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Immersive Learning Research Network

Exploring the Universal XR Design Strategies Considering Interactive Learning Experiences: A Case Study

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Abstract. This short paper explored integrating Extended Reality (XR) technology with Universal Design for Learning (UDL) principles to foster an inclusive learning experience suitable for all learners. Employing an iterative development approach based on the Successive Approximation Model (SAM2), we developed an XR-based prototype for computer science education that caters to diverse learning styles while ensuring accessibility and effectiveness. The study presents a design case that integrates UDL's fundamental principles: representation, action, expression, and engagement. Through XR technology, personalized and inclusive learning pathways are established, benefiting learners of all abilities and backgrounds. The research underscores the significance of integrating emerging technologies with inclusive design principles to advance the educational landscape, emphasizing the importance of educational tools that are both engaging and accessible to all.

Keywords: Extended Reality, Learning Experience, Universal Design for Learning.

1 Introduction

Extended Reality (XR) encompasses both physical and virtual environments where human-computer interactions take place through technology and hardware-generated interactions [1, 2]. This technology fosters immersive learning environments that facilitate visualization and interaction with content to an unprecedented degree. XR accommodates diverse learning styles, fostering engagement and comprehension, thus enhancing the educational journey across various fields.

Despite the promising advancements in XR technologies for educational purposes, significant gaps still need to be in fully realizing its potential across diverse learning environments. Firstly, more empirical research must be conducted to systematically measure the effectiveness of XR applications in real-world educational settings [3]. Current studies often focus on short-term impacts without assessing long-term retention and comprehension across varied demographic groups. Furthermore, there is a lack of comprehensive guidelines integrating UDL principles into XR content development, which is critical for ensuring accessibility and inclusivity in these immersive learning environments [4]. Additionally, while XR technologies are poised to transform educational experiences, their adoption in mainstream education needs to be improved by several barriers [5]. These include the high cost of XR hardware, the need for technical expertise to develop and implement XR learning modules, and the potential for cognitive overload due to overly complex interfaces. These challenges suggest a crucial need for research that explores cost-effective, scalable XR solutions and addresses the usability and accessibility concerns that can limit their effectiveness for diverse populations.

The application of Universal Design for Learning (UDL) principles is crucial to creating engaging and inclusive learning experiences (LX) [6, 7]. UDL principles prioritize the development of educational content that is accessible and effective for all learners, regardless of their differences or learning preferences. This approach emphasizes the importance of integrating user experience design (UXD) into learning design and technology to ensure that educational technologies like XR are designed with the learner's needs and experiences in mind [8, 9]. The potential of XR to significantly enhance LX by offering interactive and personalized learning pathways aligns with the increasing importance of individualized and inclusive education.

This study aims to illustrate a case of XR learning content design that applies UDL guidelines to foster an inclusive learning experience. The objective is to create educational tools that engage and cater to a diverse learner population. XR content developed in accordance with the representation, action, expression, and engagement principles outlined by UDL seeks to leverage XR technology to provide immersive, interactive, and inclusive learning experiences. This ensures that learners of all abilities and backgrounds equally benefit from educational innovations. This study underscores the significance and necessity of integrating emerging technologies with inclusive design principles to enhance the educational landscape for all learners.

2 Literature Review

2.1 Extended Reality (XR) in Education

In recent years, there has been a surge of interest in harnessing extended reality (XR) technologies to create more immersive learning experiences. XR encompasses both physical and virtual environments where human-computer interactions occur through technology and hardware-generated interactions [1, 2]. This technology has demonstrated significant efficacy in education and training [10]. Unlike Virtual Reality (VR), XR allows for the augmentation of virtual objects within a physical environment, making it safer for users. Moreover, it facilitates the transfer of learning content into real-life scenarios, fostering practical and hands-on learning experiences [11]. Consequently, XR technology has gained popularity in fields such as medicine [12], where simulation-based learning is essential, as well as in manufacturing and production [1], where safety is paramount in job training.

XR offers learners a more lifelike learning environment, enhancing motivation and engagement [13]. While XR provides learners with rich learning opportunities, the effectiveness of related research is not consistently demonstrated. Multimodal interactions in XR, utilizing multiple senses, may lead to cognitive overload for some learners [14]. Additionally, XR may not be suitable for all learning situations or environments due to its high dependence on specific contexts [15]. Furthermore, XR technology may pose challenges for learners who are unfamiliar with it. Therefore, from an educational standpoint, it is imperative to design learner-centered XR-based learning environments that prioritize the learning experience.

2.2 Extended Reality (XR) in Education

The notion of LX extends beyond merely leaving an impression on an individual; it encompasses practical knowledge acquired through collaborative meaning-making, reflective practice, and deliberate interaction with digital technologies, whether through human-computer or human-human engagement [16]. This definition encompasses any form of interaction or learning encounter, such as a course or program. A well-designed LX is crucial for engaging learners and aiding their comprehension of the material. The increasing interest in UXD within the instructional design realm reflects a growing recognition of the importance of individual LX while utilizing learning technologies [9].

XR technology has the potential to significantly enrich the LX by crafting interactive environments that effectively engage learners [12]. Effective LX design integrates learning objectives, instructional strategies, and assessment methods to deliver a comprehensive experience. Integrating XR into LX design necessitates thoughtful consideration of how these technologies can elevate and enhance the learning journey. This may involve leveraging XR to illustrate complex concepts, fostering collaborative learning opportunities, and tailoring learning paths to create an immersive and captivating LX that captures learners' attention and enhances their comprehension visually and interactively [8]. Hence, when designing LX with XR, it is vital to determine how these technologies can enhance the appeal and efficacy of learning while fostering a deep connection with the subject matter.

Developing effective technology-based learning environments that account for learners' needs and technological capabilities demands meticulous planning and a profound understanding of LX principles [17, 18]. Educators and instructional designers must ensure that XR experiences are both technologically sophisticated and pedagogically sound [19]. They should create suitable, user-friendly, and engaging XR content that is relevant to learners from diverse backgrounds and abilities. By prioritizing LX in XR-based educational tool design, educators can develop engaging and inclusive learning experiences that cater to various learning styles and preferences, thus making education adaptable and accessible to all learners.

[20] introduced an instructional design model focused on crafting engaging learning experiences in an XR environment. This model, grounded in Bloom's Taxonomy, incorporates multiple levels of knowledge to design interactive learning experiences. Figure 1 provides a detailed depiction of the multilayered instructional design model.

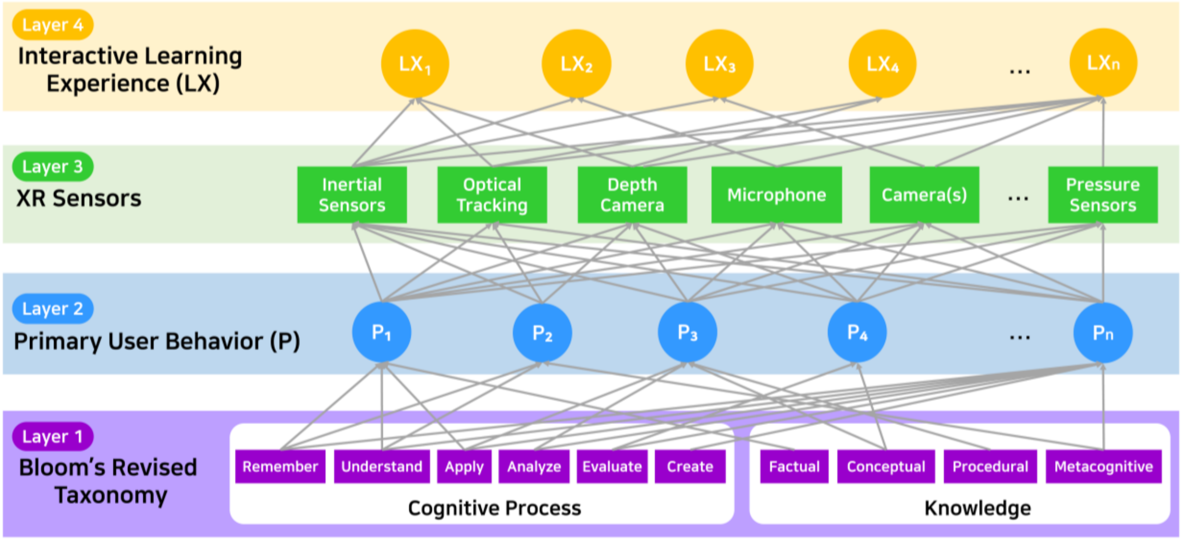

Fig. 1. Framework of Interactive Learning Experience in the XR Environment [20].

2.3 Universal Design in Learning (UDL)

UDL is a comprehensive educational framework designed to enhance the learning experience for all learners by recognizing and accommodating the diversity of learners [6, 7]. It achieves this by offering multiple means of representation, expression, and engagement [21], fostering adaptable learning environments that can accommodate individual differences in learning. UDL acknowledges that each learner has a unique learning style and emphasizes the importance of creating educational experiences that are accessible and effective for all, regardless of their abilities, backgrounds, or learning styles.

The Center for Applied Special Technology (CAST) developed one of the most prominent frameworks for UDL, aiming to assist educators in restructuring the education system while considering learners' variability [6]. The UDL framework consists of three essential components, outlined in Table 1: Representation ensures that all learners can access educational content through various presentation formats; Action & Expression provides learners with a variety of ways to demonstrate their understanding; and Engagement focuses on offering diverse and captivating methods to capture learners' interests and promote their persistence. These principles collaborate to establish an educational environment that is inclusive, adaptable, and effective for all learners.

The principles pertaining to UDL are known to play a crucial role in the realm of XR-based learning. XR technology provides novel and engaging methods to involve learners, and by integrating UDL into XR design, educators can present content in a variety of formats [22, 23]. This approach enables learners to demonstrate their understanding and interact with the material in diverse ways, which proves particularly advantageous in heterogeneous school environments where learners possess varying abilities and learning preferences. By integrating UDL principles into XR-based learning, educators can develop innovative and advanced experiences that cater to the needs of every learner, ensuring equitable access to these educational tools for all.

Table 1. Universal Design for Learning (UDL) framework [21].

Principle	UDL Guideline
Principle 1. Provide multiple means of Representation	1.1 Provide options for Perception 1.2 Provide options for Language & Symbols 1.3 Provide options for Comprehension
Principle 2. Provide multiple means of Action & Expression	2.1 Provide options for Physical Action 2.2 Provide options for Expression & Communication 2.3 Provide options for Executive Functions
Principle 3. Provide multiple means of Engagement	3.1 Provide options for Recruiting Interest 3.2 Provide options for Sustaining Effort & Persistence 3.3 Provide options for Self-Regulation

3 Method

This study aims to develop XR-based content that follows the UDL guidelines to promote an inclusive learning environment. To archive this, we utilized the Successive Approximation Model (SAM2), an iterative development model suggested by [24]. As a rapid prototyping approach, the SAM model can undergo constant improvements based on prompt feedback and adjustments, simplifying the development process and making it possible to implement more effective and timely enhancements [25].

The project began by identifying challenging CS concepts that often pose learning difficulties due to their abstract nature. The design focus of this study is on CS education, chosen due to its increasing importance and the diverse learning challenges it presents, including abstract concepts and varying learning needs. Initial design considerations were informed through consultations with CS educators and examining existing educational materials, ensuring the XR content aligned with real educational needs.

The application aims to offer an immersive and interactive environment to assist learners in understanding CS concepts. The XR-based application, a product of cutting-edge technology, was created using Microsoft's HoloLens 2 as the hardware platform and the Unity3D engine, complemented by Microsoft's Mixed Reality Toolkit (MRTK). The development process was iterative, focusing on the continuous refinement of the XR application. The first prototype focused on basic interactive representations of CS concepts, designed to test the feasibility of the XR environment and the integration of UDL principles. Subsequent iterations expanded the content complexity and interactivity based on theoretical feedback and design critiques from an instructional design team.

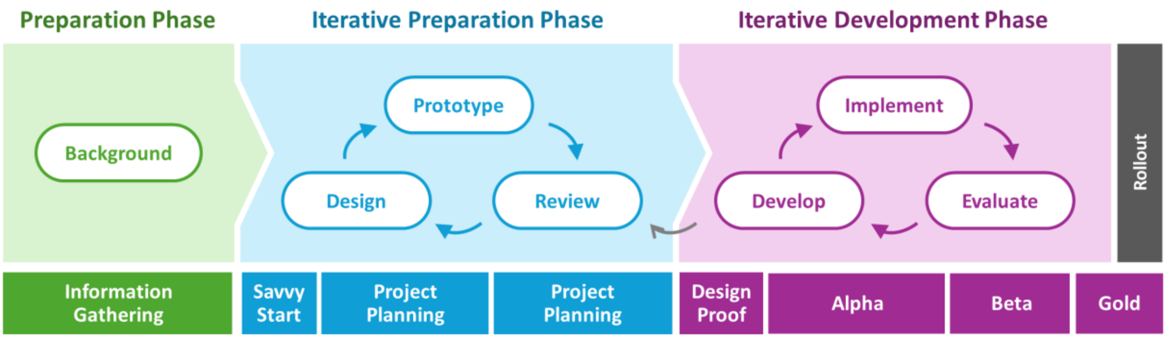

Fig. 2. Successive Approximation Model (SAM2) Process Diagram [24].

4 Universal XR Design

4.1 Overview of Computer Science (CS) Education

CS involves the exploration of computers and algorithmic processes, encompassing their principles, hardware and software designs, applications, and societal implications [26]. Key components of CS education include Computing Systems, Networks, and the Internet, Data and Analysis, Algorithms and Programming, and the Impacts of Computing [27]. Algorithms hold significant importance as they are designed for execution by both humans and computers. Initially, learners are introduced to age-appropriate real-world algorithms during their early grades. As they advance, they delve into the development, combination, and decomposition of algorithms, as well as the assessment of competing algorithms. The content aims to acquaint learners with engaging algorithms (see Table 2). Following Bloom's revised taxonomy, the learning content is structured from lower to higher levels in the cognitive process dimension.

4.2 Principle 1: Representation

Representation involves employing various presentation methods to accommodate diverse learning preferences and styles. To foster learner autonomy, individuals could select their preferred content from a menu and adjust subtitles and sounds based on their sensory preferences. Pictograms were complemented with text descriptions to ensure clarity, and the content was logically organized using menus. Clear explanations were provided for flowchart symbols and other notations to aid learners in understanding and applying concepts. The learning stages were structured to activate prior knowledge and emphasize cognitive processes to reinforce foundational learning. Additionally, visualization techniques were utilized to guide learners during instructional segments, facilitating effective information processing and retention. Figure 3 illustrates learners toggling captions and sound on/off via the hand menu, ensuring text accompanies pictograms, and organizing learning content through menus.

Table 2. Learning Procedure for 'An Introduction to Algorithms'

Step 1: Understanding Algorithm Concepts
- Identify and define the key components of an algorithm.
- Describe how algorithms are used in various real-world applications.
Step 2: Exploring Algorithm Representation Methods
- Compare and contrast different methods of algorithm representation.
- Analyze the various representation methods in specific contexts.
Step 3: Developing a Shortest Path Algorithm
- Design a shortest path algorithm for a given problem scenario.
- Test the algorithm with different inputs to ensure its correctness and efficiency.
Step 4: Reflecting on Learning Outcomes
- Reflect on the learning process and identify areas of strength and areas for improvement.
- Set goals for further development in the area of algorithms and problem-solving.

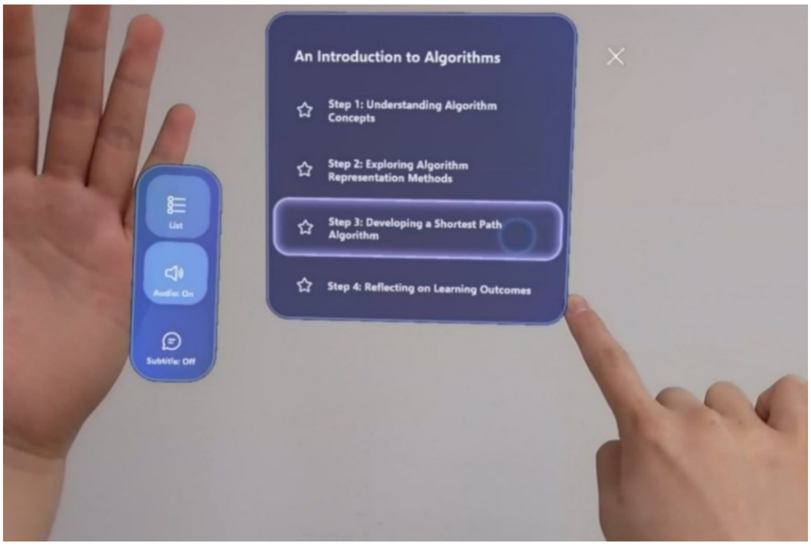

Fig. 3. Hand menu for 'An Introduction to Algorithms''.

4.3 Principle 2: Action and Expression

The principles of Action and Expression are vital for facilitating effective communication. To support this, the agent will pose questions that learners can answer through speech or typing. Figure 4 depicts the different response modes accessible to the learner. Clear learning objectives and processes are presented to guide appropriate goal setting. These objectives are structured to assist learners in setting goals and attaining success. Furthermore, the system offers feedback and guidance to aid learning. It is crucial to help learners comprehend their progress and pinpoint areas needing additional attention. Overall, the system is devised to encourage effective communication and facilitate meaningful learning experiences for the learner.

4.4 Principle 3: Engagement

Achieving effective learning necessitates robust engagement, gauging learners' immersion, enthusiasm, and drive throughout the educational journey. Leveraging hand-tracking technology, we enhanced motivation by empowering learners to gauge distances using their hands. Upon task completion, we offered affirmative feedback, igniting a sense of accomplishment akin to a bursting firecracker. Crucially, fostering personal coping mechanisms and strategies is imperative for promoting self-regulation. Consequently, we proposed a similar task to empower learners to autonomously undertake it, fostering their self-regulation skills. Moreover, the task is intentionally crafted to prompt learners to introspect and evaluate their performance post-activity.

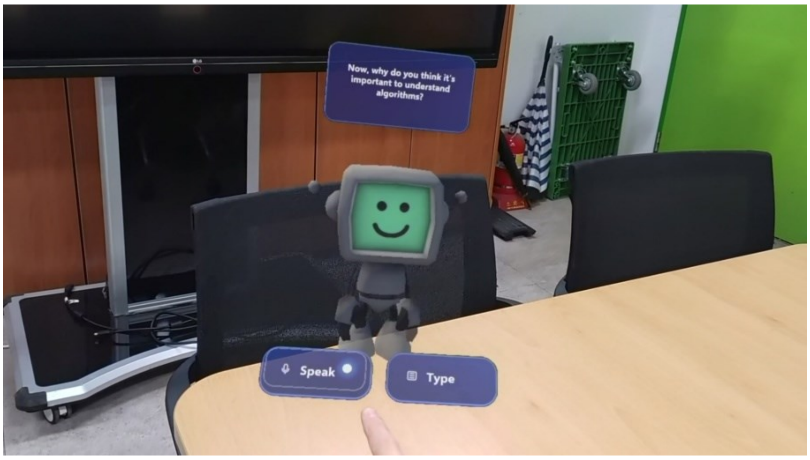

Fig. 4. Response Method Selection during Agent Interaction.

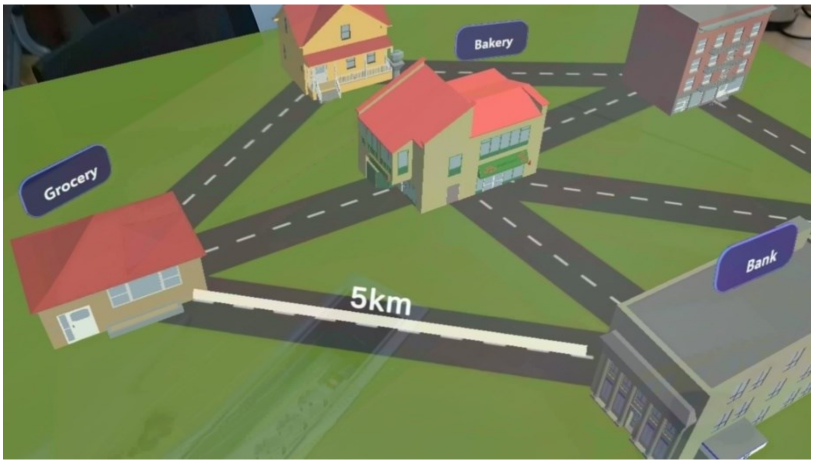

Fig. 5. Illustration of the Shortest Path Problem Activity.

5 Conclusion

This research explored implementing universal extended reality (XR) design principles focusing on algorithmic learning processes in CS education. The study observed that integrating diverse representation methods and interactive tools can improve learners' engagement and understanding. It is important to note that learners interact with algorithm concepts differently at various stages, and this study presents a framework for creating an inclusive learning experience using XR technology. The study recognizes the significance of inclusivity, diversity, and equity in educational design and introduces a design case based on Universal Design for Learning (UDL) principles.

However, the study faces several limitations, notably the high cost associated with XR devices such as the HoloLens 2. The expense presents challenges, including distribution issues akin to those encountered with Head-Mounted Display (HMD) based virtual reality systems in real-world educational settings [28]. Additionally, the personalized nature of HMD learning content restricts participation to learners wearing the headset, limiting inclusivity. To address these challenges, a proposed solution involves leveraging XR devices for learning while allowing peers to observe the process through monitors [29, 30]. This approach facilitates simultaneous participation and collaboration among multiple learners, overcoming the constraints of individual HMDs and fostering broader class engagement. Furthermore, this approach can mitigate economic barriers, expand educational opportunities, and ensure equitable access to XR learning for all learners.

The study underscores the significance of inclusive learning design and explores how technology can cultivate engaging and accessible learning environments for all learners. It provides a range of strategies to enhance inclusivity and accessibility in XR learning environments, advocating for the integration of technological advancements with principles of educational equity. Further research should focus on enhancing the affordability of extended reality technologies, improving accessibility in educational settings, and ensuring that diverse and inclusive learning experiences benefit all learners.

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