

Immersive Virtual Reality Serious Game Studies in Education: A Brief Review

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ABSTRACT

Currently, immersive virtual reality environments (IVR) are providing interactive learning experiences in various fields including “education”. Especially after covid-19 pandemic, the popularity of the online learning environment has increased, and the IVR would be a possible alternative to other mediums in online learning. The previous reviews usually contain related literature before the pandemic. There is a need to better understand the current body of knowledge on IVR. The specific application contexts, research designs, and possible results of the current works needed to be clarified. To answer this question a literature review was conducted between 2013-2023 years on the “Web of Science” database for “IVR” and “serious games” keywords in the field of “education”. Then, 18 articles are reviewed and the main themes are provided. As a result, the majority of the articles were found as “applied studies” and the main research intent was to determine “cognitive effects” including knowledge improvement. Depending on literature analyses qualitative and quantitative study results can be listed as; “IVR in the form of serious game” in general was found and perceived as an effective medium for learning in various fields of education. In addition, some study results about instructional design decisions of IVR applications and the effectiveness of IVR comparing other types of mediums are provided. The study recommends taking into account educational theories behind the design of IVR and related multimedia design principles.

Keywords: game effectiveness, game-based learning, immersive virtual reality, literature review, serious games

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1. Introduction

In recent years, with the development of technology, there has been a growing interest in immersive virtual reality (IVR) applications. IVR consists of “immersive” and “virtual reality” terms. “Virtual Reality” is defined by the Oxford online library as “a computer-generated simulation of a lifelike environment that can be interacted with in a seemingly real or physical way by a person...”. When the “immersive” keyword is added, it somehow deeper the level of perception of VR.

The idea of providing 3D virtual worlds is not new, previous forms of 3D game-like environments provided some sense of virtual reality. However, the amount of “immersiveness” increased over time, with the addition of devices such as head-mounted displays. These devices invoke more senses and that results in more virtual reality perception with respect to traditional 3D game-like applications -that is called desktop virtual reality (DVR)-, the new form of reality is called IVR that possibly result in a feeling of “being there”. The interactive and immersive nature of DVR and IVR applications have some potential in various fields including education.

In the related literature, there are review studies (Freina & Ott, 2015; Pellas et al., 2021; Radianti et al., 2020) about educational IVR applications. These studies focus on applications in K12 and higher education. Especially in the last few years after the covid 19 “IVR” gained importance and new studies have been conducted. The current study differs from the previous ones by including a broader category of “education” studies and including additional studies after the pandemic. Currently, there is a need for a better understanding of educational IVR studies including possible application areas, specific research designs, and main findings.

An IVR application could be designed according to various learning theories such as behaviorism, cognitivism, constructivism, connectivism, or social cognitivism. Whatever the approach is, the IVR applications will add the value of “interaction” and “concrete representations” to a learning process which is the advantage of “multimedia presentations”. Mayer (2005) described advantageous and design principles of multimedia usage in the cognitive theory of multimedia learning. Then, Makransky (2021) added the “immersion principle” to the theory, according to that, immersive virtual worlds would be beneficial if they are designed according to multimedia design principles. In addition, IVR would provide a feeling of “being there” and that motivates learners. Therefore, the “safe”, “interactive” and “motivating” nature of the IVR could make them popular in the future of learning. In this regard, it is important to find out the best practices in the design of IVR for learning.

The nature of IVR applications does not have to be in the form of games. There would be various usage intends. Regarding education, the interactive and motivating nature of “games” would be beneficial. The games that are designed to teach something are called “serious games”. Wouters et al. (2013) define the “serious game” (SG) as an interactive, feedback-driven experience that is shaped by learning objectives and creates an intention to overcome obstacles within a limited and rule-based environment. Therefore, compared to previous studies this study intended to find out the effectiveness of IVR applications in the form of serious games. The findings of this “IVR serious game applications in the field of education” review would give an idea when developing and deciding to apply them in educational settings.

2. Materials and Methods

As a systematic literature review, “immersive virtual reality” and “serious games” keywords are searched in the “Web of Science” database. In the last 10 years (between 2013-2023) 97 journal articles were found but only 66 of them have full text online. The articles are listed in different discipline areas; there were 27 engineering, 20 computer science, 19 medicine, and 18 education articles. Number of articles in the other fields was 7 or less. Some of the articles are categorized into 2 or more categories. Among the discipline areas, “education” is selected because the primary intent of this study is to learn the current findings of IVR serious games in the education field. As a result, 18 education articles were reviewed. Although one of the potential areas of IVR seems to be education, the number of medicine, computer science, and engineering studies is higher. The education comes forth, only 27% of the articles related to education. Table 1 summarizes the literature review criteria.

Table 1.

Literature review criteria

Search Words	Included Library	Restrictions	Results
(immersive virtual reality) and (serious games)	Web of Science	Content Type: Journal article Year: 2013-2023 Field: Education Reach type: Full text online	18 articles

The found articles are reviewed and results are reported in the following section.

3. Results and Discussion

In the study, the founded 18 educational IVR serious game researches are analyzed. Specifically, research types, application domains, methodology, and main findings of the research are analyzed and some main themes are created. Table 2 summarizes the general paper types, area/field of study, research intent, and main findings.

Firstly, as research types, it is identified that most studies are applied studies with experimental design (13 studies). There are literature reviews (4 studies) and one theoretical study. Moreover, many of the studies are determined in the domain of avoiding dangerous situations (6 studies) like disaster preparation, and diminishing danger in different fields. In addition, some studies search for instructional design methods (4 studies), and type of medium comparisons (2 studies) and one study aims to create a development framework. Finally, although almost all of the studies somehow search for the learning gains or academic performance of participants, 5 studies specifically look for knowledge improvement or similar variables. Therefore, it seems that the majority of the applications are “applied” and somehow related to “knowledge acquisition” and “avoiding dangerous situations”.

When the application designs and domains are reviewed it is understood that many authors are trying to find the effectiveness of IVR with experimentations. The IVR applications are usually done in “avoiding danger” situations, it would be because giving this kind of games in real life usually dangerous or not easy to conduct. For example, Boel et al. (2023) tried an IVR application for vocational students because some of their education occurs in dangerous situations.

Moreover, research has a diversity of research questions and findings related to different aspects of IVRs. Table 2 summarizes the specified details of the studies.

Table 2.

Type, area, research intent, and main findings of the reviewed articles

Reference	Paper Type	Area/field	Research intent	Main findings
Alrehaili & Al Osman (2019)	Applied	Effectiveness of different mediums on learning of honeybees	Do participants learn better on IVR or DVR than traditional learners in an immersive role-playing game(RPG) in which they play a honeybee role?	All groups improved learning gains compared to the pretest. Immersion levels for both tested VR-PRGs did not have a significant effect on learning. DVR-RPG game result in significantly higher knowledge retention than the conventional group. Both IVR and DVR groups have significantly higher motivation than conventional groups.
Boel et al. (2023)	Applied	Vocational school dangerous situations	Would vocational high school students find an IVR valuable and are the design elements of it appropriate?	Students and teachers found the game valuable in terms of spatial presence, involvement, design, interest/enjoyment, and value/usefulness.
Cavalcanti et al. (2021)	Applied	User experience in risky virtual environments ?	How do users behave in risk situations on IVR? What type of warning is more suitable?	Participants tend to test the consequences of their actions instead of maintaining safety. On stress factor time they are not accessed textual signals.
Chittaro & Buttussi (2015)	Applied	Aircraft emergency	Does an immersive serious game teach better than a safety	After an immediate knowledge test, and retention test the study showed that immersive serious game was superior to the safety card.

Reference	Paper Type	Area/field	Research intent	Main findings
			card on an aircraft emergency?	According to subjective analysis, immersive serious games are perceived as more engaging and fear-arousing than safety cards, that factor would improve retention.
Dong et al. (2023)	Applied	Cognitive ability improvement in cognitively impaired students	Do serious games improve the cognitive skills of cognitively impaired students?	Game completion time over continuing trials is decreased. After 15 days of repeated VR game applications, impaired students benefited from gamified cognitive training. Children's cognitive function and motor ability are increased.
Feng et al. (2018)	Literature review/ Framework	IVR development framework	Depending on the literature what would be an IVR SG design framework in the context of building evacuation training and research?	Depending on 15 articles in the literature they developed a framework for developing and implementing IVR SGs for evacuation research. This framework consisted of before development(understanding pedagogical and behavioral impact), IVR equipment selection(head mounted vs projection-based display), gaming environment development, and implementation stages.
Feng et al. (2020)	Applied	Instructional mechanisms	Which instructional method(pre-game assessment, post-game assesment or immediate feedback) is better on IVR?	Post-game assesment found most beneficial instructional mechanism with greater knowledge acquisition and self-efficacy improvement.
Ferguson et al. (2020)	Applied	Interaction mode and study structure effect	Does interaction mode (interacting with the environment or passive play) and study structure (giving explicit or implicit objectives) effect knowledge, presence, cognitive interest, and engagement in VR games?	Players who navigate freely (active group) have more positive cognitive interest and a feeling of presence. Providing game story/structure implicitly increased recall of spatial information.
Gasteiger et al. (2022)	Literature review/ Paper analysis	Effectiveness of VR and AR studies for health workers	Do VR and AR studies show that they are valuable for health workers?	It is found that high-fidelity simulations result in a higher perception of realism, easier visualization of patient anatomy, and interactive experience which then result in higher satisfaction and more effective learning. Immersive VR and AR provide immersion and this improves learning and skill performance.

Reference	Paper Type	Area/field	Research intent	Main findings
				For novices VR and AR practices would result in technical proficiency, skill acquisition and better performance.
Hainey et al., (2016)	Literature review	Game-based effectiveness in primary education	Does game-based application valuable in primary education?	The study reveals that in order to make a correct understanding in GBL on primary education randomized controlled trial studies and longitudinal studies should be made. They founded 29 articles look for knowledge acquisition and content understanding, 6 affective and motivational categories, 6 perceptual and cognitive categories and 4 behavioral change.
Hara et al. (2021)	Applied	Nursery education	Design and heuristics evaluation in IVR for the development of communication competence skills.	Because all of the heuristics are validated, the participants indicated that the developed game is suitable for nursery education. The study concluded that the appearance and usefulness of the game is validated by the nursery students, it provides a safe and pleasant environment for communication competency.
Jagger et al. (2015)	Applied	Business Ethics	Does a serious IVR game improve business ethics?	Students found the game beneficial for learning ethics by developing skills and improving knowledge that could be transferred to the real world.
Lamb et al. (2018)	Applied	The effects of different mediums on DNA education	Do learning gains differ in video presentation, serious games, VR games, and hands-on activities in DNA education?	VR condition provides better outcomes in learning tests than the other 3 conditions. According to HSD results, VR has a greater hemodynamic response than video lectures but is not different from the serious education group. Serious game-based education and VR groups increased the outcomes compared to the video-based group but did not differ from the hands-on activity group.
Liu et al. (2023)	Applied	Video training in emergency behavior	Whether giving video instruction before an emergency (fire and shooter) situation is effecting the participants' behaviour on a VR game?	Participants who took the video-based training more often followed the instructions in the VR game instead of following others. Video based training improved their self-efficacy, shooter simulation had a higher level of self-efficacy than the fire emergency.

Reference	Paper Type	Area/field	Research intent	Main findings
				The study completed that video-based training is an effective way of improving participants' emergency preparedness and changing their behaviour patterns. Also, training effectiveness would change according to emergency types.
Lorenzo-Alvarez et al. (2019)	Applied	Medical education	Does a serious IVR game useful in medical education?	Participants of the Second Life VR game rated the various parts of the game experience as 8.1 or higher over 10. Participants in the game get significantly higher scores than non-participants. From that result, they concluded that SecondLife is an effective and well-accepted tool for radiological anatomy and radiological content.
Skulmowski & Xu (2021)	Theoretical	Cognitive load	Factors that would impact cognitive load in the field of digital and online learning.	There are various challenges in digital applications that needs to be taken into account when dealing with cognitive load theories. The major challenges are interactive learning media, immersion, disfluency, realism and redundant elements.
Williams-Bell et al. (2014)	Literature review	Serious games and VR in Fire Service	Do the literature studies show that a successful serious VR game is possible for fire service worker education?	Currently gaming technology is capable of many needs in fire service but still has difficulties in providing a real-world scenario. The future simulation games should take into account the physical requirements that fire workers encounter in an emergency.
Xu & Dai (2022)	Applied	Collaboration in VR / disaster education	Is collaborative learning and IVR more effective in disaster education?	Participants feel more engaged in the cooperative virtual training game and have higher learning gains.

When the research intentions are reviewed, it becomes apparent that many researchers are investigating the appropriateness or effectiveness of IVR in various fields. This effectiveness is mainly researched by applications by comparison with control groups. In these studies, they look for knowledge gains or some other indicators like perceptions of students. Moreover, to test the appropriateness of IVR in specific fields some studies created literature reviews. The main outcome of these studies is that “IVR serious games look appropriate for various fields and they would result in usually meaningful learning gains and positive perceptions” (Alrehaili & Al Osman, 2019; Boel et al., 2023; Chittaro & Buttussi, 2015; Dong et al., 2023; Hara et al., 2021; Jagger et al., 2015; Lamb et al., 2018; Xu & Dai, 2022). For example, it is reported that IVR has a potential in fire service education (Williams-Bell et al. 2014), medical education (Lorenzo-Alvarez et al. ,2019), emergency situation education (Liu et al., 2023), nursery education (Hara et al., 2021), aircraft emergency education (Chittaro & Buttussi, 2015) and business ethics education (Jagger et al., 2015). Many studies in this review reported a potential benefit of IVR for learning, that finding is aligned with previous studies (e.g. Makransky, 2021; Radianti et al., 2020).

Some of the studies search for different types of instructional designs or mediums on different dependent variables like knowledge gain or perceptions. In one study, Feng et al. (2018) found that post-game assessment is more beneficial than pre-assessment and instant feedback. Actually, this conclusion would change according to theoretical approach in the application, but in this case students benefit more if they made some conclusion after they studied the IVR. Dong et al. (2023) showed that IVR would improve the cognitive skills of students with cognitive deficiencies. This finding is important because it could be a sign of the fact that; the “motivating” and “interactive” nature of the IVR serious games would help the learners that have various difficulties in a regular learning process. In addition, Ferguson et al. (2020) indicated that interaction with the environment and providing implicit direction is better for an IVR. Again, this result should be regarded according to the learning theory behind the IVR application, but it could be inferred that “interaction” and type of “descriptions” should be designed carefully like personalization or other multimedia design principles of Mayer (2005). Moreover, it seems serious games in desktop or immersive VR form have similar or better opportunities than other methods like video lectures or traditional learning forms (Alrehaili & Al Osman, 2019; Lamb et al., 2018). Actually effect of different types of digital media on knowledge gain is a continuing debate. It is better to think the specific design of the medium and it's align with the specific learning objective. On the other hand, in many cases “concrete experience”, “immersion” and “interaction” would be helpful because they motivate the students (Makransky, 2021).

Skulmowski & Xu (2021) discussed the cognitive load in digital learning and argued that the current digital learning tools have new challenges for the cognitive load. The cognitive load is normally at the center of the multimedia design principles (Mayer, 2005). Some bad designs would result in extensive extraneous cognitive load and that make learning more difficult. Similarly, Makransky (2021) pointed out the potential risk of extraneous cognitive load in IVR applications. IVR should be carefully design by taking into account multimedia design principles. Finally, Feng et al. (2018) provided an IVR development framework depending on the literature. They provide a list of steps for developing an effective IVR, especially for evacuation studies. This framework would help in the production of more beneficial and successful IVR applications.

4. Conclusion

In this research studies about immersive virtual reality serious games are reviewed and main themes are described. Depending on the review of 18 articles of the IVR serious game studies; usually applied and review studies are found and they are in general accepted as “appropriate” in various fields of education. This finding was aligned with some previous research (e.g. Makransky, 2021; Radianti et al., 2020). In general, they improved learning gains and they were perceived as valuable learning tools. In addition, some studies advised better methods in the design and application of IVR serious games. It is advised that these methods should be considered according to specific learning theories in the design of IVR, but findings regarding the multimedia design theory, the recommendations need to be taken into account in many cases.

This research is valuable in terms of showing a summary of the current IVR serious game studies that are published in the Web of Science database. The unique value of the study concerning the previous review research is taking into account “serious games” and having related literature after the COVID-19 pandemic. These findings would help practitioners in IVR application development or IVR implementation in educational settings in many ways. Specifically, in many fields -especially the cases that include difficulties with applications-

IVR has learning potential. Practitioners should be aware that different theoretical approaches within the IVR design would result in different levels of learning gains or skill development. They especially should take into account the risk of higher extraneous cognitive load. They should take into account related multimedia design principles and IVR development frameworks.

The current research has some limitations as well. The scope of the review is limited to one database that is “web of science” and one field that is “education”. The field of education is selected because the specific intend of the review is about education. As a database “web of science” is selected because it is one of the important databases. It would be considered that the current database would present a valid representation of the current IVR literature. The other databases were not included but the inclusion of other databases in the future studies is recommended. Similarly, including other fields in addition to “education” would give additional lenses about the IVR applications. Moreover, the future studies would concentrate into effectiveness of IVR in a domain of a specific learning theory or effect of specific multimedia principles in their designs.

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