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Virtual reality in education: The promise, progress, and challenge

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Virtual Reality (VR) has made significant inroads into both the consumer and professional sectors. As VR has matured as a technology, its overall practicality for use in education has also increased. However, due to the rapid evolution of the technology, the educational field struggles to stay informed of the latest advancements, changing affordances, and pedagogical applications. Even the authors' own 2018 work that categorized VR technology for different educational applications, is no longer completely applicable to the current educational landscape. Though education struggles to keep up with technological developments, both researchers and practitioners have been contributing to a growing body of knowledge and experience. Accordingly, this article explores the progress of VR in educational research and classroom practice through three key questions: (1) What benefits does VR offer for education?, (2) What are the challenges to applying VR in an educational context?, and (3) Has VR matured to a point where it is useful for a wide range of educational purposes? Through a review of literature published from 2017–2020, the authors explore these questions to provide a snapshot of how VR is being used in classrooms and educational research. The authors conclude with predictions for the future and suggestions for future research.

Keywords: CALL, virtual reality, educational technology, distance learning

Forum

Introduction

Virtual Reality (VR) is a tool that many language educators have considered for use in their classrooms. However, since VR is a continually evolving technology with quickly changing features, applications, and educational affordances, it is difficult for teachers to understand exactly what the technology is and what it can bring to their classrooms. During the 1990s the term virtual reality appeared to have had differing definitions depending on whether it was being discussed in the consumer space or in academia. In academic articles discussing VR, the term was used to describe a variety of modes of 3D avatar-based interactive experiences. (Steuer, 1992; Cruz-Neira, Sandin & DeFanti, 1993; Robertson, Czerwinski & Dantzich, 1997). However, in consumer materials from the same period, VR is almost exclusively referred to as a head-mounted display (HMD) or headset that has some level of interactivity through either head/body rotation and/or motion.

While the advent of new HMD VR products starting in early 2010s has further solidified the definition of VR as a headset-powered experience in the mind of popular culture, modern academic articles can still be found referring to non-headset-based VR experiences. In particular, Linden Labs' Second Life has been the focus of a number of academic articles on VR despite it being desktop PC software using a keyboard, mouse, and monitor (Swanson, 2008; Schmidt & Stewart, 2009; Chen, 2016; Paramaxi, 2020). However perhaps due to the rise in popularity of newer VR headsets, the use of the term VR in academia appears to be shifting towards its more popular consumer definition. Hence moving forward, this article will focus on the considerable number of research articles that have emerged recently focused on VR as a headset only.

In the VR technology space, the technology has gone through a period of rapid innovation since the release of the first modern headsets in 2013. Every year since then until the time of writing this article, new headsets have become available that have added new levels of immersion, removed barriers to entry or have simply lowered the price significantly compared to previous devices. For educators, each new innovation has brought VR closer to becoming a practical tool for use in classrooms around the world. However, due to this rapid innovation, academic research on their use in classrooms from as few as five years ago can now have little connection to the current state of the technology.

Even this paper's authors' own research into the affordances of VR for education, published as recently as 2018, is already dated (Lege & Bonner, 2018). In that paper the authors categorized VR into three separate categories: *High-end*, *mobile* and *mass-distributed*, each with their own classroom affordances and activities. *High-end VR* encapsulated the most powerful VR hardware, providing fully interactive head and hand tracking experiences tethered to powerful and expensive PCs. *Mobile VR* focused on using flagship quality smartphones to power simple VR headsets, providing limited interactive games and experiences. *Mass-distributed VR* encompassed disposable cardboard headsets powered by any smartphone, offering passive 360-degree video viewing.

As of late 2020, the middle category, *mobile VR*, is already obsolete, with both Google and Samsung, the manufacturers of smartphone-powered VR headsets, ending production of the devices in late 2019 (Roettgers, 2019; Hayden, 2019). This category has since been replaced with standalone VR headsets. These devices offer all the immersion and full head and hand tracking experiences of high-end VR but require no tethering to a PC or smartphone and are available for less than the price of a cheap laptop computer.

This rapid change in the technology highlights the need for up-to-date information to be made available for anyone looking to use VR in their learning environments. The changing landscape of VR has opened a wealth of new opportunities that require a wealth of new research. As the hardware continues to improve and the price keeps decreasing, the affordances for classrooms will continue to change.

Implementing new technologies to meet curricular demands and reach instructional outcomes is often a difficult process, requiring a lot of trial and error. Tertiary education frequently benefits from connected well-funded research environments, allowing for systematic testing and implementation of technologies. On the other hand, most primary and secondary educational environments simply lack the funding, knowhow, and capacity to pursue this method of data driven adoption, except in the rare cases when hardware manufacturers sponsor research in these domains. When VR is used in primary to secondary education, publications take on the form of blogs and word of mouth style communication that are often informal and anecdotal, providing little support for their claims. However, this does not lessen the importance of these publications, as these VR educational experiences can provide great insights into the pedagogy driving actual use of VR. The claims and perceived benefits also provide researchers with hypotheses to investigate further in later rigorous testing. Hence, the authors will include a review of both types of VR publications, those written scientifically and those that are aimed at the general public, in an effort to better encapsulate the true state of VR in education in 2021. To do so, authors will include publications within the range of 2017–2020. The paper will focus on the following questions:

1. What benefits does VR offer for education?
2. What are the challenges to applying VR in an educational context?
3. Has VR matured to a point where it is useful for a wide range of educational purposes?[

VR in education 2017–2020

What benefits does VR offer for education?

Engagement. VR is a novel technology for many, though its prevalence at theme parks and attractions have begun to some degree to reduce its mystique. Notwithstanding the increasing likelihood that students have at some point experienced a form of VR potentially reducing the novelty factor, VR in education has consistently been found to be motivating and exciting for students. Researchers frequently include measures of motivation and interest in their studies, and their findings consistently show that VR stimulates participants' interest and engagement with the subject matter (Costa & Melotti, 2012). VR has also been linked to a rise in student's motivation by many researchers (see Tai, Chen, & Todd, 2020; Cho, 2018; Kaplan-Rakowski & Wojdynski, 2018; Velev, 2017). In their study comparing a lesson delivered using a slideshow to a lesson using VR, Parong and Mayer (2018) found that students were "happier, more excited, and less bored" (p. 8) when taught using VR. Kavanagh, Luxton-Reilly, Wuensche, and Plimmer (2017) point out as a part of their systematic review of VR research from 2010 to 2017 that "the increased immersion facilitated by VR was mentioned as a motivation factor in 46 (out of 99) of the papers analyzed (making it the most commonly mentioned factor)" (p. 96). For now, or until the technology becomes banal, VR promotes interest and excitement, the importance of which cannot be underplayed, as learning does not take place effectively in the absence of these catalysts.

Inaccessible environments. VR technology allows users to supplant their current reality with a virtual environment that can be any location, real or imagined. Educators can leverage this capability to meet educational objectives that cannot satisfactorily be met within the constraints imposed by the current physical location. In many contexts, activities such as field trips are both logistically and cost prohibitive. However, projects like Blazauskas, Maskeliunas, and Kersiene's (2017), which used VR as a way to conduct a historical tour of a city, show that VR can provide access to learning experiences. Researchers Hu-Au and Lee (2018) note that VR is perfect for schools seeking learning experiences, but unable to venture out into the field. Educators have been using VR for this very purpose. Nicolson (2018), head of a primary school in the UK, notes that their school used VR to teach about inaccessible environments like the arctic or deep ocean. Hunt, from Oak Run Middle School in Texas, USA, said of their virtual field trip initiative that "We want to encourage students to look beyond their hometowns and realize there's a big world out there for them to see" (2018). Harvard University's Nicole Mills employed VR to allow French students to visit Paris, noting that the VR experiences "captured a part of Parisian daily culture that often can't be described in words (i.e., the sounds, the atmosphere, etc.)" ("Virtual reality narratives in foreign language pedagogy," 2020, para. 1). At a university in Japan, Frazier and Roloff-Rothman (2019) used VR to provide access for global issues students to refugee camps, American political rallies and religious pilgrimages via 360-degree videos. They noted that "joining believers on the Hajj pilgrimage to Mecca or wandering the halls of a Buddhist temple in a far-away country can make religion come alive in a way that two-dimensional videos cannot" (p. 15). The sense of presence generated by the marriage of quality VR hardware and software can enable powerful experiences in any conceivable location. It is also worth noting that these experiences also provide those with limited mobility with an equal way to join their classmates in such virtual journeys. However, it should be noted that the benefits of using VR for these types of experiences are notoriously hard to measure through empirical research and data collection.

Spatial memory. Promoting engagement and fostering motivation is not the only area where VR can influence education. Immersive VR places learners within a virtual space and allows them to move freely and interact within that space. This allows for not only locomotion, but the ability to see objects and scenes from multiple angles and perspectives. Researchers such as Pollard et. al (2020) have hypothesized that this could lead to increased retention and recall of the scene and objects within it. Pollard et. al designed a rigorous within-subjects design study investigating spatial learning in virtual environments over three conditions: Low, medium, and high immersion. The conditions differed with regards to the technology employed to deliver content: The low-immersion condition used a desktop monitor and speakers, medium used a head-mounted display (HMD) that partially occluded participants' surroundings, and the high-immersion condition used a high-end VR system, the *Oculus Rift.* The high-immersion condition performed significantly better on both the yes/no object and the multiple-choice measures compared to the medium and low groups (p. 6). The researchers hypothesize that the ability to view the scenes from multiple angles may have contributed to these results.

Cho (2018) similarly focused on the ability of VR to orient users within a virtual environment. Cho's study focused on the concept of *Memory of Loci* (see Foer, 2012), in which memories are stored in sequential locations based within a mental image (often referred to as memory palaces). Cho found that "due to a sense of presence, if learners replicate language study in VR simulation, it can help them remember words more efficiently" (p. 59). Huttner and Robra-Bissantz also conducted a study comparing the use of VR for creating memory palaces to those displayed on a laptop display and were able to show a 5–7% increase in test scores for the VR group versus the laptop (2017). Comparable research conducted by Krokos, Plaisant, and Varshney comparing desktop PCs and VR found similar results (2018).

Furthermore, VR researchers have examined whether VR is able to improve learning and retention of vocabulary in a new language. Tai, Chen, and Todd (2020) conducted an experiment comparing student performance following content delivered by video to content experienced in VR. Participants were given a delayed posttest by the researchers who found "VR players demonstrated better vocabulary retention than the video watchers" and that "VR appears to have helped learners store the target words in long term memories" (p. 13). While these results are promising, it should be noted that in this study the VR participants were able to directly interact with the content, while the video watchers were passive, possibly explaining the significant results. However, other researchers have also found similar results. Madini and Alshaikhi's (2017) study examined the use of VR videos for vocabulary retention, finding that VR helped participants to retain lexical items. In addition, Alfadil (2017) carried out a comparative study in which VR was pitted against traditional best practice for vocabulary. The researchers found a similar result showing that participants using VR "had greater achievement in learning vocabulary than those using the traditional method in learning vocabulary" (p. 49). Perhaps, the additional dimension of spatial orientation offered by VR allows for learners to create more mental connections (connecting more neurons), in turn leading to greater memory retention.

Empathy training. VR not only allows users to visit new worlds, but also offers the ability to place the user in the position of another person. The implications of this have not been lost on developers or educators, as evidenced by the large numbers of high-quality VR experiences designed for the purpose of fostering empathy and promoting understanding. Some of these popular applications include *Anne Frank House VR, Driving While Black, Notes on Blindness,* and Stanford University's *Becoming Homeless: A Human Experience.* Chang et. al (2019) even taught students about sexism in math classes by having students embody the perspective of female students.

Dr. Courtney Cogburn of the Virtual Human Interaction Lab at Stanford University created *1000 Cut Journey*, "an immersive virtual reality experience that allows you to walk in the shoes of Michael Sterling, a Black male, and encounter racism first-hand, as a young child, an adolescent, and a young adult." This project, conducted as a part of an investigation into empathy and perspective taking, was aimed at helping students understand the realities of racism and promote effective and collective social action (Roswell et al., 2020).

Educators have also benefited from the wealth of 360-degree videos that can be viewed in VR to help learners understand more of the human experience by placing them in the position of others. Educators have had their students experience the Syrian refugee crisis American political rallies, and a Hajj pilgrimage to Mecca (Frazier & Roloff-Rothman, 2019).

When used in this manner to build empathy, researchers have found that VR offers unique benefits when compared with other mediums of instruction. Stavroulia and Lanitis (2019) used VR to help teacher trainees experience what it is like to be both a student and a teacher of a class. Their study showed significance with regards to "the empathy scale related to the teachers' ability to put himself/herself in the position of a student who is racially and/or ethnically different" (p. 32). Herrera, Bailenston, Weisz, Ogle, and Zak (2018) conducted a study examining the effects of using immersive VR to teach about the experience of homelessness and compared this to the effect of a first-person text-based narrative. Participants received follow-up surveys at two, four, and eight weeks after the intervention. With regards to attitudes towards the homeless and dehumanization of the homeless, the study found that though participant attitudes were similar immediately following the intervention, "the attitudes deteriorated at a significantly slower rate and were consistently more favorable for participants in the [VR] condition than the participants in the [non-VR] condition" (p. 19). Herrera et al. also reported that participants in the VR condition "reported feeling more connected and empathetic toward the homeless" (p. 29). The immersive capabilities of VR can allow for powerful perspective-taking tasks; experiences that may lead to lasting learning.

Distance learning. VR also has the potential to extend learning opportunities to new places and demographics beyond face-to-face learning. Its potential to bring people together across large distances and provide them with immersive environments where they can interact with others may help overcome the shortcomings of current online learning and distance education practices. Chang, Zhang, and Jin (2017) outline the potential role of VR in distance education focusing on the potential affordances offered by multi-user virtual campuses where students can meet and work together. Additionally, the authors' own paper (Frazier, Bonner, and Lege, 2019) outlines some of the current affordances and limitations of VR for distance learning. In this paper, the authors discussed the continuing issue of the rapidly changing software landscape and the difficulty in creating content for multi-user VR software when the software's continued existence hinges on its mass adoption by a very small user base (p. 4).

In their review of VR literature Kavanagh et al. (2017), found that a number of papers referenced using VR for distance learning. While in many cases, these references deal with the perceived benefits or potential of VR for this kind of learning (see Clark, 2019), there have been a few research studies evaluating its actual use in practice. Urueta and Ogi (2020) found that VR was useful for task-based language distance learning, noting that when used correctly, VR can provide alternative immersive learning methods with a high level of student-teacher interaction" (p. 366). Berns et al. (2019) created a language learning VR environment focused on AI voice-activated 360-degree videos, providing opportunities for distance learners to immerse themselves in realistic 2nd-language environments and interact with virtual conversational agents. The 2020 coronavirus pandemic has shifted the focus of practically all education towards distance education, acting as a catalyst for research and practice searching for more effective methods of remote learning. VR is likely to receive more scrutiny for its ability to provide experiences that have become difficult in the current situation.

What are the challenges to applying VR in an educational context?

Lack of VR specific pedagogy. Though VR can be force-fitted into existing educational paradigms with some success, researchers agree that to use it to its potential for learning there needs to be solid pedagogy associated with VR. Hu-Au and Lee (2018) argue that if educators simply try to replicate "face-to-face didactic experiences of learning" (p. 223), this will only result in problematic implementation. Elmqaddem (2019) points out that "it will be necessary to know how to build and deploy educational programs that are well adapted to this technology" (p. 237). Scavarelli et al. (2020) remark that the greatest challenge in using VR is "determining how best to utilize this technology to better enhance students' learning in a manner that is not merely recreating, or replacing the physical classroom" (p. 17). Therefore, pedagogy needs to be developed directly for VR. Indeed, in many of the current works reviewing VR for educational purposes a common criticism is a lack of informed pedagogy underpinning use of VR.

This may also be a contributing factor explaining the mixed findings in the literature. Without a clear pedagogy as a basis for the underpinning instructional design of a given activity, it is difficult to evaluate the activity, as the methodology itself may not have been suitable for learning in VR. Even back in 2015, Fowler recognized the issue that "it is difficult, and some would say impossible to separate the technology from the pedagogy" (p. 421). This sentiment is still a valid concern today and is especially important as, at the time of publication of this article, the viability of using VR for education has dramatically increased as a result of falling prices and higher market penetration. Recognizing this, there have been recent developments on the development of a VR-specific pedagogy. First, Southgate's (2020) Actioned Pedagogy for Immersive Learning guides educators interested in VR to consider important questions about the teacher themselves, the learners, and the technology. Lege, Bonner, Frazier, and Pascucci (2020) developed a framework to analyze commercial off-the-shelf (COTS) VR applications to help educators successfully use them in the classroom. However, there is still a need for educators to apply these frameworks in a way that supports sound pedagogical application of VR. It is clear, however, that more research needs to be carried out to clearly ascertain what instructional needs VR can fulfil better than other mediums of instruction.

Though there is a need for a VR specific pedagogy, there are some common threads identified in the literature that provide clear pedagogical direction. Kavanagh et. al (2017) conducted an exhaustive review of publications focused on VR in education. Many studies they reviewed identified constructivism as justification for focusing on VR. Constructivism is "allowing students to construct their own knowledge from meaningful experiences" (Hu-Au & Lee, 2018). Constructivism's focus on providing meaningful experiences is a foundation for many hands-on educational approaches that are diametrically opposed to more traditional educational models that focus on rote memorization or test taking. Hu-Au and Lee go so far to say that education using VR "should be founded on constructivist learning models" (p. 223). Indeed, the immersive experiences of well-designed VR allow for learners to engage in meaningful experiences, which they then can use to develop their understanding of a subject. In Makransky, Terkildsen, and Mayer's (2017) science lab simulation study, participants received text-based instructions that they followed in a VR recreation of a science laboratory. This was followed by multiple-choice quizzes combined with actually completing the lab tasks in VR. They found "the VR group produced significantly higher ratings of presence than the PC group" (p. 8), but that this led to less learning of the target concepts. The design of this particular task may not have been suitable for leveraging the strengths of VR, which according to the tenets of constructivism should be focused on the experience itself, rather than on details presented through text prompts. Accordingly, another challenge facing educators and researchers is leveraging the unique affordances of VR through instructional and research designs that operate within models such as constructivism.

Cognitive demand. VR, in and of itself, is far from being a solution to the complex needs and demands of the educational sector. In fact, there are unique challenges to using VR.

The immersive capacity of VR is not only its greatest affordance, it is also a factor that may contribute to the difficulty of using it effectively. Pollard et. al (2020) remark that "higher levels of immersion sometimes do not improve learning performance" (p. 2). Parong and Mayer (2018) explain that learning is better in the absence of extraneous input, noting that the complex nature of immersive VR can lead to "extraneous cognitive processing" (p. 2), in turn detracting from the ability of the medium to promote learning of a specific concept. In their words, "Immersive VR may create so much extraneous cognitive processing that the learner does not have sufficient cognitive resources left to learn the essential material in the lesson" (p. 10). Makransky, Terkildsen, and Mayer (2017) observed that when participants of their study were using VR there was an increase on the processing demands of working memory that led to a decrease in knowledge acquisition.

Cognitive load (Sweller, 1994) is a real concern when using VR to teach a specific concept, as the human brain has finite resources to devote to a task. However, with the knowledge that this is a potential problem, educators can scaffold and take action to mitigate this issue. This is exactly what Parong and Mayer (2018) did in their study, by introducing summary tasks in between VR sessions. When they incorporated this, they were able to achieve the same learning outcomes as their control group, while maintaining the other positive effects introduced by VR, such as engagement and motivation. Carefully considering both cognitive demands placed on the learner and the learning outcomes is important when planning VR educational experiences. VR may not be the most suitable instructional medium, or it may be effective only when properly scaffolded.

Immersion breaking. While cognitive load is something that can be to an extent controlled through instructional design, there are other factors that can render VR ineffective for education. The degree to which a VR experience is able to immerse users depends on a complex confluence of factors stemming from both VR hardware and software. If this is not done well, the immersive benefits of VR can be diminished by illusion-breaking elements such as visual aberrations or low-quality 3D assets. Kavanagh et. al (2017), in their review of scientific studies related to VR in education, found that some studies indicated that if the VR experience was insufficiently realistic, "this may detract for the learning experience" (p. 102). This does not mean that every experience needs true-to-life, photorealistic visuals (many of the best VR experiences use a low-poly, simple color palette art style), but that there is consistency and a lack of visual elements that distract from the experience. If immersion is broken, learners are missing out on the primary reason to use VR in the first place.

It is also important to consider the technology's limitations in maintaining immersion. Low resolution displays, especially on mass-distributed VR experiences, can make visuals appear blurry and permanently out of focus. Visual aberrations and stuttering caused by complex visual environments can cause nausea, especially when users turn their heads too quickly. High temperatures, humidity and headset discomfort from extended use can all also break immersion by inducing sweat, fogging the lenses and irritating the skin.

Other considerations. While VR's popularity continues to grow, it is still a niche technology that may be unfamiliar to both students and teachers alike. Southgate et al. (2018) assert that teachers need to introduce VR into their classrooms in a measured manner, taking into account the novelty aspect and the need to address it before beginning the classroom activities proper. They state "Students needed time to play in (VR) to emerge from the novelty stage to familiarize themselves with its affordances and consider how these might be used in learning tasks" (p. 8).

Southgate et al. (2019) also draws attention to the need to focus on gender when considering VR for classroom activities, especially in secondary education. "Girls were much less likely to have had previous exposure to VR with a HMD, and wearing the HMD was problematic for a small number of girls who found it uncomfortable or 'embarrassing'" (p. 28). Issues surrounding femininity, masculinity, and "the male gaze" need to be accounted for in a medium that prevents the user from being able to see the gaze of others and how they themselves appear to others in the classroom while they are present in VR.

Conclusion

Technology continues to evolve rapidly, changing everyday norms and influencing every facet of human existence. Even simply being aware of the latest technological innovations can be daunting, and applying the technology even more so. The field of education often adapts to change more slowly than other sectors, but always inevitably transforms to embrace or accommodate change. New technologies, once consigned to the fringes of education in the hands of tech-savvy teachers, often become part of the mainstream paradigm. Digital delivery of lessons through video conferencing software once fell into this category, but now has become an educational norm. VR has now begun this transition from a fringe technology to a technology capable of being used in mainstream practice. The VR of 5 years ago is radically different from the VR of today, meaning that beliefs and common assumptions about the technology may in actuality be entirely false. Educators would do well to stay abreast of advances to the technology and avoid dismissing VR as a gadget for only the "tech teachers." VR has matured to a point where it is not only theoretically useful for educational purposes but has clear practical applications. Falling costs, mass-market availability, and improved immersive capabilities mean that VR is not only feasible, but practical for educational use.

Whilst there are now clear applications and pedagogies developing around VR, there remain important considerations and challenges unique to the technology. VR is still new enough that it retains a novelty factor when used in classrooms. Upon initial use, teachers may observe high levels of student engagement and motivation and see this as the primary benefit of the technology. However, it is imperative that educators move beyond this honeymoon phase and focus on the pedagogies and experiences that VR makes possible. Without clear pedagogical justification and student outcomes in place, VR can become just a diversion or distraction.

The 2020 coronavirus pandemic has also highlighted just how much global issues can impact educational models. VR, in particular, is a device that students wear, meaning that especially in the current situation, sanitation is a huge concern; possibly rendering the concept of a classroom set of VR headsets obsolete. Instead, VR has been receiving attention as a tool for distance education and home study. It may become a key player in a post device era "where digital technology use diversifies beyond the dominance of laptop/tablet/smartphone use" (Godhe, Lilja, & Selwyn, 2019, p. 1). The ingrained weaknesses that are part of current educational technologies are creating a niche, one that may just be filled by VR.

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