Oyarzun, & R. M. Reese (Eds.) *A Practitioner's Guide to Instructional Design in Higher Education*. (pp. 69-78). EdTech Books.
- Doğan, D., Demir, Ö., & Tüzün, H. (2022). Exploring the role of situational flow experience in learning through design in 3D multi-user virtual environments. *International Journal of Technology and Design Education*, 32(4), 2217-2237. <https://doi.org/10.1007/s10798-021-09680-8>
- Eutsler, L., & Long, C. S. (2021). Preservice teachers' acceptance of virtual reality to plan science instruction. *Journal of Educational Technology & Society*, 24(2), 28-43.
- Gay, L. R., Mills, G. E., & Airasian, P. W. (2011). *Educational Research: Competencies for Analysis and Applications*. Pearson Higher Ed.
- Han, I., & Patterson, T. (2020). Teacher learning through technology-enhanced curriculum design using virtual reality. *Teachers College Record*, 122(7), 1-34. <https://doi.org/10.1177/016146812012200706>
- Khan, R., Plahouras, J., Johnston, B. C., Scaffidi, M. A., Grover, S. C., & Walsh, C. M. (2019). Virtual reality simulation training in endoscopy: a Cochrane review and meta-analysis. *Endoscopy*, 51(07), 653-664. <https://doi.org/10.1055/a-0894-4400>
- Lee, J. J., & Hu-Au, E. (2021). E3XR: An analytical framework for ethical, educational and eudaimonic XR design. *Frontiers in Virtual Reality*, 2, 697667. <https://doi.org/10.3389/frvir.2021.697667>
- Li, Q., Clark, B., & Winchester, I. (2010). Instructional design and technology grounded in enactivism: A paradigm shift? *British Journal of Educational Technology*, 41(3), 403-419. <http://doi.org/10.1111/j.1467-8535.2009.00954.x>
- Li, Q., Lemieux, C., Vandermeiden, E., & Nathoo, S. (2013). Are you ready to teach secondary mathematics in the 21st century? A study of preservice teachers' digital game design experience. *Journal of Research on Technology in Education*, 45(4), 309-337. <http://doi.org/10.1080/15391523.2013.10782608>
- Liu, D., Dede, C., Huang, R., & Richards, J. (2017). *Virtual, augmented, and mixed realities in education*. Springer.

- Lyk, P. B., Majgaard, G., Dietrich, T., & Stock, C. (2019). Co-designing an immersive and interactive alcohol resistance training tool using 360-degree video. *Proceedings of the European Conference on Games Based Learning*, 450–458. <https://doi.org.proxy-tu.researchport.umd.edu/10.34190/GBL19.081>
- Maheux, J.-F., & Proulx, J. (2015). Doing mathematics: Analysing data with/in an enactivist-inspired approach. *ZDM*, 47(2), 211–221. <http://doi.org/10.1007/s11858-014-0642-7>
- Maiese, M. (2017). Transformative learning, enactivism, and affectivity. *Studies in Philosophy and Education*, 36(2), 197–216. <https://link.springer.com/article/10.1007/s11217-015-9506-z>
- Meccawy, M. (2022). Creating an immersive xr learning experience: A roadmap for educators. *Electronics*, 11(21), 3547. <https://doi.org/10.3390/electronics11213547>
- Michos, K., & Hernández-Leo, D. (2020). CIDA: A collective inquiry framework to study and support teachers as designers in technological environments. *Computers & Education*, 143, 103679. <http://doi.org/10.1016/j.compedu.2019.103679>
- Miles, M., & Huberman, A. (1994). *An Expanded Sourcebook: Qualitative Data Analysis* (2nd ed.). Sage Publications.
- Mystakidis, S., Fragkaki, M., & Filippousis, G. (2021). Ready teacher one: virtual and augmented reality online professional development for K-12 school teachers. *Computers*, 10(10), 134. <https://doi.org/10.3390/computers10100134>
- O'Shea, P., & Curry-Corcoran, D. (2013). The viability and value of student and teacher-created augmented reality experiences. *International Journal of Virtual and Personal Learning Environments*, 4(3), 78–87.
- Patterson, T., & Han, I. (2019). Learning to teach with virtual reality: Lessons from one elementary teacher. *TechTrends: Linking Research & Practice to Improve Learning*, 63(4), 463–469.
- Pinnegar, S., & Hamilton, M. L. (2009). *Self-study of practice as a genre of qualitative research: Theory, methodology, and practice* (Vol. 8). Springer Science & Business Media.
- Proulx, J. (2004). The enactivist theory of cognition and behaviorism: An account of the processes of individual sense-making. Complexity Science and Educational Research conference,

- Chaffey', Locks, Canada.
<https://www.researchgate.net/publication/338124333>
- Seckin Kapucu, M., Yurtseven Avci, Z., & Sural, I. (2021). Innovative approaches in development of educational materials: A case study of science teachers. *Turkish Online Journal of Distance Education*, 22(4), 58–81.
- Sibbald, S. L., Paciocco, S., Fournie, M., Van Asseldonk, R., & Scurr, T. (2021, September). Continuing to enhance the quality of case study methodology in health services research. *Healthcare Management Forum* 34(5) 291-296. SAGE Publications.
- Stake, R. E. (1995). *The Art of Case Study Research*. Sage.
- Stanney, K. M., Skinner, A., & Hughes, C. (2023). Exercisable Learning-Theory and Evidence-Based Andragogy for Training Effectiveness using XR (ELEVATE-XR): Elevating the ROI of Immersive Technologies. *International Journal of Human-Computer Interaction*, 39(11), 2177-2198. <https://doi.org/10.1080/10447318.2023.2188529>
- Varela, F., & Maturana, H. (1992). *The Tree of Knowledge*. Shambhala.
- Yildirim, B., Sahin-Topalcengiz, E., Arikan, G., & Timur, S. (2020). Using virtual reality in the classroom: Reflections of STEM teachers on the use of teaching and learning Tools. *Journal of Education in Science, Environment and Health*, 6(3), 231–245.
- Yin, R. (2014). *Case study research: Design and methods* (5th ed.). Sage.