Exploration of Challenges and Solutions for the User Interface of Virtual Reality Applications in the Fields of Education and Training

BIRGIT REITER and RUDOLF C. GARSTENAUER

ABSTRACT

Virtual Reality (VR) is a rapidly growing trend in computer science, offering a multitude of games, apps, and educational content. In a VR environment, it is possible to simulate almost every situation or visualize abstract concepts. In this reality, the user is able to gain an immersive, hands-on experience. It is a powerful technology and has a lot of potential. However, VR education faces several challenges that must be addressed in the future. Therefore, in this research, the utilization of virtual reality as a teaching environment is examined. Additionally, the challenges and successes encountered by this technology are identified.

KEYWORDS

virtual reality, education, interactive learning, educational games, edutainment

1 INTRODUCTION

The term Virtual Reality was initially defined in 1960 [4]. Since its inception, VR has undergone significant evolution, encompassing both software and hardware to simulate a convincing sensory illusion of presence in another environment [20]. Noteworthy attempts to create a believable VR experience date back to the 1980s [1, 18], with ongoing technological advancements each year. The potential for utilizing VR in educational settings has been contemplated since its early days, resulting in numerous studies on the subject [1].

Over the past decade, there has been a substantial surge in the development of new VR technologies, accompanied by an increasing public demand. According to [2] VR gaming will exceed $86.22 billion by 2031, thus the evolution of new VR technologies will become faster, and the prices will get more affordable for private users. For example, in 2020 the VR-Headset *Meta Quest 2* was released, which is a powerful piece of hardware for a relatively low price tag [6]. Thus, more people will have access to VR in general and make it easier for educational institutions to do VR assisted education.

The application of VR in education offers various advantages, ranging from enhancing safety during simulations of emergencies [14, 20] to providing hands-on experience in tasks such as medical procedures [2, 24]. When utilized effectively, VR can be a very powerful tool, assisting users in skill enhancement in a gamified environment [11, 20, 21].

Using VR as educational asset has also its challenges, like physical discomfort [12] and most importantly Cybersickness [19].

This new technology has come a long way and for some it is still not ready to be used in an educational context [4]. We investigate claims like this and take a closer look at the challenges and successes educational VR has achieved so far. By doing this, we aim to contribute to the current ongoing discussion regarding the effectiveness of VR assisted teaching in general.

1.1 Research Questions

In our work, we are investigating the development of VR in the educational context over the past decade (2013-2023). To guide our exploration, we have formulated the following research questions:

(1) Is there evidence for advanced learning outcomes and increased student engagement?
(2) What areas are benefiting the most of the usage of VR for teaching?
(3) What challenges and successes have been observed in integrating VR into teaching?

1.2 Methodology

As a methodology for our literature research, the *Systematic Literature Review* (SLR) was chosen. Initially, the above-mentioned research questions were defined. According to the PI(CO)C Scheme [13] these research questions should be considered from three perspectives:

- Population: Who is affected?
- Intervention: What is affecting?
- Context: How is it affecting?

In the context of this work, our population consists of students, the primary users of Virtual Reality equipment in education. The scope of the education level ranges from primary school up to university level. Teachers are also a significant part of the population. They need to be able to use the programs and integrate them into their lessons and lectures. Furthermore, they are often involved in the design process of such programs, contributing their expertise and know how, so the applications are most beneficial for students.
The intervention represents the application of Virtual Reality as a teaching method. It focuses on different fields of study, exploring both the advantages and drawbacks associated with its implementation.
As for the context, we defined two scenarios. On the one hand is the classical classroom teaching with students being physically present in the classroom and using the VR equipment. The second scenario would be a virtual classroom where students are sitting at home or some other remote place and connecting to their classroom via the VR technology.

As a primary source for papers, we used the "ACM Digital Library" [3]. To find fitting resources, the following keywords were defined:

- Education
- Virtual Reality
- Interaction
- Edutainment
- Educational Games
- Simulation
- Immersion

To focus on the core topics of this paper, some exclusion criteria for resource selection were defined. Papers solely focusing on technical aspects of software and hardware are not considered. Additionally, papers lacking an educational focus are excluded. This would apply to papers only dealing with gaming and gaming experience. The defined timeframe restricts the publishing years of the papers to the last 10 years. Lastly, the main focus should lie on scientific resources. Therefore, sources like newspaper articles, websites and similar Therefore non-scientific sources like newspaper articles and websites are avoided if possible.

We integrated a total of 24 papers into our research. Currently, there seems to be a notable increase in the number of papers, as illustrated in figure 1. Not all the past 10 years could be covered with the papers considered in our work. Even after a focused search for the time span between 2013 and 2016 no papers fitting our criteria could be added. Although there are papers in our research which cover that time span [4, 15]. However, their release date is later than these specific years.

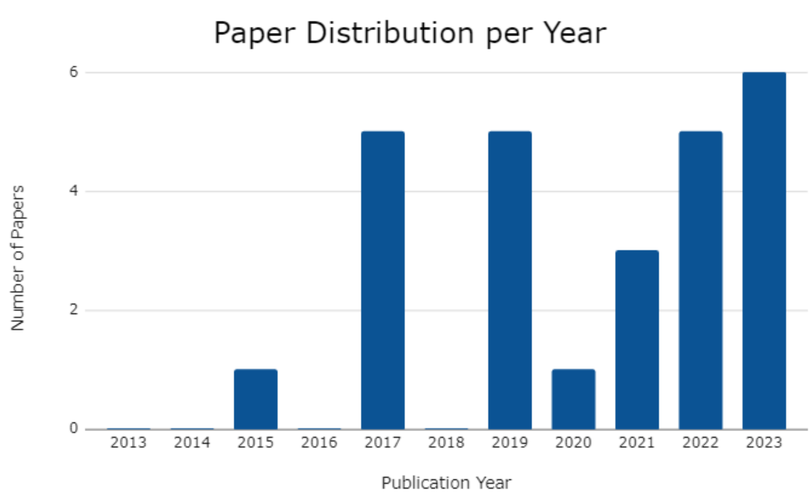

Fig. 1. Paper distribution over the last decade

To evaluate the used sources, the following distinct categories were defined:

Subject Category

- Natural Sciences
- Medical Training
- Engineering
- Software Development
- Emergency Training
- Sports and Fitness

Educational Level

- Primary School
- Secondary School
- University Level

Each paper was assigned to one or more categories it deals with. This approach simplifies the comparison of different findings on the same topic. Additionally, the significance of different topics and trends can be visualized.

Figure 2 clearly shows that most subjects cover the educational level of secondary school and university level. Finding literature considering applications for smaller children was rather challenging.

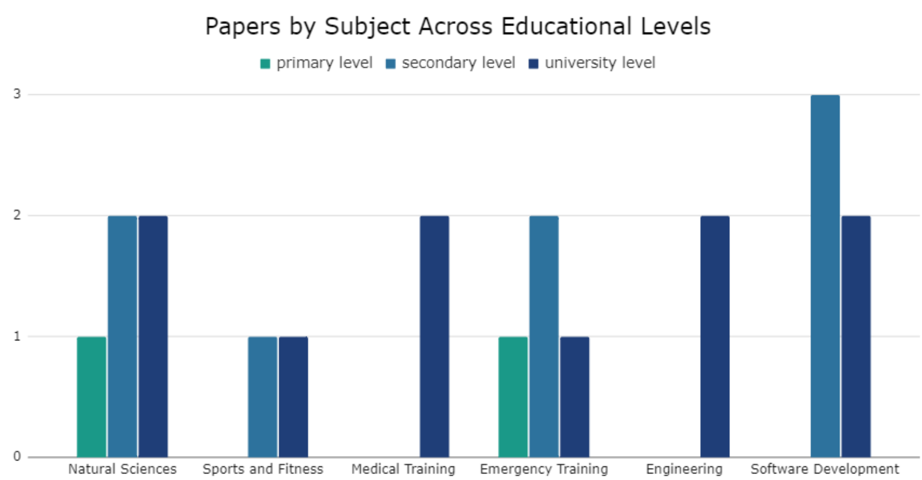

Fig. 2. Assignment of papers to one or multiple subject categories

After analyzing the subject distribution across the elected 24 papers, it is evident that the most prominent topic is "Natural Sciences" followed by "Software Development". The least prevalent category is "Sports and Fitness". Most papers were missing the educational aspect when dealing with this topic, leading to their exclusion. As shown in figure 3, the remaining subjects are represented in a more or less balanced way.

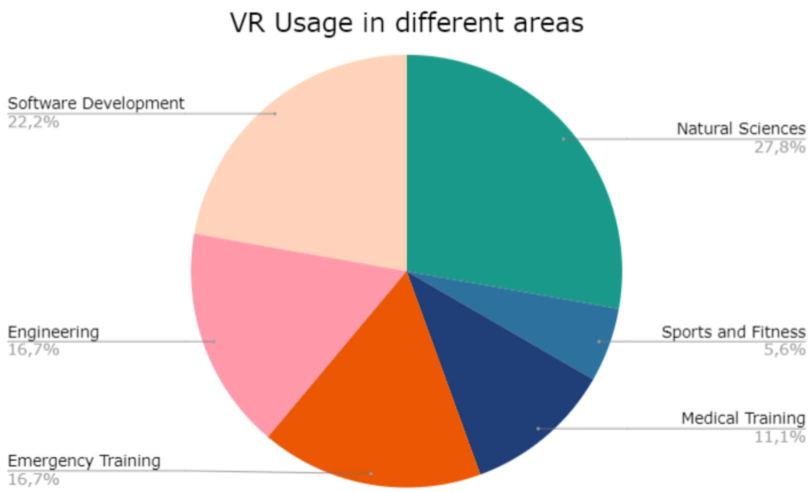

Fig. 3. Distribution of Fields of Application

2 RELATED WORK

As stated in the introduction [Section 1] the topic of VR education has grown in interest over the past years. There are many intriguing papers that cover a lot of different aspects and use case studies about that topic.

One of the most cited papers in the field of VR education is the work of Jaziar Radianti et al. [20]. In this non-exhaustive literature research, the authors cover a lot of theoretical background, history, and trends. By analyzing the latest scientific works on this topic, the authors provide a deep insight into the current problems of VR education, which we will also cover in our work [Section 6]. Another fundamental paper is the literature analysis done by Lai et al. [15] published in 2020, which covers the last 26 years (1994-2020) of VR Education.

Other noteworthy works cover special use cases of VR, such as the work of Ding et al. [2]. In their work, the authors focus on the utilization of VR in medical training and compare it to traditional educational games. The work of Kavanagh et al. [22] covers the utilization of VR educational technology in an engineering context. The authors provide an interesting insight into that topic and state that VR will most likely become more evident in the coming years. Similarly, [2, 23, 26] also cover medical VR training. Hee Lee et al. [9] list in their work a lot of benefits, disadvantages, and risks concerning VR application in general, with an emphasis on education in robotics.

Other works focus on different topics like natural sciences [1, 8, 17], software development [7, 21, 25], emergency training [24, 26] and sports [24]. Those will be investigated further, in Section 3.

One big aspect that will be discussed in Section 6.3 and Section 6.4 is Cybersickness and other physical discomfort caused by VR applications and hardware. The work of Qu et al. [19] is investigating the phenomenon of Cybersickness and Kim et al. [12] about user discomfort like neck pain. These two works are important auxiliary papers to substantiate these claims with sources.

3 IMPACT OF VR ON DIFFERENT EDUCATIONAL FIELDS

As already mentioned in section 1.2 we encountered six areas which are using VR in education. This section will provide an overview of how this usage looks like.

3.1 Natural Sciences

For subjects in natural sciences, it is often difficult for the students to grasp the learning content due to the abstract nature of the matter [8]. Considering for example geography classes, it just is impossible to travel around the globe to actually see what is taught in class. Additionally, experiments in physics and chemistry might be too complex, infeasible for teachers to arrange or even too risky for direct observation. The usage of VR is an attractive option to overcome some of these problems.

In geography lessons, there are VR games available that enable students to virtually explore various locations worldwide. As part of their assignments, they're tasked to capture photographs and record videos in these foreign locations [1].

Moreover, in biology, students can work in a virtual laboratory. They practice techniques such as cell culturing, cell transfection, and protein expression. The learning progress is evaluated through multiple-choice tests [17].

3.2 Medical Training

The challenges in medical education are evident. Studying anatomy is difficult without access to cadavers for dissection. Likewise, the anxiety of learning surgical procedures can cause nervousness of students. VR provides a safe environment for practice, allowing familiarization with operations and various medical tools without the concern of harming anyone [23, 26].

Furthermore, simulating patients and specific scenarios proves to be an invaluable approach [2]. The "VR Bronch" application, for instance, is designed to facilitate learning the assembly of tools used in tracheobronchoscopy and understanding their components. Currently, the focus isn't on surgical aspects; instead, the goal is to memorize the assembly process without guidance [26].

Another example is the training of surgical procedures to treat cerebral aneurysms. Through this, students can enhance their skills and build up confidence [2].

However, learning content doesn't have to be exclusively practical. Engaging with the theoretical aspects of neuroanatomy through a VR app, which presents CT (computed tomography) and MRI (magnetic resonance imaging) images, not only enhances student involvement but also creates a more captivating and interesting learning experience [23].

3.3 Engineering

Engineering education frequently involves exposure to physical dangers. In fields like electrical engineering, hands-on experiments with essential concepts can put students at great risk. Utilizing a VR application for conducting experiments offers a save environment, preventing potentially life-threatening errors. Moreover, simulating construction sites and familiarizing learners with hazards virtually enhances their awareness before entering real-life scenarios [22].

The advantages of VR extend beyond practical applications. For instance, understanding ancient construction techniques can be more effectively taught through immersive demonstrations, providing a tangible learning experience compared to studying solely from books and theoretical principles [22].

3.4 Software Development

In Software Development, numerous games have been devised to facilitate the introduction to programming. Some games utilize diversely shaped objects to represent different data types, making concepts more tangible [21]. In the game “Cubely” segments of code are depicted as distinct cubes. Players can manipulate and arrange them freely to construct executable code sequences [25]. Another approach is the incorporation of a storyline and the progression through code-based puzzles within the game. This leads to an enhancement in engagement of students [7].
For beginners, delving into programming can often appear abstract. These games are specifically designed to take out the sometimes overwhelming complexities when learning programming. By offering interactive, visually intuitive representations of code and its functionalities, these games aim to make the learning process more accessible and engaging.

3.5 Emergency Training

Emergency preparedness often hinges on theoretical instruction, particularly in the context of natural disasters. Typical practice considering building fires involves periodic fire evacuation drills, typically held once or twice a year. To enhance comprehension and readiness in such scenarios, utilizing VR applications becomes invaluable.
These applications are designed to instruct individuals on crucial actions during emergencies, such as proper techniques to shelter under a desk during an earthquake or to safely exit a building in the event of a fire or earthquake. They also familiarize users with the locations of essential materials like fire extinguishers or fire blankets [10, 14].
Moreover, there exist interactive programs addressing social emergencies, like school violence or abduction scenarios. The primary objective is to educate children on how to prevent these situations and, if encountered, how to navigate and escape them safely [14].

3.6 Sports and Fitness

Utilizing Virtual Reality for athlete training has shown promising results in enhancing reaction times. One such game, “Perifocus” specifically targets the improvement of color and shape detection within the peripheral vision. Traditionally, enhancing peripheral vision can be boring and time-consuming. However, “Perifocus” reframes this training within a shooting game context, keeping the users engaged and enthusiastic with the exercises [24].
Despite the evident positive outcomes associated with this training method, the focus within this domain revolves around games that prioritize entertainment or physical workouts. The educational dimension, as addressed by “Perifocus” is often underrepresented.

4 IMPACT OF VR ON THE LEARNING OUTCOME AND STUDENT ENGAGEMENT

4.1 Student engagement

Several studies, including [1, 5, 15], suggest that students exhibit higher motivation when Virtual Reality is used as a teaching method. However, the enjoyment of using applications on PC is often comparable to VR [7, 16].
Notably, students facing difficulties in keeping up with lessons show increased motivation and interest, while high-achieving students experience no benefit but also no negative impact on their performance [11].

4.2 Learning outcome

Opinions on the impact of VR on learning outcomes differ. Some papers indicate no significant difference in knowledge levels between students using VR and those taught with traditional methods [23].
In the context of virtual science labs, students report a higher sense of presence and attentiveness with VR, but the actual learning gains seem lower than in traditional labs. Cognitive workload measurements reveal that students are more overloaded during learning using VR compared to the PC version of the simulation [17].
In most cases, there is no significant difference between student groups using VR and those taught through traditional methods [7, 22, 23]. This can be viewed positively, suggesting that VR does not compromise learning outcomes. An analysis of 29 papers in [8] revealed that approximately half of them reported positive learning outcomes with the use of VR. Additionally, [11] states that the learning outcome of weaker students is in fact higher when VR comes into play.

5 SUCCESSES

There are several advantages of using Virtual Reality in education, frequently highlighted in literature. This section gives an overview why VR is considered beneficial in an educational aspect.

5.1 Constraint-Free Simulations

One key benefit is experiencing otherwise inaccessible places due to time or spatial constraints. Students can travel virtually to foreign countries, learn about different cultures, or even journey through historical eras [10]. Witnessing the construction techniques of the Great Wall of China, for instance, becomes more tangible when seen firsthand instead of just receiving information in text or audio form [22]. Moreover, exploring different planets of the solar system or natural underwater habitats becomes achievable using this technology [4].
In medical education, where access to cadavers for dissection courses is limited and costly, Virtual Reality simulations clearly visualize complex anatomic relationships for the students.
It also aids in preparing future surgeons by familiarizing them with procedures and equipment, improving their confidence and proficiency without endangering real patients during training [23].
Additionally, traditional simulation training equipment which imitates the haptic of the devices are often inaccessible [26].

5.2 Risk-Free Simulations

VR also serves as a safe avenue for experiences too hazardous for real-life replication. For instance, practicing earthquake response in games ensures a realistic yet secure environment [14]. Simulating dangerous scenarios like for example building fires are way too costly to be repeated. Using a VR safety game allows unlimited repetitions to get the necessary skills and routine in such situations [16].
Considering traditional subjects taught at school or university, certain experiments in fields like chemistry or physics pose risks unsuitable for student labs. Simulating those can give good insights without risking the health or life of the students. VR simulations offer insightful experiences without jeopardizing students' safety, allowing limitless repetition [4, 16].

5.3 No Spacial Constraints

The scarcity of lab space in educational institutions poses a challenge, mitigated by VR. The labs no longer depend on the spatial capacity of the educational institutions. Distance learning students can easily participate in the labs [22]. This became especially important during the COVID-19 pandemic, facilitating distant students' participation in labs and reducing the need for constant teacher supervision [17, 26].

5.4 Inclusivity

VR enhances inclusivity by aiding people with special needs in different situations. Developmentally disabled people can participate in job training, for instance, to learn how to behave when serving food in a restaurant. Enabling participation of people with hearing impairments in scientific experiments by showing sign language in a way the person can keep concentrating on the learning content would be another aspect. VR eliminates physical limitations, allowing engagement in mechanical tasks regardless of mobility [22].

5.5 Immersion

Overall, students find VR-based learning motivating and engaging. Students with no interest in participating in the courses are enthusiastic and start interacting in class [10, 11, 16]. The immersion in the subject becomes evident as students work diligently and attentively, free from distractions [11]. Engaging in immersive learning through VR not only prolongs their focus but also enhances their cognitive, psychomotor, and emotional skills more effectively [20]. Most students find using VR in class as intuitive as other learning materials [23].

5.6 Cost Efficiency

In the past, the VR technology was prohibitively expensive, limiting its accessibility. Fortunately, this barrier is steadily diminishing as multiple manufacturers enter the market, leading to more affordable prices [5, 8, 15]. Moreover, issues like cyber sickness are decreasing due to advancements in motion-tracking technology, contributing to a smoother VR experience [4].

6 CHALLENGES

Despite the overall successes of VR in education, the integration of this technology into mainstream educational practices faces several notable challenges. This is a non-exhaustive list of challenges the field is currently facing, and some of them are more severe than others.

6.1 Lack of Definitive Design Patterns

One notable challenge is that there are no predefined design patterns for VR educational content, as highlighted in the work of Jaziar Radianti et al. [20]. This even means that the meaning of a word isn't defined, and thus can cause several misunderstandings among experts in this field. For instance, there are varied interpretations of the term *realistic* across different studies. Some developers state that an environment has to be as authentic as possible to be labeled *realistic*, while others argue that a scenario just needs to be recognized to be considered *realistic* [20]. The use of different terms in papers poses a significant problem, leading to confusion and misunderstandings among VR developers, authors, and designers. This discrepancy emphasizes the importance of standardized design patterns in the topic of VR. This is one reason of the ongoing debate among VR-experts regarding the readiness of VR for real educational content[20].

6.2 Cost and Maintenance Implications

Equipping a school class with VR headsets is a substantial financial commitment. The initial price of a suitable VR headset, including peripherals, is around €300, which is already a reasonable price. However, the initial costs are not the main issue here. VR equipment has ongoing costs, such as cleaning and careful handling, especially with ever-changing users. If the users do not handle the technology with care, additional costs like replacing lenses, head straps, etc. will add to the initial price tag [15, 22]. Therefore, teachers must consider whether future users are capable of managing this responsibility. This consideration is particularly relevant for classes with younger children, making it less likely for them to be equipped with such tools. This is a problem because especially younger audiences could also benefit from these technologies, which might be seen as not mature enough to handle the responsibility of such a fragile piece of technology.

6.3 Physical Discomfort

Extended usage of VR headsets can lead to physical discomfort, manifesting as headaches and neck pain. Eunjee Kim et al. wrote in their work [12] the following: "These symptoms developing twice as rapidly compared to users of traditional desktop monitors." Therefore, users must exercise caution regarding the duration and proper adjustment of the VR headset. Taking regular breaks and engaging in neck-release exercises are strongly recommended practices.

6.4 Cybersickness

Another difficult challenge for using VR technology more often in education is the common occurrence of cybersickness among users [12, 19]. Cybersickness is a temporary condition and caused similar to motion-sickness. It can lead to discomfort, nausea, dizziness, or even more severe symptoms in extreme cases. This phenomenon is relatively widespread among VR users, and it seems that certain individuals may be "*incompatible*" with current VR technology, raising concerns about inclusivity and accessibility. Finding a solution to this phenomenon is crucial for the future of VR technology in education.

7 CONCLUSIONS AND OPEN ISSUES

In this paper, we investigated VR as a tool for education over the past decade. We have done this by investigating the impact to learning outcomes utilizing VR technology. Overall, the consensus is that VR delivers great benefits for educational purposes, [1, 4, 5, 8, 10, 15, 17, 22, 26]. Nonetheless, certain studies suggest that in specific instances, the anticipated learning outcome was below the expectations [7, 17].

We also investigated the areas which are benefiting the most from VR education (Section 3) and learned that the main profiteer are subjects like medicine, engineering, and chemistry where VR allows simulating hazardous or risky situations safe and relatively cost-efficient [4, 16].

In section 4 we investigated the impact on learning outcome (Section 4.2) and motivation (Section 4.1), which was not that high as one would expect. Finally, we listed the challenges (Section 6) it is facing, as well as the successes (Section 5) it can achieve. Cybersickness (Section 6.4) is one of the biggest drawbacks of this technology that has to be addressed in order to be successful in the future.

Another challenge is that currently the VR Community lacks an overall design pattern [20] and therefore most of the latest published works can be misinterpreted by colleagues and developers. Nonetheless, VR education is offering a lot of positive aspects like to be able to simulate anything (Section 5.1) and being able to simulate dangerous situations (Section 5.3) without risk for the trainee.

Virtual Reality is on a fast track for even more growth than in the past decade. According to [20], authors now have a solid base of experimental studies from previous years to build on. This paves the way for VR education to become a big part of future classrooms sooner than we might think.

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