Is Immersive Virtual Reality in K-12 Education Ready for Primetime? Challenges, Possibilities, and Considerations

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ABSTRACT

As education enters a digitalized era, educators are embracing new tools such as immersive virtual reality (IVR) for K–12 teaching. Here, we examine the benefits of using IVR in K-12 education and highlight interesting existing use cases. Then, we acknowledge the lack of a framework for IVR use with children and propose key components that should be incorporated into such a framework. Additionally, we outline pressing topics and research questions that are essential to advance the field. We conclude that, although IVR holds great promises for shaping the digital future of education, there are still several challenges to consider.

Index Terms: Human-centered computing [Human computer interaction(HCI)]: Interaction Paradigms—Virtual Reality

1 INTRODUCTION

The current student population, comprising mainly of Generation Z (individuals born between 1997 and 2012) and Generation Alpha (individuals born after 2012), has grown up with or is growing up with technology as an integral part of their everyday lives. They have the technical competency to effectively use digital technologies but are unable to imagine a life without them [15]. Therefore, to engage and attract these generations, the integration of digital technologies into the learning process in educational settings is crucial. Here, we focus on one of these technologies, i.e., Immersive Virtual Reality (IVR), whose unique characteristics hold great potential for bringing K-12 education to the digital era [4, 35, 37] and shaping the future of education and training.

The use of IVR technology has seen a tremendous increase over the past decades in various industries, with education being no exception. Although it follows a trend [19, 29], IVR is considered a valuable tool that transforms the learning experience in unprecedented ways. In our view, the application of IVR in education, as well as in other sectors, is ideal when the traditional method :

- is too expensive (*cost*),
- is dangerous and thus unfeasible in an educational setting (*risk*),
- falls short both in terms of the user experience and the learning outcomes (*effectiveness*) [13].

Consider the example of teaching anatomy using IVR. Students can interact with three-dimensional (3D) models of the human body, allowing them to freely explore each organ and its specific function (e.g. through pop-up windows) as well as how the different organs are interconnected, at their own pace. In this scenario, the use of IVR results in reduced costs associated with the need for physical models of the human body or cadavers (cost factor), reduced health-related risks associated with the use of cadavers (risk factor), and increased levels of interactivity and engagement that are associated with improved learning outcomes over conventional methods (effectiveness factor) [47].

Following its profound competitive advantages when applied judiciously, the use of IVR technology in educational contexts is further supported by several theories (for a comprehensive list, see [4, 19]). One of these is the embodied learning theory [24]. This theory suggests that effective learning requires not only the mind (i.e., cognitive processes) but also the interaction between the body and the external environment. Through direct experiences with the outer world, like movements, gestures, object manipulations as well as haptic interactions [8], learners are physically engaged in the learning process. This hands-on, experiential learning provides a more holistic way of actively acquiring information through complex mind-body-environment interactions and forms the basis for reaching desirable learning goals. IVR is a medium that fosters this experiential, embodied learning, with a recent systematic review highlighting this as the main advantage of this technology [10]. Unlike other digital mediums popular among students, such as tablets or laptops, IVR immerses students in 3D digital environments and allows them to have first-person experiences, interact with, and manipulate the learning content using hand controllers [4, 5].

In sum, IVR possesses the necessary qualities to act as a platform that:

- represents a means of technology that is essential for reaching and attracting current and future generations of students,
- provides a reliable alternative in cases where traditional methods are costly, dangerous, and/or insufficient, and
- is validated by various learning theories as a means of providing a holistic way of learning.

2 BENEFITS OF IMMERSIVE VIRTUAL REALITY IN K-12 EDUCATION

Education, learning, and knowledge transfer are at the core of a prosperous society and are becoming increasingly important [21, 41]. IVR is revolutionizing education and learning, broadly construed, by providing more immersive and interactive experiences for users, both emotionally and physically. IVR is being used successfully for training and education in various populations due to its efficacy, including immediate and long-term knowledge retention [27], as well as the ability to transfer skills learned in IVR to real-world situations [38]. For these reasons, organizations in the medical, driving, and firefighting industries are using IVR to enhance the performance of their employees in training scenarios like surgical rooms [14], virtual driving simulations [6], and fire training simulations [7] respectively.

In a similar way, the application of IVR in K-12 or higher education settings has been shown to have overall positive effects on learning performance, spatial knowledge representation, experiential learning, motivation, and engagement [2, 9, 10, 16, 20, 28, 32]. IVR can enhance classroom experiences by providing interactive and engaging tools for classroom communication, collaboration, and

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critical thinking [10]. By using IVR, students become active participants in the lesson, fostering a sense of agency. This approach transforms the student from being a passive consumer of information to an active explorer and discoverer of information within a digital environment with unique capabilities [23].

The flexibility of IVR allows for the representation of the natural complexity of the world and enables the emergence of different types of interaction, such as social, emotional, and physical. For example, in social IVR experiences, students can collaborate and socially negotiate with other participants and avatars [1]. This offers a new dimension to computer-assisted learning that can lead to the development of less racial bias, improved social skills, and better interpersonal skills after exposure to social situations [26, 34]. Therefore, incorporating IVR in both formal and non-formal education provides educators with new tools to enhance learning and engagement, increase knowledge retention and transfer, and develop students' social skills both within and outside of the educational setting.

2.1 Existing Use Cases of Immersive Virtual Reality in K-12 Education

IVR is an innovative learning tool that enables students to gain a fresh perspective and real-life experience of the phenomena they are studying, which can be hardly experienced using conventional teaching methods. It is delivered by educators (e.g., parents, teachers, school nurses) at home or in the classroom and usually needs minimum space and equipment. A widely used example of the application of IVR in education is the distribution of ClassVR's virtual classrooms [22]. This platform provides educators with fully integrated, classroom-ready VR headsets, headset management, secure storage and charging solutions, and, most importantly, curriculum-aligned content. It offers a variety of virtual and augmented reality educational content that is age-appropriate, inclusive and covers a range of subjects in most curricula. This is a prime example of how IVR can be applied to various applications and subjects, resulting in a diversified educational impact. But the successful implementation of IVR in K-12 programs does not stop here. For instance, IVR can help students reach new places that are otherwise unreachable through virtual field trips in the context of an earth science school course [17]. They can explore in first-person and interact with new places like the Roman Augusta Emerita's archaeological site [44], or the solar system [16]. Furthermore, IVR can help in developing problem-solving skills [3], understanding complex physics concepts [12], teaching science lessons [20], and even learning a foreign language [36]. Ultimately, the increasing availability of new technologies and the development of immersive, interactive educational content that expands the realm of what is possible are driving the rapid growth of using IVR in K-12 and higher education contexts.

3 Child-Computer Interaction: Towards an Integrative Framework for Immersive Virtual Reality Use

Despite the many existing use cases, IVR provides new ways of learning and interacting with educational content in digital environments and as such provides a relatively new type of child-computer interaction (CCI). Currently, an integrative framework for the use of IVR for children is lacking. To some extent, this can be attributed to the fact that IVR headsets were not intended for use by children under the age of 13, according to the regulations of certain VR manufacturers [4, 40]. However, we can not overlook that children are frequent IVR users for educational purposes [25], which calls for an integrative framework that, among else, takes into account the cognitive, affective, and developmental stages of children [11]. Although numerous issues related to CCI in the context of IVR use could be included in this framework, here we focus on four of them that, in our view, are of greater interest: user experience (UX), accessibility-inclusivity, child-centered content development, and ethics/data privacy. We briefly explore each of them in turn.

1. *User Experience (UX)*: Developing usable, flexible, and effective experiences and interactions for children in IVR is a critical part of the medium's adoption. Currently, there is a gap in our understanding of the UX of children in IVR. The headsets were not designed for use by children and have, therefore, not been thoroughly tested and optimized for this specific group of users. Understanding the ways children interact and engage with IVR content is also important. Key themes in this issue revolve around the usability evaluation and the ergonomics of IVR devices for use by children, the side effects of long-term use, as well as general health and safety measures for IVR use. Recent studies on the presence of adverse symptomatology from IVR use in children have produced mixed results [42, 46], therefore more research is needed to understand the effects of IVR on children.

2. *Accessibility-Inclusivity*: Recently, the Committee on the Rights of the Child of the United Nations (UN) published a report on children's rights in digital environments [33]. Among else, the Committee suggested that all children should be given equal access to digital technologies regardless of age, sex, disability, socioeconomic or political status. Given that classrooms and educational settings host children from diverse cultural and socioeconomic backgrounds, as well as different types of neurodiversity and sexual orientation, this is an important issue to address. To ensure the effective implementation of IVR in educational settings, adopting a "disadvantage minimization" approach is necessary. After all, the use of technology in general, and IVR in particular, should strive to temper biases and not create new ones. Key themes in this issue include designing more accessible hardware, new methodologies for evaluating accessibility in the classroom, and developing inclusive and accessible interactions for IVR by taking into account the human factor.

3. *Child-centered content development*: IVR educational content development is not just a digitalization of traditional curricula. It's about creating transformative ways of interacting and engaging with the learning experience. To achieve this, professionals who develop IVR educational content should take into account the various theories that validate the use of IVR (e.g., embodied [24] or multimedia [30] learning) as well as the specific psychological, emotional and developmental aspects of the target users (e.g., school-aged children). For example, it's been suggested that children may find it difficult to dissociate between what's real and what's virtual due to certain characteristics of the IVR experience (e.g., increased sense of presence) and the developmental immaturity of certain brain areas [5]. Acting in an IVR environment as if it was real, though, poses significant risks under certain situations. One way to mitigate such risks would be to involve children throughout the process of content development from inspiration to ideation and implementation. This participatory or co-design approach [18] will ensure, to some extent, that the content is cognitively, socially, emotionally, and age-appropriate.

4. *Ethical issues/ Data privacy*: The use of IVR with children in but also outside educational contexts raises ethical and data privacy concerns. The UN Committee's report on children's rights presented earlier, mentions the word "privacy" in several instances. Currently, there is no transparency regarding the collection, type (e.g., usage), and treatment of data from IVR devices. The integration of multimodal (e.g, vision, audition, touch) sensors in new IVR headsets will likely result in VR companies having access to even more data. This issue requires higher-order legislation or policies, which typically take time to be decided and implemented. However, it is essential for families and teachers to be aware of how their children's/students' data are being used and for researchers to inform them about data treatment by both themselves and VR companies. The issue is pressing and for the time being good reference points for the ethical use

of IVR can be found in [40] and [39].

4 Application of Immersive Virtual Reality in K-12 Education: Forward-Looking Topics

In addition to the issues discussed in previous sections, this section presents topics in the form of, where applicable, thought-provoking research questions that hold great potential for driving the field forward (Forward-looking topics, FLTs). The list of FLTs is not exhaustive and should be considered as a starting point for future investigations.

4.1 FLT-1: Interdisciplinary communication and collaboration

To foster innovation in the field, it is essential for the different low-level stakeholders (i.e., families, schools/teachers, researchers, and developers) to talk to each other. However, these stakeholders often have disparate communication channels and do not always speak the same "language", as they approach things from different perspectives. *Therefore, what would be the best platform to build/disseminate knowledge as well as share resources about the use of IVR in K-12 education in a way that promotes interdisciplinary communication for the advantage of all the parties involved?*

4.2 FLT-2: Educate the educators

The successful implementation of IVR in educational settings largely depends on the attitudes and skills of educators, specifically teachers [43]. However, many teachers already have busy schedules and lack technical proficiency, which, in turn, impedes their ability to effectively use IVR technology in their daily practice. The field will only progress when teachers understand the added value (and the side effects) of this technology and how to implement it effectively. In addition, the transition from traditional teaching practices to digital ones is likely to change the nature of teaching. The role of the teacher will evolve from content delivery to content facilitator. Consequently, teachers will focus more on creating opportunities for exploration and discovery, rather than solely providing information and assessing retention. Therefore, it is vital to better understand teachers' perspectives on the use of IVR in their classrooms as well as to provide them with the necessary training to adapt to their evolving roles in the digital age. *What are their main concerns as education becomes more digitalized? How and in what ways can we support them to understand and then introduce the use of IVR in their teaching? What incentives could be provided? What kind of resources can we provide to make this integration easier?*

4.3 FLT-3: Focus on (added) value, the best is yet to come

The cost of IVR technology has been considered a barrier to adoption [4] and continues to be prohibitive and unscalable for many educational systems. Although the cost has decreased since the early days of IVR and is expected to decrease in the coming years, it is not the only factor that hampers the adoption at scale. To our view, equally important is the value IVR brings as an innovative learning tool to those who use it, particularly students. Demonstrating a clear, evidence-based case for the value that IVR brings to education is likely to outweigh any concerns related to cost in the long run. A good starting point for this would be questions such as: *Which school subjects (e.g., chemistry or biology) are most likely to benefit from the use of IVR based on the cost-risk-effectiveness formula presented at the beginning? What are the characteristics of those subjects that make IVR more effective? Are there situations where the use of other technologies, such as Augmented or Mixed Reality (AR/MR), may be more appropriate than IVR? Which types of students are more likely to benefit from the use of IVR (e.g., those who learn by doing)? Are there gender or other biases in the use and/or effectiveness of IVR in the classroom? What are the possibilities of blended learning, i.e., using IVR in certain areas while following the traditional teaching methods in others?*. Although progress has been made in this direction, further research is definitely needed.

4.4 FLT-4: Adaptive/Personalized learning

As the next generation of spatial computing platforms (IVR, AR, MR) continues to advance, along with the rise of Artificial Intelligence (AI), new opportunities for education are likely to emerge. One such opportunity relates to the concept of adaptive/personalized learning [45]. Specifically, the educational content within IVR can be personalized to the student's learning needs and abilities, by adjusting factors such as the level of difficulty, the pace of delivery, the number of repetitions, and the type of interaction in the learning experience. This way, the to-be-learned information is adapted to the individual characteristics of the student, and not the other way around, which can increase engagement and maximize learning outcomes. With the incorporation of various biosensors, such as eye-tracking, into new IVR headsets, personalization can become even more effective. For example, variables (e.g., pupil dilation) from these biosensors can be used to infer cognitive load, an important feature to measure for multimedia learning [30, 31]. Before the realization of personalized learning in IVR, though, an open dialogue should be initiated, as previously discussed, to ensure the ethical and respectful use of data and data privacy [40].

5 Conclusion

In the coming years, the decreasing cost of IVR headsets and the development of new educational applications are likely to increase the adoption of this technology in education and learning settings for a variety of use cases. Although preliminary work already exists in this space (e.g., [4,10,33,39,40,42]) important ethical, technological, and psychological challenges stemming from this adoption need to be closely examined. To achieve this, more concerted efforts from and synergies between the different parties involved (i.e., families, teachers, schools, governments, regulatory bodies, researchers, developers, and VR vendors) will be necessary. Further research and new policies and procedures are essential to ensure a safe, ethical, respectful, and child-centered implementation of the technology both in formal and non-formal educational settings. We hope that the challenges and possibilities discussed in this paper, as well as those that will be addressed during the workshop, will spark new interest in investigating the use of IVR in K-12 education.

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