Cornell University

The Utility of Virtual Reality Systems in Education

Affordances, Challenges, and Future Innovations to the Virtual Experience

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Introduction to Virtual Reality Systems

The virtual reality system is an innovative display medium that immerses the viewer into a seemingly three-dimensional virtual environment; it is often equipped with interactive sound and visual stimuli, and requires physical movements by a user to interact with the environment. The most common way an immersive experience can be accessed is through a private headset, which commonly covers the entirety of the user's eyes and ears. The mounted headset provides a screen close to the eye and displays a rendered image of the digital environment. The image then changes in parallel to the position of the user's head, creating a real-time panoramic view that appears like an interactive environment. In addition to the user's head direction and tilt, the user's location relative to the physical space they are in, hand motions, and sometimes vocals, are tracked with sensors; and the displays in front of your eyes change in relation, mimicking the ever-changing visual plane one would see in reality.

Virtual reality (VR) is projected to be used in numerous applications, ranging from the entertainment industry, to emotional therapy. This study was conducted to understand and establish the placement of VR systems in the educational field.

An investigation of studies conducted at various educational establishments around the globe determined that there are many different perspectives by which the utility of VR can be explored, most of which communicate that VR cannot currently be an effective educational tool, but could be in the future.

To summarize the similarities of the studies, most research was conducted on college-age students, at a respective collegiate-level educational environment. Studies also followed a very similar methodology. Before the educational process, researchers had participants complete pre-assessments for a specific genre of material, which would most commonly appear in the scientific genre. Participants would then proceed through a learning phase, by which they may or may not have utilized VR environments to study the material. After completion of the learning phase, participants completed a post-assessment. Researchers analyzed the respective data for any conclusive evidence of the benefits or detriments of a virtual educational model of the concept.

For this study, VR system refers to a user viewing the medium of display by which the user is completely immersed in a digital environment. The user must use technological modes to interact with such an environment; and thus, cannot perceive the majority of the physical environment in which they are actually in. A VR interaction, or experience, refers to the act of learning or the interactive process a student undergoes when engaging with a VR system.

Affordances of Immersive Technology

Cornell Communications Professor, Andrea Stevenson Won discusses that typical classroom settings can interfere with classical demonstrations of information. In the case of chemistry, old chemicals or materials can result in experimental failure for students; furthermore, some resources are too costly to be accessible to students.[1] Won continues to say that even with access to resources, instructors can waste copious amounts of time trying to physically set up a demonstration. And even when the demonstration is successfully enacted, students can be distracted by other peers or other factors in the classroom.

VR can offer students what Won calls “a very pure learning experience”[2]. A majority of a user’s surroundings -distractions included- are easily removed by the VR system. The student is more directly engaged and focused toward the learning experience due to the fact that the VR

[1] McKee, Doug, Edward O’Neill, and Andrea Stevenson Won. “Virtual Reality and Teaching with Andrea Stevenson Won.” Audio blog post. Teach Better Podcast. Teach Better. Doug McKee and Edward O’Neill, 7 Mar. 2018. Web. 27, Jan. 2019.

[2] Ibid.

experience is individualized by a headset. In addition, Won claims that “learning is much better when there is text with illustrations, close to each other” and that VR affords this well because text can appear on top of or alongside your visual stimuli.

A majority of the studies consulted stated as their hypothesis that VR would allow for students to conceptualize temporal and spatial relationships more easily. In a study focused around teaching chemical structures, educator Zahira Merchant and her team argue that, “that both components of spatial ability, spatial relation and spatial orientation, play a significant role in chemistry performance” and that perhaps this understanding can be improved by the interactive visualization of the VR experience.[3]

Similarly, Associate Professor Wadee Alhalabi, at King Abdul Aziz University highlights that VR interactions “[allow] users to live through experiences that they could not have gained through the real world for multiple reasons such as risk, high cost, lack of time and others”[4]. This argument is evident in educational topics involving astronomy; students are provided an environment to study physical objects considerably distant, such as the Moon, using a digital rendition that provides it within an arm’s reach. In addition, Alhalabi offers that “VR techniques contribute to ensuring a substitute for the human body”[5] in the medicinal field. Not only can VR environments provide physically or monetarily unattainable resources, but it can also produce suitable environments conducive to failure, and repetition.

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[3] Merchant, Z., Goetz, E., Keeney-Kennicutt, W., Cifuentes, L., Kwok, O. and Davis, T. (2013), “Exploring 3-D virtual reality technology for spatial ability and chemistry achievement”. Journal of Computer Assisted Learning, 29: 579-590. doi:10.1111/jcal.12018, Web. 4 Apr. 2019., 580.

[4] Alhalabi, Wadee. “Virtual reality systems enhance students’ achievements in engineering education”. 10 July 2016. Behavior and Technology. VOL. 35, NO. 11, 919-925. 26 Jul. 2016. DOI: 10.1080/0144929X.2016.1212931 Web. 18 Feb. 2019., 920.

[5] Ibid., 921.

The Cost of Accessibility

In light of the observed affordances of VR, there are also challenges of VR educational integration. And, it is illuminating to note the location wherein such technology is accessible to educators. General education mainly takes place within facilities such as primary and secondary schools, and colleges —which is why the majority of studies consulted are located there. However, of all facilities available, the locations observed have relatively large endowments. Given Cornell University's 7.2-billion-dollar endowment[6] and King Abdul Aziz University's one-billion-dollar endowment[7] as just a few examples alone, it is evident these research institutes are extremely well funded. Cornell itself ranks as having the twelfth most funded research program in the United States on renowned college ranking website, TheBestSchools.org.[8] The average VR headset alone on the market costs about 450 dollars[9], in addition to computers and rooms to use and house such resources.

It would be a costly investment to provide students each their own individual headset, and thus it is justified that many of the studies referenced only one classroom, or course, where students participating. The current price of VR technology hinders the accessibility of the platform, and thus cannot be judged as an overarching, monumentally impactful, educational procedure if only select students can use or afford it.

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[6] Lefkowitz, Melanie. "Cornell Sees 10.6 Percent Return on FY18 Investments." Cornell Chronicle, Cornell University, 3 Oct. 2018, news.cornell.edu/stories/2018/10/cornell-sees-106-percent-return-fy18-investments#. Web. 5 May. 2019.

[7] Times Higher Education. "King Abdulaziz University: Key Facts." *Times Higher Education (THE)*, 15 May 2018, www.timeshighereducation.com/hub/king-abdulaziz-university/p/key-facts.

[8] Barham, James A. "The 100 Richest Universities: Their Generosity and Commitment to Research 2018." *The Best Schools*, TheBestSchools.org, July 2018, thebestschools.org/features/richest-universities-endowments-generosity-research/. Web. 8 May. 2019.

[9] Greenwald, Will. "The Best VR Headsets for 2019." *PCMAG*, 30 Apr. 2019, www.pcmag.com/article/342537/the-best-virtual-reality-vr-headsets.

The Issue of Quantifying Knowledge

Another issue noted is the objective of detecting, measuring, and comparing students' cognitive behavior in order to make a conclusion about how successfully they have learned a new concept. In this paper an analysis of a student's ability to conceptualize, retain, and apply, a new concept will be referred to as the quantification of "successful learning". The simplest of measures conducted to evaluate successful learning is to have participants complete a paper exam at the introduction and conclusion of the study.

Researchers at Cornell University, who worked alongside Professor Won, had 172 college aged students compete a study centered on phases of the Moon.[10] As their method of investigation, the 172 participants were divided into three main groups, the first of which, would learn through a VR environment. The next group learned through a "hands-on" model using a ball attached to a stick, with a light source that mimicked the Sun and Moon interaction.[11] Lastly, the third group learned the Moon phases through a desktop simulation. After comparing the pre-test and post-test scores, their study concluded that there was no statistical difference between the individual learning processes. However, in light of the failure of the VR experience, the Cornell researchers proposed an interesting argument: "while the non-significant difference between conditions does not indicate virtual reality as one that enhances learning over traditional methods, it does show that VR can perform just as well."[12] VR can be considered a failure from a perspective where it is required to allow students to perform better than classical methods.

[10] Madden, Jack H., Andrea Stevenson Won, Jonathon P. Schuldt, Byungdoo Kim, Swati Pandita, Yilu Sun, T. J. Stone, and Natasha Holmes. "Virtual Reality as a Teaching Tool for Moon Phases and Beyond." Physics Education Research Conference 2018. Washington, DC: 2018. of PER Conference. 27 Feb. 2019 <https://www.compadre.org/Repository/document/ServeFile.cfm?ID=14819&DocID=4966>., 2.
[11] Ibid., 1.
[12] Ibid., 4.

However, VR can be perceived as a success from the argument that students are able to learn just as well through the VR experience as they can with other, already familiar, methods.

Merchant and her team also held a study involving 408 college students in a similar manner.[13] Students were "administered an 11-question chemistry achievement test and two measures of spatial ability (Purdue Visualization of Rotations Test, Card Rotations Test)".[14]

The researchers provided some participants with software that allowed them "to see molecules in a [three-dimensional] perspective by copying, linking and rotating the molecules"[15]. They compared these participants against a control group who have been provided printed images of the molecule structures instead. After examination, their conclusion stated that "the results [show] that there were no statistically significant differences in the pretest scores on any of the measures of students' knowledge"[16] —which included five different exam subjects related to the three-dimensional structure of molecules.

In both studies highlighted, it was deduced that VR is no different than other types of learning methods. When the pre- and post-assessments were analyzed, there appeared no benefit or cost to learning through the VR experience. The lengths taken to provide a sufficient measure of successful learning is admirable. The assessments allow for easy quantification of whether a concept is known or not and are easily distributable to large amounts of students. However, the examination process is rudimentary, and lacks a breadth of coverage when discussing all the parts of an effective learning experience.

[13] Merchant, Goetz, Keeney-Kennicutt, Cifuentes, Kwok, and Davis. "Exploring 3-D virtual reality technology for spatial ability and chemistry achievement"., 582.
[14] Ibid., 579.
[15] Merchant, Goetz, Keeney-Kennicutt, Cifuentes, Kwok, and Davis. "Exploring 3-D virtual reality technology for spatial ability and chemistry achievement"., 584.
[16] Ibid., 585.

Referencing Merchant and her team once more, they note in their discussion an important factor in regards to assessing information recognition. They state that "although the goal of imparting the instruction in [three-dimensional] virtual environment was to allow students to think in a [three-dimensional] space, the assessment method used to evaluate their learning used a [two-dimensional] format"[17].

Students using the VR platform develop knowledge of concepts spatially and temporally, as if to interact with objects in a real environment with depth and field. The examinations presented to students, designed to measure understanding, eliminate the spatial tasks students were required to perform in practice. The professors continue to say "the students in the virtual reality environment may have developed the ability to think in a 3-D space but not the ability to articulate this understanding when assessed using 2-D assessments. This highlights the importance of designing assessment strategies that are consistent with the format in which the instruction was imparted"[18].

Cognitive Load

Educator Liou Hsin-Hun conducted a study with ten and eleven-year-old students located in a primary school in Taiwan. Her process is unique due to her methodology of measuring successful learning. She references the "Cognitive Load Theory" (CLT), an educational theory that investigates different "cognitive loads" undertaken while learning. An "intrinsic load" is determined by the learning content itself, a "germane load" is the process by which "learners process new information and then integrate it into their knowledge structures", which is equally integral to learning new material. She says, "appropriate instructional activities and material

[17] Ibid., 588.

[18] Merchant, Goetz, Keeney-Kennicutt, Cifuentes, Kwok, and Davis. "Exploring 3-D virtual reality technology for spatial ability and chemistry achievement"., 588.

design can minimize the extraneous load"—material that does not benefit learning— "and maximize germane load to ensure effective learning"[19].

Compared to the studies surrounding Moon phases and molecule structures, Liou investigates is a different perspective by which to quantify the educational process. She and her team consider the amount of energy required to process material within her results. She states that CLT "is one of the fundamental theories used to analyze the mental effort and predict the learning effectiveness with new technologies". To describe why this aspect may be significant they discuss that, "the students may have the similar intrinsic loads [when learning,] because they processed the same complexity of the learning contents. However, they may have different degrees of mental effort, in terms of the extraneous and the germane load, because they were requested to handle different amounts of multimedia objects".[20]

It is imperative to consider the amount of mental effort it takes a student to also learn the material, extraneous of its intrinsic load. In this sense, there is another degree by which successful learning can be benefitted or undermined by introducing a new form of technology. Liou continued to say, "such a difference [in mental effort] may cause the students have different levels of extraneous and germane load so that their learning effectiveness might be affected"[21].

In an effort to capture this extraneous load, Professor Merchant and her team indirectly tried to compensate for what Liou discussed. They included a survey for which students have had "gaming experience" prior to their study. Experience with gaming environments tend to engage similar spatial and temporal interactions to that of immersive reality environments, and thus

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[19] Liou, Hsin-Hun, et al. "The Influences of the 2D Image-Based Augmented Reality and Virtual Reality on Student Learning." *Journal of Educational Technology & Society*, vol. 20, no. 3, 2017, pp. 110–121. Web. 1 Mar. 2019., 113.

[20] Liou. "The Influences of the 2D Image-Based Augmented Reality and Virtual Reality on Student Learning., 113.
[21] Ibid., 113.

could potentially provide an advantage to such students when learning by engaging the same skillsets. They considered this effect on their results, however found that there was no significant advantage to these students[22].

What the team did find, however, that students without gaming experience, or low-spatial ability, improved their knowledge of chemical structures to a greater degree than that of students who considered themselves “gamers”. When considering the cognitive load required for a student to process information, a three-dimensional production of information allowed students to visualize and interpret three-dimensional concepts more easily. Although this result contradicted their hypothesis, researchers said that, “[this] highlights the effectiveness of the instruction delivered in the three-dimensional virtual reality environment because students who had the most difficulty conducting two-dimensional mental rotation were now able to think in a three-dimensional space and translate the same into two-dimensional perspective after receiving spatial instruction in [three-dimensional virtual environment].”[23]

Furthermore, in Won’s study, they elicited feedback from participants about their experience interacting with the technology, which verbalized the cognitive loads that students carried throughout the process of learning. One participant in particular said, “[having] a overall space to see where everything is helps a lot. Even in class I still had a hard time understanding what they are talking about in concept. But I think I learned a lot in VR and being able to manipulate the environment on my own accord",[24] which parallels the findings previously mentioned by Merchant and her team. The platform helps students who have difficulty

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[22] Merchant, Goetz, Keeney-Kennicutt, Cifuentes, Kwok, and Davis. “Exploring 3-D virtual reality technology for spatial ability and chemistry achievement”., 587.
[23] Merchant, Goetz, Keeney-Kennicutt, Cifuentes, Kwok, and Davis. “Exploring 3-D virtual reality technology for spatial ability and chemistry achievement”., 587.
[24] Madden, Won, Schuldt, Kim, Pandita, Sun, Stone, Holmes. "Virtual Reality as a Teaching Tool for Moon Phases and Beyond”., 3.

conceptualizing three-dimensional ideas, by providing a model in a spatial and temporal capacity and decreasing the germane load students must undertake to absorb information.

Another participant in Won's study complains that, "since I'm very new to [interacting with virtual reality systems] I spent most of my time just trying to figure out how it worked." This illuminates another challenge provided by virtual reality: it is unfamiliar. Extra effort has to be undertaken to learn how to first interact with the platform, and only once fully understood, can the participant understand how to learn from it. The VR experience can be highly distracting and disorienting to those who have never used the system, which undermines the entire intention of learning with it.

It is essential to consider the cognitive efforts students undergo while trying to interact with the VR system itself. Immersive technology still largely unfamiliar to in the educational system; there are most times an orientation period where users must orient themselves to interact with the digital interface. Such requirements and confusions can hinder the student from learning the underlying educational content of the environment itself. However, similar to the penetration of other new technologies to the market, once VR systems are as commonplace as cell phones or computers, the users will begin to understand how to interact with this emerging technology more efficiently, simply, and develop a mental model of interaction. Once this takes place, virtual reality systems may be able to afford much more for the educational environment.

Spectacle

In continuation with participant feedback to Won's study, another participant exclaimed that once in the immersive environment, "it was almost too overwhelming and it was as if I was too excited to be in space to actually commit to learning the moon phases".[25] The participant

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[25] Madden, Won, Schuldt, Kim, Pandita, Sun, Stone, Holmes. "Virtual Reality as a Teaching Tool for Moon Phases and Beyond"., 3.

verbalized the emotional reaction VR users can have while interacting with the technology. As with the other participant's feedback, it is evident that not all reactions towards VR contained as much positivity.

In regards to the studies consulted, whenever researchers asked students what method they preferred or would have preferred to learn from, participants chose virtual reality. At Cornell, 78.2% of the study participants answered that VR was their preferred method to learning, compared to a computer simulator, or model demonstration.

In addition, Associate Professor Wadee Alhalabi at King Abdul Aziz University compared the results of varying degrees of visual immersion. Visual stimuli for participants ranged from a wall mounted system, a head mounted system with three degrees of freedom, and another head mounted system with six degrees of freedom[26]. Their study allowed for participants to repeat any five-minute-long technological interaction voluntarily. He found that the head mounted display with six degrees of freedom was repeated on average 4.98 times, whereas the head mounted system with only three degrees of freedom was repeated 4.46 times. The control group with no technological interaction was repeated on average 1.63 times.[27]

The number of times a process was repeated could communicate the following of many arguments. Firstly, participants could repeat a process if it was hard to understand or interact with. If a concept was not understood at the first try, students might be inclined to revisit the program. This would then provide another example of the extra cognitive load undertaken by students using an unfamiliar system. Secondly, another motivation for a participant to return to the VR experience would be their interest in the particular method. Similar to the results found in

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[26] Alhalabi. "Virtual reality systems enhance students' achievements in engineering education"., 922.
[27] Ibid., 924.

Won's study, students at King Abdul Aziz University are also attracted in particular to VR systems.

In 2019, VR is considered a largely disruptive technology. It is showcased in news articles, movies, television shows, advertisements, and many more. In addition to mass coverage, media outlets hypothesize the great potential of the new technology and speak positively about its social disruptions. For example, Sol Rogers for Forbes business magazine produced an article rather enthusiastically titled, "Five Ways VR Is Making The World A Better Place", saying that, "virtual reality can change what a person sees, how they think, what they feel and even how they behave"[28].

An article published by "AlltheResearch", a leading market research provider, expects that the global marker for VR systems will grow by 40.5% every year.[29] In addition the articles like Sol Rogers', many articles similar to "AlltheResearch" urge their readers to watch for particular trends and changes in the VR platform, as it might be a beneficial to track its technological transformation.

Due to the coverage and outlook of its potential uses, VR has an allure to its users, students, educators, and businesses alike. Compared to the results of the various studies investigated, it is evident that the technology is fetishized due to several factors. Its unfamiliarity, potential impact, and constant reformation intrigues many. However distracting a student's excitement may be towards interacting with a VR system, it is another mode by which this VR is

[28] Rogers, Sol. "Five Ways VR Is Making The World A Better Place." *Forbes*, Forbes Magazine, 7 Mar. 2019, www.forbes.com/sites/solrogers/2019/03/07/five-ways-vr-is-making-the-world-a-better-place/#1c08db4e69a9.
[29] AllTheResearch. "Global Augmented Reality and Virtual Reality Market-2016-2023." *AllTheResearch*, May 2019, www.alltheresearch.com/report/4/-market.

beneficial to educators. An increase in a student's interest and enthusiasm towards learning can be considered beneficial to successful learning as well.

For the Future

Similar to any emerging technology, VR is constantly evolving and being improved upon. In consideration for the brevity of the VR qualities analyzed, all research journals consulted were published within the past six years, most of which were publish earlier this year, 2019. This investigation refers to the most current abilities and effects of the VR system, but its conclusions cannot be made final because of how VR technology intends to change. Although there have been many concerns addressed about the effectiveness of VR systems in an educational environment, it highlights several opportunities for improvement that can help VR afford much more for students.

As investigated at King Abdul Aziz University, varying degrees of sensory interactivity and physical freedom has an effect on participant's ability to absorb information. Although there was no correlation between the degree of immersion and success of learning, it is not erroneous to hypothesize that a more realistic and fluid user-environment interaction can lead to a better learning experience. Currently systems lack many life-like qualities; there are challenges ranging from environment building, texture rendering, to user controls. When extracting VR systems to its core elements, it is more similar to a 360-degree panorama around the viewer, than with reality itself.

Companies such as Facebook have communicated interest in the emerging VR market, and have produced several papers on their contributions and forecasted improvements to the product. They are focus on creating even more life-like interactions such as the retinal blur[30] in

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[30] Chapman, M., Fix, A., Kaplanyan, A. Lanman, D., Xiao, L., "DeepFocus: Learned Image Synthesis for Computational Displays." *Facebook Reality Labs*. Web. 8 May, 2019., 1-13.

human vision, and simulating your entire body and facial movements[31]. Like many other investors of the technology, Facebook aims to improve user-interactivity, which will greatly decrease germane cognitive load required for students to interact with this platform in classrooms.

Additionally, as VR matures as a technology, it will become more accessible to students. To assess the extent to which it helps with successful learning, the breadth of its reach can also be considered. It was investigated whether or not any studies about VR effectiveness were carried out in developing countries as different cultural environments can have an overwhelming influence on all aspects of a student's interaction with immersive technology. However, no definitive evidence was able to be recovered, and most coverage about VR remained in highly developed locations — it is very costly, and more of a luxury item than an everyday commodity. This platform is only accessible to locations where there are plentiful resources and higher standards of education. It can be speculated that if this platform were provided to less fortunate areas, it could provide much more or less benefit. However, in developed countries alone, when the VR system becomes cheaper and popular on the market, it will be able to offer a more substantial impact to the educational system by being more accessible to students from varying socioeconomic backgrounds.

Lastly, when analyzing whether students have successfully learned a concept, it is imperative to examine the student in the same way they learned it. Meaning, that there may be a loss of conceptual understanding or application when a student must transfer their three-dimensional knowledge to a two-dimensional evaluator. In the future, benefits of virtual reality may be observed when students practice their knowledge in a three-dimensional space. This

[31] Toothman, N., Neff, M. "The Impact of Avatar Tracking Errors on User Experience in VR." *Facebook Reality Labs*. Web. 8 May, 2019., 1-11.

argument is evident in areas of study where students are eventually required to apply these skillsets such as architecture or mechanical engineering. In these fields, students are encouraged to use digital visualization within their course of study, and then apply their knowledge to a structure in reality. Once all dimensions of the learning process are considered, and the long-time effects of a virtual educational interaction, can the true value of the platform be assessed.

Conclusion

This investigation considered varying results, with little legitimate evidence of success of virtual reality in education. Arguments provided for a successful interaction appeared biased, and all studies lacked sufficient diversity and controlled variables to easily decipher why the VR experience was successful or a failure.

The weakness of existing studies is the process by which successful learning is measured. There are many degrees and perspectives to which successful learning can be interpreted. Length of concept remembered, successful application of a concept in reality, the number of students affected by the platform, and enthusiasm for students to learn a new concept can all be evaluated when weighing the impact of the platform.

Ultimately, there is no definitive way to accurately quantify a successful learning experience. There are immeasurable direct and indirect impacts, such as the cognitive load and cultural and socioeconomic factors, that affect a student's ability to understand a new concept. If a study were to revert to the simplest of measures of successful learning, however, researchers may choose to measure the ability for a student to remember a concept. This has been evaluated using pre-tests and post-tests during previous studies, but future studies should eventually evaluate a student when actually Appling a concept in three-dimensional space.

In succession to all of these improvements, once VR systems become more popular in the global market, they will be a more distinctly positive impact offered by VR systems. More so, when the quality of VR systems and interactions improve, there may be a more easily processable learning experience as well.

Given the outlook for what improvements are to come for this platform, there can be confident expectation that the affordances of virtual reality systems will continue to grow, especially in the educational field.

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