



Exploitation of virtual reality in education

University of Oulu
Information Processing Science
Bachelor Thesis
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2024

Abstract

Virtual reality technology has seen rapid development and decrease in cost in recent years. Use of virtual reality in educational contexts has seen substantial interest from academics, and thus studies about the effectiveness of virtual reality as a learning environment have emerged. This literature review aims to identify general trends found in studies using virtual reality in educational environments, more precisely using head-mounted displays to immerse learners into a virtual world, and what gaps in research need to be filled in future studies about incorporating virtual reality into education. Studies from the last ten years were search and selected from three different scientific databases. It was found that research about the topic mostly consisted of exploratory work, with issues such as lack of implementation of learning theories into the designs of the learning environments, and emphasis on determining the usability of the technology. Critical components of learning using virtual reality, such as presence, the sense of belonging to a virtual world as if it were reality, are still poorly understood. Distinct differences between head-mounted displays exist, possibly contributing to the difficulty of accurately determining general guidelines for creating efficacious virtual reality learning environments.

Keywords

education, virtual reality, virtual learning environment

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Foreword

The advancement of technologies in general seems to only be accelerating as time passes, and virtual reality hasn't been an exception in this matter. A young me looking at the Kickstarter page of the Oculus Rift couldn't even begin to imagine the things modern virtual reality systems are capable of now. Today, I can slide on a virtual reality headset and fly in a fighter jet, unable to perceive even the smallest imperfections of the image created by the screens mere centimeters from my eyes. Technology has brought us a world where we can experience things which we simply couldn't before.

While virtual reality is certainly interesting from a perspective looking for entertainment, it shouldn't be brushed off as being just for that. By giving us the ability to essentially manufacture experiences, virtual reality allows us to train and teach people in ways that are either inconvenient or outright impossible without it. For instance, it's possible to practice how to act in otherwise life-threatening situations without any presence of danger at all, granting the ability to train as much as one needs before actually confronting said situation, significantly reducing the risk of injury or death. With these things in mind, virtual reality very quickly becomes a potentially valuable asset when integrated into the process of education.

As an example, the aviation industry has used completely immersive and unfathomably complex simulators to train pilots for the real thing, and the transfer of skills learned from these simulations into the real world is undeniable. However, these simulators are extremely expensive to make and to maintain and requires well trained (and paid) operators. Today, consumer grade virtual reality systems are affordable and offer a high-quality experience. Although certainly not comparable to the quality one might expect from an industry grade flight simulator, we are still at a point where those unfamiliar with virtual reality can become completely immersed in a virtual environment using only a head-mounted display and a pair of handheld controllers. This paves the way for many interesting and important questions, such as: how can we apply this technology to educate and train people better? What training tasks are suitable for a virtual reality environment? What effect does using virtual reality have on learning outcomes?

The aim of this literature review is to examine how virtual reality technology has been used in education over the last decade, how effective it is as a tool for educators and students and how the users feel about the experience. Further details about the technical aspects of virtual reality systems, the limitations that come with them, the literature concerning virtual reality in educational contexts and the future of research of this topic. Since virtual reality is still a somewhat novel technology, its introduction to everyday life remains yet to be seen. The research that has been done on the topic has so far been exploratory in nature, with limited integration of established educational theories into the design of the studies and a lack of standardized, empirical methods that could be used to measure the outcomes of the experiments.

03.10.2024

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Abbreviations

AR	Augmented Reality
CAVE	Cave Automatic Virtual Environment
CLT	Cognitive Load Theory
HMD	Head-Mounted Display
VE	Virtual Environment
VR	Virtual Reality
VRLE	Virtual Reality Learning Environment

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1. Introduction

Educational institutions have always been interested in the adaptation and utilization of information technology to augment the teaching process, and to improve workflow and organization. Information technology has evolved rapidly, which has created a plethora of new opportunities for educators to incorporate useful technologies into their work. Virtual reality (VR) is one technology that has seen impressive advancement recently (Coyne, Merritt, Parmentier, Sharpton, & Takemoto, 2019).

The use of VR in the context of education has also caught the attention of researchers. The ability to create a virtual environment (VE) that a user can explore and interact with makes learning tasks and skills that are high risk, require expensive or fragile equipment, or have a rare event as a prerequisite significantly more convenient (Mehrfard et al., 2019).

1.1 Research problem and method

The purpose of this literature review (Green, 2006) is to get an overview of how VR has been and is being used in educational environments. In addition to that, the practicality and effectiveness of the technology in this context is also explored. A focus point will be what kind of research should be conducted in future studies to accelerate finding the critical factors that will allow more effectual use of VR in education. It could be argued that the potential of VR applications, not only when used in education, is close to endless. It can be used to not only enhance current teaching methods, but to create completely new ones that were previously not convenient or in the realm of possibility altogether.

Three academic databases were searched for relevant papers to be used for this review. The databases were: IEEE, ScienceDirect and Ebsco. For all the databases, the search keywords used were: ("virtual learning environment") AND ("virtual reality") AND (education) AND ("head-mounted display"). Time constrains used for all database searches were publications from 2010-2020. For the Ebsco search, results were further limited to be in English only.

The IEEE search resulted in 18 papers. The ScienceDirect resulted in 35 papers. The Ebsco search resulted in 7 papers. All the results were inspected to determine if they contributed to the topic at hand. Out of the total 60 papers, 36 were thought to provide relevant information needed to answer the research questions. Additional sources include references from said papers. Papers that were excluded included ones that covered applications for augmented and mixed reality.

1.2 Structure of the thesis

The review will start by clearing up definitions about virtual reality and concepts closely related to it and essential to the studies reviewed. From the reviewed papers, central themes and motifs, important findings and limitations are extracted and discussed. Future research topics will be proposed using the results of the reviews.

2. Virtual reality technology

The following section defines what can be considered immersive technologies and the different types of virtual realities that are generally discussed. In addition to that, the means of representing said virtual worlds using different types of stimuli, and the methods of interaction between the user and the virtual reality will be defined. Technical details about VR system architecture and hardware will also be discussed.

Virtual reality technology has been around since the 1960s in the form of systems including head-mounted displays, enveloping the user in a virtual world (Bashabsheh, Alzoubi, & Ali, 2019; Mehrfard et al., 2019). There are multiple different approaches to defining immersive technology, such as technology that creates environments indistinguishable from the real world (Lee, Chung, & Lee, 2013). Despite the varying definitions, a key element of virtual reality is immersion, which can be described as the “sensation of being in an environment” (Sherman & Craig, 2003).

2.1 VR, AR and CAVE

There are multiple different types of immersive technologies. Virtual reality, which will be the focus point of the studies reviewed, is often seen as a head-mounted display worn by the user, which includes displays inside the device and some form of motion tracking technology to gather information about the orientation and position of the device. Augmented reality (AR) can be described as insertion of virtual entities into the real world, such as objects or text, using displays, usually in the form of see-through glasses (Suh & Prophet, 2018). The Cave automatic virtual environment (CAVE) is a set of displays or projectors, which mostly or completely surround the user. A major limitation to CAVE systems are their high cost and low portability (Sherman & Craig, 2003), and as a result more convenient (such as HMD-based systems) technologies have attracted more interest from entertainment industries and scholars alike.

2.2 Sensory inputs and control schemas

Virtual reality technology relies on providing high quality sensory stimuli to immerse the user in the virtual world. These stimuli include visual, auditory, haptic and olfactory. The vast majority of studies which examine the use of virtual reality in various contexts only provide the user with visual representations of the virtual environments. In a ten-year review of research that used virtual reality in educational environments, reviewing 53 articles in total, only 12 articles were found to include auditory stimuli (Mikropoulos & Natsis, 2011). Haptic systems provide the user with sense of touch, giving them more accurate feedback of their interactions with virtual objects. In addition to touch, systems which change the heat and wind according to the VE are possible (Ewert, Schuster, Johansson, Schilberg, & Jeschke, 2013). Haptic technology, alongside with olfactory, is not very sophisticated as of today, and as a result rarely included in VR systems (Mikropoulos & Natsis, 2011).

The way the user interacts with the virtual world can contribute to the efficiency at which the user will navigate the environment, although exploration and movement are not always a vital part of one. The simplest way to control a virtual avatar is with a traditional keyboard, mouse or gamepad (Szczurowski & Smith, 2018). When it comes to immersion, these are not the best options if the goal of the VE is to achieve accuracy compared to the reality. Head-mounted displays can be equipped with markers that are tracked by infrared cameras inside the real-world environment the user occupies (Ewert

et al., 2013). This means that the user can walk around in the real world, and corresponding movements will be transferred to the avatar inside the virtual reality. The limited amount of space in the real environment usually makes this approach undesirable.

2.3 System architecture

Rendering a high-resolution image of a simulated scene is a computationally demanding task. In addition to that, head-mounted displays usually have use two displays, one for each eye. This makes rendering even simple geometry in real-time challenging. As a result, solutions involving using client-server models have been taken advantage of (Ewert et al., 2013; Granado, Viola, Zambrano, & Quizhpi, 2016; Quishpe-Armas, Cedeño-Viveros, Meléndez-Campos, Suárez-Mora, & Camacho-Leon, 2015). Instead of doing all the hard computation on a local machine or in an embedded system, the work is offloaded onto a server that has significantly higher compute capability. Information of the state of the environment is sent to the server, which does the required calculations for an updated representation of the virtual world, which is then sent back to the hardware over a wireless internet connection. This can also be used as an inexpensive scalable solution, as contrary to having to provide each user with their own machine. VR systems available to consumers as of writing most typically simply connect an HMD to a computers graphics processing unit in order to render images on the screens inside.

2.4 Differences between HMDs'

The entertainment industry has taken great interest in VR technology. A wide variety of HMDs are available as a result. It is important to note that intrinsic differences between these HMDs exist. As this review focuses on VR technology involving the use of HMDs', the possible varying factors in the devices should be kept in mind when examining the results of the studies. A comparative study by Arian et al. (2019) describes the salient characteristics of an HMD and how they would be measured. The most important categories these characteristics can be divided into are image quality and comfortability. Image quality includes the resolution of the display(s) inside the HMD, field of view and text readability. Comfortability includes interpupillary distance adjustability, heat management, weight of the device, neck strain and compatibility with glasses. These factors can have a profound effect on the overall user experience and immersion felt by the user, and these effects can carry over to results of studies using the technology. (Mehrfard et al., 2019)

3. Findings

The following section will first review the theoretical background included in the papers, discussing different types of learning theories used. Evaluation methods used to measure the findings of the reviewed papers will be listed, and the learning techniques and types of environments adopted by the studies. General trends in research questions found in the studies and limitations of VR will also be discussed.

3.1 Theoretical foundations

Some theories relating to pedagogy and the brain function have been attributed to designing virtual reality learning environments (VRLEs). A more accurate description and reasoning for their uses will be explained next.

3.1.1 Pedagogical approaches

For an educational process to reach its desired goals, it is required for an appropriate learning theory to be implemented. A learning paradigm commonly mentioned in educational VR environment studies is the *constructive learning theory* (Mikropoulos & Natsis, 2011; Suh & Prophet, 2018). The constructivism theory suggests that “learners take an active role in learning” (Huang, Rauch, & Liaw, 2010). Learning is connected with an experience itself, and new knowledge is synthesized using said experience, combined with previously accumulated knowledge from past experiences.

Constructivism is often included in educational VR applications as it is a prime tool for creating the needed experiences for learning to take place (Huang et al., 2010). Despite the functionality and importance of learning theories, majority of studies that cover the educational use of VR do not make use of them when designing learning environments (Radianti, Majchrzak, Fromm, & Wohlgenannt, 2020).

3.1.2 Cognitive load theory

Cognitive load theory (CLT) describes how working memory mediates learning and points out how limitations in working memory capacity can impede learning outcomes depending on the qualities of the learning task (Sweller, 2005). Being aware of the three different types of cognitive load proposed by CLT can aid in designing high quality educational tasks. The types are intrinsic, extraneous and germane. Intrinsic load is the innate difficulty of the task and cannot be changed by the design of the learning environment (Sweller, 2010). It is based on the prior knowledge of the learner. Extraneous load is mediated by the instructional method, and it does not directly correlate to learning (van Merriënboer & Sweller, 2005). Finally, germane load is theorized to be responsible for the actual learning and consists of the way and form the learning material is presented to the learner (Khalil, Paas, Johnson, & Payer, 2005). For effective learning to take place, the total amount of cognitive load, consisting of all the forementioned three types, must not exceed the working memory capacity of the learner (Lee & Wong, 2014). Therefore, when designing VR learning environments, the goal is to minimize extraneous load and optimize germane load. One of the reasons why VR is believed to be an effective way of learning is the capability of creating environments where extraneous load can be brought to lower levels than with traditional teaching methods (Lee & Wong, 2014).

3.2 Research methods

General trends in the evaluation methods found to be used in the reviewed studies are described more in detail next, as well as what different types of virtual environments, such as games or interactive simulations, were commonly used in the studies.

3.2.1 Evaluation

Assessing the improvement in learning outcomes when using VR in education was one of the main goals of multiple studies that were reviewed. A commonly used evaluation method was pre- and post-experiment questionnaires (Bashabsheh et al., 2019; Chiba & Hamamoto, 2018; Huang, 2018). The questionnaires were used to gather self-reported information on the experienced effectiveness of learning and other personal details, such as enjoyment. Likert-type scales were used in the questionnaires, which gives the subject responding a scale of intensity of agreement they feel best corresponds with the question (Bashabsheh et al., 2019). Results from the questionnaires were used for further statistical analysis to determine whether an effect could be observed compared to traditional learning methods. In addition to questionnaires, quantitative data about the learning task itself was also measured to offset possible biases that inevitably exist in self-reported observations.

3.2.2 Training content and techniques

Different styles of learning were used based on the type of knowledge that attempted to be transferred to the learner. Games, simulations and virtual worlds were used to present information to the learner (Merchant, Goetz, Cifuentes, Keeney-Kennicutt, & Davis, 2014). Games, or “serious games” were found to be most effective when teaching actions and skills, or procedural knowledge (Merchant et al., 2014; Vaughan, Gabrys, & Dubey, 2016). If conveying procedural knowledge was attempted by using simulations or virtual worlds, where the learner played the role of an observer, learning was not as effective. On the contrary, when factual information, or descriptive knowledge was presented, simulations (both interactive and non-interactive) and virtual worlds resulted in a better ability to recall the content of the training (Cheng & Tsai, 2019; Merchant et al., 2014; Yu, Saham, Sahami, Sessions, & Denn, 2017; Zhao & Klippel, 2019). Authors of these papers suggest that in virtual worlds where a time constraint exists, such as a presentation-like simulation, and where free exploration of the world is excluded, learning outcomes are negatively impacted. Creating metaphorical representations of abstract concepts can benefit weak learners, but strong students generally preferred traditional teaching methods (Dengel, 2018).

Traditional teaching methods have a teacher-centered approach. Using VR technology, the focus can be shifted to the students, where the students are presented with the learning material, such as an experiment, and instructed to conduct the experiment with little intervention. One study had students dissect a virtual frog and found that student-centered approach might produce superior learning outcomes compared to traditional methods (Lee & Wong, 2014). This is tied to the cognitive load theory discussed earlier, as this way extraneous load can be lowered, leaving more of the working memory for germane load, improving learning (Lee & Wong, 2014). VR also opens up the possibility of placing students in situations where in an equivalent real-world scenario the students or another person’s health and safety is put at risk.

3.3 Trends

Patterns relating to multiple topics were identified, and the highlights are pointed out in the following sections.

3.3.1 Learning outcomes

A general trend in the studies was that an improvement in the effectiveness of learning across multiple disciplines was observed. Biological education showed superior learning outcomes compared to conventional teaching (Lee & Wong, 2014). Behavioral skills were found to be transferable into a real-world environment (Çakiroğlu & Gökoğlu, 2019). Students found learning in educational VR environments to be more enjoyable and had high levels of interest towards using the technology in educational applications, resulting in a better ability to focus on assigned tasks (Bashabsheh et al., 2019; Ray & Deb, 2016). Use of the technology was found to be able to improve overall student performance (Ray & Deb, 2016). One study used VR to teach students Tai Chi, a Chinese martial art, and found that the speed of learning was accelerated, but the quality of the learning varied (Chen et al., 2019).

3.3.2 Role of presence

Presence can be defined as the sense of physically occupying a VR environment (Cho, Yim, & Paik, 2015). Presence is related to the feeling of immersion: higher immersion will result in a higher sense of presence. Researchers have shown a lot of interest in examining the role of presence in educational VR environments (Cheng & Tsai, 2019). It is believed that the sense of presence is crucial to the learning process, as it enhances the sense of “experiencing” something inside a virtual space (Mikropoulos & Natsis, 2011). However, it is possible for “over-immersion” to occur, which seems to have negative effects on learning (Chen et al., 2019; Mikropoulos & Natsis, 2011). This finding is also supported by the cognitive load theory: if the user experiences sensory overload, the capacity of their working memory will be exceeded, resulting in poor learning performance.

3.3.3 Level of fidelity

Fidelity is the accuracy at which events, objects and actions are represented inside a virtual world compared to the real-world equivalent (McMahan, Bowman, Zielinski, & Brady, 2012). Presumptions made by researchers about fidelity have been that a higher level of fidelity will result in a higher sense of presence, improving the overall user experience and any results that might be accompanied. However, this does not seem to be the case (Bhargava, Bertrand, Gramopadhye, Madathil, & Babu, 2018). A paper in Medical Education has shown that the effectiveness of training remained high even in simulations with low levels of fidelity (Norman, Dore, & Grierson, 2012). There does not seem to be significant differences in training performance when comparing low- and high-fidelity environments, but mid-level fidelity has shown to produce negative effects (Bhargava et al., 2018). Creating high fidelity virtual environments takes more time to develop, increasing total production cost, without necessarily positively contributing to the goal. Therefore, when designing educational VR environments, the appropriate level of fidelity at which it should be implemented should be taken into consideration.

3.3.4 Focus on usability

Although many of the reviewed studies set out measuring the learning outcomes when using VR technology in education, most of the focus was on the usability and user experience aspects of the experiments. The same trend was noted in a prior literature review conducted nine years ago (Mikropoulos & Natsis, 2011). This is something that should be considered in future research, as virtual reality as a technology has matured rapidly, yet information about the effects of VR in regular teaching is very limited. This is a gap in research.

3.3.5 Absence of real data

Studies have been done to assess the usability of VR in the context of education, and the benefits that come from using the technology. Despite this, no comprehensive, long-term research has been conducted that would show the real results of implementing VR into the curricula of different fields. No concrete data exists.

3.4 Limitations of VR

General limitations of the virtual reality technology itself were identified and will be discussed in the next four sections.

3.4.1 Deployment

There is limited access to VR equipment for multiple reasons. The cost of VR hardware, such as HMDs, has been rapidly decreasing since 2017 (Coyne et al., 2019) but is still very expensive. A machine with a powerful graphics processing unit is also a requirement for the operation of these devices. It is possible to eliminate the requirement of a desktop computer by using a smartphone and cardboard to create an HMD, by using Google Cardboard as an example (Ray & Deb, 2016). If this would be used in an educational institution, a smartphone would still be required, which is a limitation by itself. The cardboard approach would also sacrifice potentially critical elements of the experience, such as the feeling of presence. In any case, mass deployment of VR systems, alike something that that would be required if it was desired to effectively and consistently use the systems in a large educational institution, is infeasible due to the raw cost.

3.4.2 Designing VRLEs

Another hard problem limiting the available uses of VR in education is the complexity of designing and developing a VR learning environment. Training people to use the needed development software and how to properly design high quality environments is time consuming and expensive (Coyne et al., 2019). With no prior design experience or training, it is easy to create ineffective learning environments, as discussed with the topics related to cognitive load theory (H.-M. Huang et al., 2010). Creating an adequate virtual 3D learning environment requires expertise in multiple fields, so generating content is not possible for most educators (Coyne et al., 2019).

3.4.3 User discomfort

Using VR means wearing a heavy HMD strapped to the user's head for prolonged periods of time. This is bound to cause discomfort to the user. The weight will strain the neck, which will cause pain. Eye discomfort in the form of dryness and pain has been reported by users (Suh & Prophet, 2018). Simulator sickness or VR sickness is also common, with

symptoms including nausea and vomiting (Datcu, Lukosch, & Brazier, 2015; Goh, Lee, & Razikin, 2016). With HMDs like Google Cardboard where holding the HMD up to the eye level is a requirement, hand discomfort has been reported (Ray & Deb, 2016; Suh & Prophet, 2018).

3.4.4 Individual differences

Some qualities of VR, such as presence, do not seem to be purely dependent on the virtual environment itself. Instead, individual differences between people can have an effect, such as age, gender, epistemological beliefs and prior experience with computers (Cho et al., 2015). The study by Cho et al. found that these factors could significantly impact the participants sense of presence in the VR environment. It is possible that results from other studies in which presence has played a critical role might need further analysis, and that future research needs to take these differences into consideration.

4. Discussion

Much work has been done to determine the practicality of using VR technology for educational purposes, and generally scholars seem excited about the future of VR, and the vast possibilities it brings. Promising results about increasing the effectiveness of learning using VR have been demonstrated (Bashabsheh et al., 2019; Çakiroğlu & Gökoğlu, 2019; Chen et al., 2019; Chiba & Hamamoto, 2018; Huang, 2018; E. A.-L. Lee & Wong, 2014; Liu et al., 2020; Merchant et al., 2014; Ryan & Poole, 2019; Szczurowski & Smith, 2018; Zhao & Klippel, 2019).

The cost of VR technology is rapidly decreasing, continually expanding availability. As accessibility grows, researchers will be able to conduct more high-quality studies as sample sizes will not be as limited and more variety will be seen in the types of implementations. Virtual reality is especially useful in training people in skills that require expensive equipment, equipment that has deployment challenges, pose immediate threat to the learners' life or that require low frequency events (Chiba & Hamamoto, 2018; Mehrfard et al., 2019).

However, the technology does not come without its limitations. More research must be done in order to determine critical factors that make virtual reality a superior teaching method compared to traditional teacher-oriented, classroom type teaching. Exploratory studies have been done about the subject, examining the problem through a constructivist lens, and also explaining the phenomena using theories about the function of the brain, such as cognitive learning theory (Bashabsheh et al., 2019; H.-M. Huang et al., 2010). Furthermore, there is a distinct lack of standardized models for evaluating the results of studies involving virtual reality, and how, for example in educational environments, virtual worlds should be designed to maximize the positive results and minimize the negatives.

In this section, problems identified in the reviewed papers will be touched on. Finally, potential research topics for future studies will be proposed based on the limitations found in the articles.

4.1 Limitations in studies

Limitations found in the studies, such as in the methodologies they adopted, will be discussed next. The studies using self-reported evaluation methods such as questionnaires to determine effectiveness in learning outcomes using VR can be considered unreliable. Standardized methods of evaluation of studies concerning this topic have not been determined. Self-reported data can be considered as triangulation of the results conceived using trustworthy methods (Lorenzo, Ángel Sicilia, & Sánchez, 2012). Data collected from VR use could be used to automate the process of evaluating and scoring to provide objective ways to assess the results of future studies (Vaughan et al., 2016).

Implementation of VR into education requires explicit training of educators on how to use the technology itself, operate the software used to create virtual environments and design scenarios that elicit effective learning (Mendez et al., 2020). This is expensive and requires a lot of time. Even understanding the basic functionalities of the software used in VR development already have a requirement of programming knowledge. This means that there is a barrier of entry to educational VR use. Educators in fields that do not require elaborate computer skills will be most affected. In addition to that, vague terminology and lack of standardized conceptualizations of virtual reality bring more difficulty in

attempts to implement VR technology into new fields. These issues apply to students and other people who will be the users of the technology as well.

As to the limitations of this study, there are several. First, the quantity of research examined was not large enough to consider this an extensive review. The ceiling year for the research was selected to be 2020, which potentially excluded the most recent advances in the field. This review was also limited in scope due to excluding a non-trivial amount of research which utilized augmented reality and mixed reality, as opposed to using pure virtual reality systems. There is also the absence of standardized methods to imperically measure the effectiveness of VR systems in the contexts presented. Additionally, the techniques used to assess the results in the papers varied, resulting in difficulties when trying to make direct comparisons.

4.2 Future work

Based on the trends, findings and limitations found in VR technology and the reviewed papers, possible useful research topics for future studies will be drew attention to in the next sections.

4.2.1 Suitability of different devices

Properties of VR HMDs vary greatly between manufacturers and devices. It has been shown that there is much diversity in deployment difficulty, image quality, induced user discomfort, compatible peripherals and technical features of different HMDs' (Mehrfard et al., 2019). What has not been studied is do these differences produce statistically significant fluctuations in results of other research, such as determined learning effectiveness when using VR. This could be an important topic for future research. It should also be noted that currently, demand for the use of VR is highest in the entertainment market (Mehrfard et al., 2019). Issues related to using VR in education might not be targeted by manufacturers for this reason, so information about what features of HMDs should be valued the most in educational use is ill-defined.

4.2.2 Retention of knowledge

Studies examining the difference in learning effectiveness using VR compared to conventional teaching methods is abundant. However, the degree of retention of the knowledge and skills learned is still unclear. There has been some exploratory work done on the subject, suggesting that skills learnt using VR learning environments are retained even after extended periods of time (Grabowski & Jankowski, 2015). Comparative studies of retention of knowledge using different teaching methods need to be done before any conclusions can be made.

4.2.3 Unexplored technologies

Virtual reality technology comes in many forms. VR, AR and mixed reality all show an enormous amount of different possible applications, many of them still unexplored. Additional peripherals for these technologies also exist, like a 360-degree treadmill used to further improve immersion by allowing the user to navigate the virtual environment by walking into any direction in real life, without the limitations of constrained space of the real environment (Ewert et al., 2013). Use of these additional technologies and their effects is poorly explored, mostly due to the low availability or because of their primitiveness. As these restrictions start to become less pronounced, more research on their practicality should be prioritized.

4.2.4 Scalable system architectures

Virtual reality technology requires a lot of computational power. As a result, the demanding computations have been offloaded to external servers in order to alleviate the problem (Granado et al., 2016; Quishpe-Armas et al., 2015; Ray & Deb, 2016). However, restrictions to the use of this model apply. A low latency between interacting and updating the virtual environment is preferable to reduce VR sickness and increase a sense of presence, so the server doing the rendering of the environment has a space limitation.

Regardless, cloud-computing has been successfully used to play videogames with sufficiently high performance (Shea, Liu, Ngai, & Cui, 2013). Therefore, research on amalgamating cloud-computing with virtual reality technology could be beneficial to assess the possibility of using cloud-computing platforms bring VR into places where powerful computers have a limited availability.

5. Conclusions

A considerable amount of research effort has already gone into evaluating the practicality and effectiveness of using VR technology in education. The research that suggests better learning outcomes for those who use VR will likely motivate even more researchers from different fields to try novel applications of VR to augment their teaching and learning experiences. No conclusive results are available as of yet, but interest in the topic should only grow as the technology develops and becomes more accessible. Higher quality systems with lower price tags will allow for a larger volume of research to be done.

However, the technology does not come without its limitations. More research must be done in order to determine critical factors that make virtual reality a superior teaching method compared to traditional teacher-oriented, classroom type teaching. Exploratory studies have been done about the subject, examining the problem through a constructivist lens, and also explaining the phenomena using theories about the function of the brain, such as cognitive learning theory. Furthermore, there is a distinct lack of standardized models for evaluating the results of studies involving virtual reality, and how, for example in educational environments, virtual worlds should be designed to maximize the positive results and minimize the negatives.

Possibilities for future work include further examination of the role of presence, and how other factors might influence the degree at which the user feels presence, if the retention of learned skills differs when training in VR compared to conventional methods and what kind of approach different fields should adopt if they want to incorporate virtual reality into their curricula.

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