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Review

The Application of Virtual Reality in Engineering Education

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Abstract: The advancement of VR technology through the increase in its processing power and decrease in its cost and form factor induced the research and market interest away from the gaming industry and towards education and training. In this paper, we argue and present evidence from vast research that VR is an excellent tool in engineering education. Through our review, we deduced that VR has positive cognitive and pedagogical benefits in engineering education, which ultimately improves the students' understanding of the subjects, performance and grades, and education experience. In addition, the benefits extend to the university/institution in terms of reduced liability, infrastructure, and cost through the use of VR as a replacement to physical laboratories. There are added benefits of equal educational experience for the students with special needs as well as distance learning students who have no access to physical labs. Furthermore, recent reviews identified that VR applications for education currently lack learning theories and objectives integration in their design. Hence, we have selected the constructivist and variation learning theories as they are currently successfully implemented in engineering education, and strong evidence shows suitability of implementation in VR for education.

Keywords: virtual reality; VR labs; engineering education; learning theories; constructivist learning theory; variation learning approach; university education

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1. Introduction

Virtual Reality (VR) technology has evolved drastically over the years by reduction in the form factor, whilst increasing in features and power. The technology's popularity in gaming platforms is highly established nowadays, however, it is also gaining interest in the fields of education, training, and healthcare. The interests arise as a result of the immersive experience and sense of presence, the feeling of being transported to the virtual environment, and losing connection to the physical world [1]. This paper argues that VR is an excellent tool for engineering education in the form of a blended learning approach in comparison to a traditional learning approach, due to its learning and cognitive benefits. In addition, the paper acknowledges the research gap identified by a systematic review of current papers which concludes that learning theories are often not considered during the design of the VR application [2], and efforts and research must take place to evaluate VR technology with emerging teaching and learning approaches [3]. Finally, the paper argues that learning theories and approaches can be implemented in the VR application design and recommends the constructive and variation learning theories/approaches with evidence of their success from multiple research papers.

In addition, the reduction of VR costs from an expensive technology available to a niche of researchers [4,5], to being available to consumers at an affordable price, makes it attractive as an economical alternative or complementary solution to the more expensive and sophisticated laboratories used in education. Therefore, this paper looks at evidence from multiple publications such as those using VR labs and arguing that the learning experience is better than traditional [6–8] while others argue that the learning experience is at least on par [9,10]. Lastly, the benefits of being affordable and as good as the physical laboratory opens new doors for distance and remote learning improvement, which will give the universities an edge in terms of their international offerings and use of technology in education, are also discussed in this paper.

Having said that, there are excellent potential benefits pedagogically and economically through integrating VR in university curriculum, especially considering the added benefits in the learning experience and the potential cost reduction and expansion in terms of experimental offerings. Hence, this paper carefully collects, studies, and analyses the most recent publications in terms of VR use in education, benefits, drawbacks, and research gaps, and uses it as grounds for the applicability of VR for engineering education. The findings are significant as the systematic review papers that are analysed point towards a gap in the deployment of the VR technology which greatly reduces the pedagogical benefits to students in education broadly and engineering education specifically. Hence, this review paper suggests with confidence a theoretical approach based on analysing recent research papers through inclusion and exclusion criteria, to closing the gap, and unlocking the full potential of VR in engineering education.

2. Past to Present

Virtual Reality (VR), in simple terms, is a computer-simulated environment which enables the user to interact with and alter their perception as a result of a mixture of sensory information sent to the human brain [11]. VR, as it exists today, is a result of many years of technological and microprocessors development capable of high-level computation at an affordable price. It started in 1960 with Morton Heilig's invention of a multi-sensory simulation device called Sensorama [12]. Sensorama is a stationary version of what is known today as a Head Mounted Display (HMD), where it plays a pre-recorded movie on a stereoscopic 3D display, with stereo sound, fans, scents generator, and a vibrating chair to stimulate the user's senses and "immerse" the user into the movie [13]. Fast forward to 1984, the first monochrome stereoscopic HMD called as Virtual Interactive Environment Workstation (VIEW) lab was created by Scott Fisher at NASA's Aerospace Human Factors Research Division [11,12]. VIEW resembled all the elements used today in a HMD including audio, body tracking, tactile and forced feedback, and connections to telerobotic systems, which made it interactive, in contrast to previous devices [14]. In the field of professional education and training, a dramatic surge of interest in VR took place in the 80s [15], which was followed by VR's appearance in higher education in the 90s in projects such as ScienceSpace Worlds, Safety World, Atom World, etc. [16].

Until the appearance of commercialized high-end VR systems such as Samsung's Oculus Rift and HTC's Vive in early to mid-2010s, VR systems were accessible only to a niche of researchers and for thousands of dollars, which prohibited its commercialization [4,5]. Today, VR is as cheap as $15, through a constructible HMD made of cardboard, sold by Google under the name of Google Cardboard [17]. According to Carruth [5], these commercialized high-end VR systems are tethered to a high-end PC at all times that makes it capable of offering high frame rates, attractive environments, and support different user interaction options. However, they are limited to a small area of the PC's proximity and require a significant amount of computational power, which comes at a great cost [5]. A more affordable VR solution is VR-ready mobile devices (smart phones) that enable the user to have lower VR experience due to the lower processing power, at a much lower cost [2,5,18,19]. Additionally, the user benefits from cordless (no cable) connection, and a higher degree of movement VR experience [5]. The main difference is the lower degree of immersion from the low-end in comparison to the high-end mobile VR HMDs [20,21].

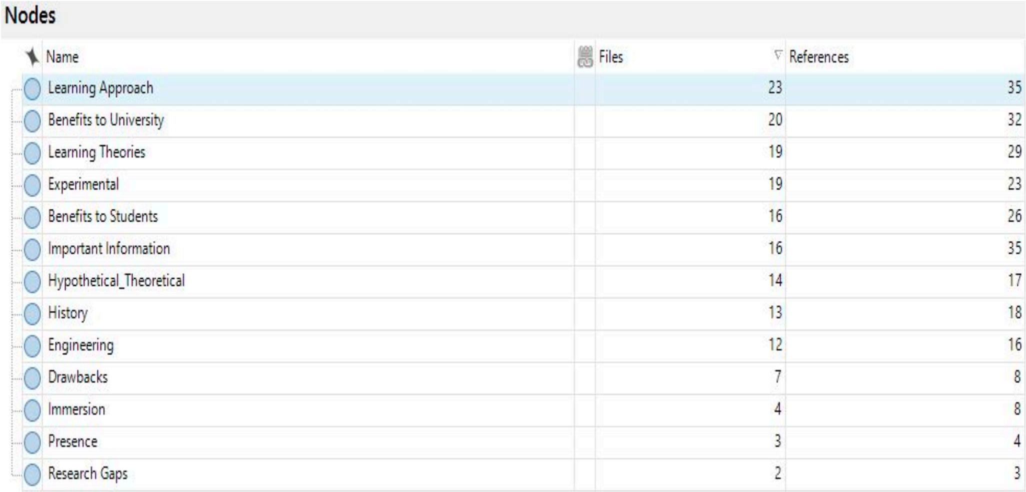
3. Immersion and Presence

Immersion is an important attribute of a VR experience and commonly defined as disconnecting the user from the real world and giving them a sense of being/presence in the virtual world [2,11,22] and is often referred to as Spatial Immersion [19,23]. Contrary to popular belief, immersion and presence are different from each other [24]. Slater [25] explains the difference through the use of colours, where a human's colour perception is different (presence), although that particular colour has a unique wavelength which defines it (immersion). In terms of VR, people can experience different levels of presence from the same immersive experience, similar to the colour example, and is defined as "human reaction to immersion" [25] (p. 2). Hence, presence relates to the amount of sensory modalities engagement, which are activated by the physical properties and the close resemblance of the virtual environment to the real one, known as immersion [25]. On the other hand, McMahan [26] argues that immersion is not limited to the physical dimensions or properties of the system, rather, it is related to the user's response to the narrative. In Janet Murray's explanation, immersion is a result of our brain's indulgence in the narrative to an extent that it transports us from the current space to the virtual environment [27]. McMahan [26] further argues that there are levels of immersion and that the system does not need to have a complete "photo- and audio-realism" (p. 68) for it to be immersive; rather, the narratives are set to align the user's expectations and actions to the conventions of the virtual world to achieve immersive experience. In contrast, Wirth, et al. [1] argue that presence as a term is often confused, and its definition depends on the academic discipline. Hence, they prefer using the term spatial presence as it closely matches the VR effect of being present in the virtual world [1]. They also argue that spatial presence can be achieved by closely mimicking the real environment visually and audially, as well as through the psychological involvement of the user through the activation of sensory modalities [1]. By looking at all these arguments, we can deduce that: the VR application must utilize features such as stereo sound, stereoscopic vision, realism, large field of view, high frames refresh rate (FPS), and head tracking, in order to engage sensory modalities to both immerse and transport the user away from the real to imaginary environment. It also must include narrative elements that sets users' expectations and aligns it with their actions, with the conventions of the virtual world to maximize their immersive experience.

4. Brief Review Methodology

Two databases were used to search for recent research studies in VR, which are ScienceDirect, and Taylor and Francis. Both are well established databases containing a large number of publications with high popularity. The reason for this selection was that ScienceDirect is more scientific and likely to find papers relating to engineering and VR applications, while Taylor and Francis is more social-sciences-biased and likely to contain papers relating to education and learning theories. The keywords used to search for the publications were: Virtual Reality, VR, Education, Engineering Education, and Immersive Reality. The publications were filtered firstly by title relevance to VR applications in education, followed by a more thorough filtering by skimming through the abstract, findings, and conclusions. From the second stage of filtering, many publications that relate to VR applications in the medical field and education, industrial training, and defence training were eliminated. Finally, secondary references were greatly used, especially the ones in the recent systematic review of papers that have crucial findings in relation to this review. The main analysis of the selected papers was based on the audience of higher education, whether a VR application is developed and tested or not, the environment in which the VR application was being used, the advantages and disadvantages of each tested application, and recommendations and future development. The discussions from Section 4 onwards are based on the analysis of the selected publications, followed by a conclusion.

From our search in the two databases, we have collected 100 research papers (including review-type papers), based on the title relevance to VR applications in education. Initial analysis carried out by going through the papers yielded an additional 40 papers and seven books, from secondary referencing. The second stage of filtering yielded a reducing to 72 papers and books, which are referenced throughout this paper. We have followed a strict methodology where we firstly adopted inclusion and exclusion criteria, followed by coding the included publications into key coding areas. The inclusion and exclusion criteria contain: (1) inclusion of publications thematically related to engineering education, and excluding industrial applications and training, medical, nursing, psychological, and healthcare training and education, entertainment, etc., (2) inclusion of a conducted experiment using VR and/or VR labs, (3) inclusion of a learning approach, (4) inclusion of learning theories in engineering education, preferably with adoption in VR or similar, (5) exclusion of augmented reality and/or a combination of immersive reality technologies. The coding areas are: learning theories, immersion, presence, learning approach, experimental, hypothetical/theoretical, student benefits, university benefits, drawbacks, research gaps, engineering, history, and important information, which are all shown in Figure 1. Then we proceeded to code the papers through Nvivo software, and we were able to correlate between the areas and determine the applicability of VR in engineering education. The main focus was on the systematic review papers, which had major findings in terms of the technology design and research gap, while the secondary focus was on the papers that have tested VR in education and their design, learning approach, and findings. These research papers where key to understanding the correlation between the different learning approaches (traditional and Blended Learning Approach (BLA)) and laboratory work that are discussed in the following section. Finally, through coding, we were able to pinpoint a widely used and a novel form of learning theory/approach that are currently used in engineering education, and have been adopted by multiple research papers in their simulations with analysis on the effects on students. Hence, we were able to correlate all the areas together to come up with a critical finding that may aid VR applications to become more useful in engineering education and be widely adopted.



Nodes

Name	Files	References
Learning Approach	23	35
Benefits to University	20	32
Learning Theories	19	29
Experimental	19	23
Benefits to Students	16	26
Important Information	16	35
Hypothetical_Theoretical	14	17
History	13	18
Engineering	12	16
Drawbacks	7	8
Immersion	4	8
Presence	3	4
Research Gaps	2	3

Figure 1. Nodal coding in Nvivo Software.

5. Learning Approaches

In trying to understand the applications of VR in engineering education, we must first carefully look at the current engineering education delivery method(s), which will be referred to as the traditional learning approach in this paper.

5.1. Current Delivery Method and VR Potential

The traditional approach for teaching engineering students is done through lectures/seminars usually in a classroom/auditorium, where the instructor explains the required material to a varying number of students. Verbal explanation and teaching are often combined with other educational tools such as a board (white/black/digital), projector (digital/overhead), and computer/laptop. In an ideal case, the instructor uses their laptop/computer to access the digital material such as PowerPoint slides or multimedia and projects it through the digital projector onto the white board. Whenever required, the use of white board markers or digital pens are used by the instructor to solve a problem or for illustrative purposes. Such learning approach is active from the instructor side but passive from the receiver (student) side as described by Sampaio, et al. [28]. In addition, the utilization of online course delivery through access to some or all of the course material online and remotely by the students is becoming a standard practice in many universities and institutions. Incorporating online e-learning and traditional is referred to a Blended Learning Approach (BLA) [29], which leads to the introduction of various tools such as Blackboard and Moodle software. However, BLA's "definition has evolved to encompass a combination of various learning strategies" [30] (p. 807) or theories such as problem-based learning, cognitive flexibility theory, anchored instruction, etc. [29]. A remarkable example is the use of Technology-Enabled Active Learning (TEAL) at Massachusetts Institute of Technology (MIT) where the learning approach is student-centred, which maximizes their learning experience and theoretical thinking. This is concluded by Dori and Belcher's research and is due to (1) hands-on experiments and interactivity, (2) visualization and engagement from technology-enabled learning and phenomena visualization, and (3) inquiry-based science instruction [31]. An important conclusion that can be drawn is that the change of the students' learning state from passive to active results in positive cognitive and pedagogical outcomes. Hence, we argue that VR as an educational tool used alongside traditional and e-learning in a BLA fashion, will actively engage the students and have positive cognitive and pedagogical benefits.

Through the use of VR in education, the students are more engaged in the learning through immersive scenarios, causing a change in the students' state of learning from passive to active. Hence, such a student-centred approach enhances practical problem-solving skills especially important for engineering students [29]. In regard to engineering education, multiple researchers show the cognitive and pedagogical benefits from using VR. In the area of teaching fluid mechanics, a subject that is daunting to students as it is considered as one of the challenging courses in engineering education [29], Berthoud and Walsh designed a VR application, which was greatly successful in increasing their students' ability to understand complex fluid mechanics problems [32]. They also highlighted that a traditional learning approach through the use of "2D diagrams and verbal description cannot fully describe the 3D motion of bodies through space" (p. 1), which is where VR as an educational tool is advantageous [32]. Furthermore, a VR study was carried out in different universities in Nigeria on VR for teaching and learning electrical/electronic technology, and found out that "VR positively affected students' academic achievement, learning interest, and engagement ... in electronics technology" [33] (p. 226). Last but not least, evidence from Astuti, et al. [34] shows better results in "critical thinking skills, and scientifical attitudes" [34] (p. 151) as seen from students who used 3D visualization tools. In addition, Kisker, et al. [35] states that the "conventional screen experiences rather leave a feeling of familiarity" in comparison to "the encoding mechanism in [VR which] might closely resemble real-life mnemonic processing ... " [35] (p. 1). This shows that using VR has a similar autobiographical memory as in performing the experiment in real life, in comparison to watching it on a projector in the classroom. This brings up to the topic of labs and practical work importance in engineering education, which will be discussed in the next subsection below. Finally, the benefits are not limited to higher education only, in fact, Rahman-Shams [36] studied the effect of using 3D VR technologies on the learning outcomes of K-12 education and found a majority of positive learning outcomes and quality of learning.

5.2. Labs in Education and VR-Labs Potential

This brings the topic of labs, workshops, and practical work, which are part of the students' contact hours in almost all universities and play a vital role in delivering the required knowledge. There is a great emphasis on the importance of labs as a central and distinctive role in science education due to the rich benefits of learning as a result of laboratory activities [37]. The students' engagement in the process of inquiry and investigation positions lab sessions in a critical place in science education [37]. In support, Baldock and Chanson show that combining problem-based and project-based learning through lab work enabled students to prepare high-quality professional reports in the area of fluid mechanics [38]. Additionally, evidence from Chanson shows that students in an Australian university achieved higher outcomes by combining lectures and fieldwork in learning hydraulics (a subject in the family of fluid mechanics) [39]. These examples show the importance of an active student-centred approach where the students' understanding of complex theories learnt in the classroom are enhanced, and they have deeper understanding of the subject taught.

When it comes to physical activities such as lab experiments, there are multiple drawbacks for any institution such as safety (liability), infrastructure, and capital. Lab experiments must be delivered in a safe manner, as the safety of the students is a top priority for any institution. Moreover, lab activities are limited to the availability of the infrastructure at the university, i.e., universities with inadequate equipment, space, and budget will offer less laboratory time for the students. According to Henderson, and the United Nations Task Force on Habitat III, students' learning at universities were undermined by "safety factors, lack of appropriate infrastructure and equipment, restriction in terms of time and space availability" [40] (p. 20). AlAwadhi, et al. [9] add that dangerous mistakes in "chemical interactions and electrical experiments" (p. 1) can cause a serious injury, and expensive materials are a hurdle for some institutions. To overcome these obstacles, Zinchenko, et al. [4], AlAwadhi, et al. [9], Valdez, et al. [41] suggest the use of VR in creating Virtual Laboratories to improve students' learning experience and knowledge. Moreover, Cobb, et al. [10] state that the increasing student numbers in the United Kingdom (UK) "[limit] the opportunity for educators to provide an active learning experience for all" (p. 1) and that it is "essential for education providers to investigate . . . innovative new teaching methodologies to provide a more satisfying learning experience in circumstances of limited space and resources" (p. 1).

There are additional advantages for the university, distance learning students, and students with special needs (disabilities) [9,12,42–44]. Using VR applications, the requirement for laboratory work is shifted from being location- to device-oriented. If distance learners have the means to buy their own VR HMD, they can benefit from being able to experience the same level of education as full-time students on campus. According to Dunnagan, et al. [45], an organic chemistry virtual laboratory was created and students' short- and long-term memories were compared to that of a traditional laboratory. The results show no significant difference between the learning outcomes, and students' memories in both, which indicates that distance learning students can benefit from being able to conduct the laboratory experiments, and receive the same learning experience as full-time on-campus students. Makransky, et al. [46] reach to a similar conclusion that there is no difference between VR learning and video learning. That supports the argument that VR can be utilized for distance learning students to receive a similar level of education and learning experience as full-time on-campus students. Additionally, this can be a distinguishing factor that gives the VR lab adopting university an edge over other universities and attract more distance learning students to their courses. However, the cost of high-end VR equipment and the setup can be an added financial burden and is an obstacle for the distance learning students. A similar approach to Shuo, et al. [47] must be developed, as they utilize mobile-based low- to medium-end VR to give distance learners the ability to conduct the experiments in a cheap and convenient way. However, this comes at the cost of the immersive level, according to Radianti, et al. [2]. On the other hand, the use of this application does not require the student or user to be in a standing position. Hence, students with special needs can benefit from the ability to experience an immersive industrial virtual experience and use the touch controllers to move in the environment. They will be able to interact with the models virtually without needing to lift or do hard physical work. For audio-impaired students, the video can be modified to include subtitles. Besides that, the student can benefit from the same experience. Although the application is very appealing towards students with special needs, it will not be suitable for visually impaired students, as the experience requires the use of an HMD, which is primarily visual.

VR lab benefits are not limited to the university or institution, but to the students' learning experience, cognition, and pedagogy. Evidence from multiple research papers which developed and used VR applications/labs highlights the potential and excellency of this technology in education. Hai Chien, et al. [48] developed and validated a VR application that mimics a construction site, allowing the students to immerse in that environment remotely (in a safe classroom setup) to improve their practical and safety experience. Hai Chien, et al. [48] has proven the use of VR to be a "powerful pedagogical" [48] (p. 1174) tool to enhance students' learning. Gargrish, et al. [49] developed an Augmented Reality (AR) application that enables students to better visualise and understand complex 3D geometries. Although the application is AR-based, it is a visualization tool similar to VR and highlights the potential benefits and applications where these tools can be used. Jin Rong, et al. [50] developed a VR application for ancient construction methods of the Great Wall of China, claiming that VR has yet to catch up in such areas that are valuable in engineering education. The ability to visualise such ancient constructions is a paramount value for education, and clearly showcases the potential of VR technology in education.

Going in depth in multiple research papers on virtual labs for engineering education, AlAwadhi, et al. [9] designed a virtual lab for electrical engineering students that is a replica of a real lab, and where they can interact with a virtual environment's equipment, and perform hands-on experiments in a safe manner. The prototype was named Virtual Electric Manual (VEMA) and was used as supplementary to the traditional classroom teaching. VEMA allowed students to practice Electrical Circuit Theory in a safe manner, where mistakes did not cause harm to the students or assets. AlAwadhi, et al. [9] used various learning theories in their design including inquiry-based, passive and active, synchronous and asynchronous, and blended approach learnings. They add that VEMA can be used by distance learning and close the gap in education quality for distance learning students, in a very cost-effective way. Likewise, Zacharia and de Jong [6] compared students' test results in virtual and traditional labs for an introductory physics course, and found that students using a virtual lab better understood and developed appropriate conceptual models of complex circuits in comparison to the traditional lab group, and also found that the students' understanding was similar in both lab setups. Similarly, Winkelmann, et al. [7] studied students performing chemistry experiments in a virtual world: Second Life (SL) and traditional lab, at a public university. Using their students' grades, surveys, and feedback, it was concluded that students performed better and held favourable views of their experiences in SL. Furthermore, Winkelmann, et al. [7] conclude that "SL setting minimized distractions and made certain aspects of the experiments easier to perform" [7] (p. 1) and add no noticeable difference between genders in terms of performance and equivalent attitudes. Finally, Guerrero-Mosquera, et al. [8] designed a virtual earthquake engineering lab that aims to reinforce the research and academic expertise of students. The lab under the name of SUSMULAB showed a significant positive feedback for its effectiveness in visualizing and conveying engineering earthquake concepts, as well as interpretation of the results. Hence, the students are able to understand and apply different fundamental concepts in earthquake engineering.

On the other hand, a neutral response was concluded in Cobb, et al. [10]'s research studying the use of the virtual world Second Life (SL) to conduct an experiment for Biotechnology Masters students at the University of East London. They found that the students required less assistance in performing the experiment in the traditional lab after completing it in the virtual lab, and that the students showed a positive feedback and requested more virtual lab experiments. However, they conclude "no difference in gains between the two groups" [10] (p. 1) and "both groups showed a significant increase in learning gain" [10] (p. 1). Whereas, a negative response was concluded in Chan and Fok's paper [51] where they have designed a virtual lab for second-year students at the University of Hong Kong, which was used in combination with traditional lab sessions at a summer term. A total of 50 engineering students participated in the survey and the responses show that the students prefer traditional laboratory to the virtual one, due to the ease of operation, flexibility, and satisfaction. The experiment, however, was done at the very early stages of VR technology on virtual labs and the responses are from a small sample group.

6. Research Gap

The use of VR has been implemented and experimented, as mentioned in multiple papers above. However, it is agreed that learning theories are often not considered during the design of the VR application and a greater focus is put towards the design and usability of the VR application, as concluded by Radianti, et al. [2] in their recent systematic review analysing 38 articles in the years 2016–2018 on VR and education. That hinders the objective of using VR in education to support and help students better understand their courses and maximise their learning experience and theoretical thinking. Additionally, Wang, et al. [3] point out that there is not enough research that identifies suitable teaching or learning paradigms for Construction Engineering Education and Training (CEET) and that more efforts and research must take place to evaluate VR technology with emerging teaching and learning approaches. This article looks at closing this research gap through the implementation of two learning theories/approaches (the constructivist learning theory and the variation learning approach) which will increase the confidence in VR technology's ability to maximise the students' engagement, learning experience, and theoretical thinking.

6.1. Contructivist Learning Theory and Variation Learning Approach

Many learning theories and approaches exist in education and have been implemented for many years with pedagogical benefits to the students. Out of these theories and approaches, we have selected the constructivist learning theory and variation learning approach as we believe that they have an excellent implementation potential in VR applications, and with existing evidence of their benefits. Hence, we first look at each of these theories/approaches in detail and lead into their integration in VR and their potential benefits.

Within epistemology, many learning theories are used in STEM education, which includes the constructivist learning theory [52]. In contrast, the variation learning approach is a part of phenomenography, newly adopted in higher education [53], and is essential to learning [54,55]. The constructivist learning theory is where the students are constantly involved in their learning [2,41,56] by allowing them to "construct" knowledge on top of their existing knowledge, leading to a unique mental representation for each learner [57]. Berthoud and Walsh [32] posits that the constructivist learning "is not just an acquisition of information, but that learners construct their knowledge by building on what they already know" (p. 2) while Sjøberg [58] and Taber [59] add that the knowledge is not passively received, but rather actively constructed. In addition, Taber [59] describes constructivism as the state of active learning through different interactions with the environment on a social, cultural, and physical level. Through the use of VR, the user/student is able to actively learn and construct knowledge by being immersed in the virtual environment, and through physical interaction with the models. Moreover, students are engaging in an active learning environment and applying the acquired knowledge from the classroom into the models in the virtual environment, trying to solve the problem in hand or prove a theorem, which overall satisfies the constructivist learning theory.

On the other hand, variation learning approach is imperative in VR application design for engineering education, and is very well explained by Marton and Pang:

> To learn something, the learner must discern what is to be learned (the object of learning). Discerning the object of learning amounts to discerning its critical aspects. To

discern an aspect, the learner must experience potential alternatives, that is, variation in a dimension corresponding to that aspect, against the background of invariance in other aspects of the same object of learning (one could not discern the color of things, for instance, if there was only one colour) [60] (p. 193).

In simple words, the student will only be able to discern (understand) when variation is applied, regardless of the method of teaching/delivery [54]. That clearly allows us to integrate this theory in the VR application, for example: changing a parameter (length of the pipe) in a model while keeping the remaining parameters constant (size of the pipe, fluid properties, etc.). Hence, the student can learn and visualize the effects of the change, and relate to the taught material, as a variation in a system of invariance is established, satisfying the variation learning approach. Through the use of the variation learning approach, Åkerlind [61] found that students' awareness of critical aspects of the studied material are increased and were able "to understand the concepts in a more complex and sophisticated way" (p. 6). Using both the constructivist and variation learning theory/approach in VR applications will greatly enhance the student's learning experience and knowledge.

6.2. Evidence

Evidence from multiple research papers points at these learning theories'/approaches' use in VR to be very effective with positive outcomes. Bashabsheh, et al. [62] posit VR as a "good tool for applying the constructivist approach" (p. 715) while Berthoud and Walsh [32] applied both theories in their simulation design to improve students' understanding of astrophysics. Moreover, Gül, et al. [63] state that learning is enhanced through the use of VR and that VR offers constructivist learning environments. In addition, Valdez, et al. [41] have integrated the constructivist theory in their design Virtual Electric Manual (VEMA; a stationary desktop VR), which was a great success in increasing student engagement and offered an effective high-value learning experience. Finally, Fraser, et al. [64] used and implemented both the constructivist and variation learning theory/approach in a Microsoft Excel visualization tool to combat the difficulties faced by students in understanding three key fluid mechanics concepts. The students' results were significantly improved in all three areas, and their feedback was positive to the Microsoft Excel visualization tool [64].

6.3. Discussion of Findings

From all of the above findings and evidences, we can say with great confidence that integrating the constructivist and variation learning theory/approach to the VR application will close the gap in the technology adaptation for engineering education and will yield pedagogical benefits to the students in engineering education. This is a new finding, as these learning theories have not been adopted into the design of the VR application before, but rather have been used in simulations that are inferior to VR in terms of their immersive ability. The VR application is theoretically superior than stationary computer screen simulations (VEMA) or a Microsoft Excel visualization tool, as the students have a higher degree of freedom through immersion, and VR tools provide the assistance necessary to students for them to be spatially present in the virtual environment. The clear benefits are evident from the multiple research papers discussed; however, it is important to note that the VR application is used in combination with traditional and electronic learning methods in a BLA fashion, and not as a stand-alone tool/form of education due to the inherent drawback discussed in the next section and in literature [19,41].

7. Drawbacks of VR

Some of the VR HMD users reported feeling dizzy after exposure to the VR environment, as stated by Clarke et al. [65]. Kennedy et al. [66] are in agreement with the dizziness and further categorises it under mental dysfunction category along with feelings of fullness of the head and difficulty concentrating. In fact, other dysfunctions exist, such as oculomotor (eye strain, difficulty focusing, and blurred vision) and physiological (general discomfort, headache, sweating, nausea, and sometimes vomiting) dysfunctions, as Kennedy further states [66]. Multiple studies agree that VR can cause sickness to its users [18] while Costello [67] added disorientation, hallucination, and dissociation as additional physical drawbacks to the VR users. Finally, physical discomfort has been reported by many research papers [43,67,68]. It is important to note that drawbacks can be fairly significant: 5% experienced moderate maladies while 2% experienced severe maladies, out of the reported 61% of the VR users who experienced physical dysfunctions, in a study done by Regan [69]. Looking closely at VR in education, many researchers have stated that some of the users reported being distracted from the learning task [4,43,68] as the main disadvantage. In addition, moving objects in the virtual environment as reported by Zinchenko, et al. [4] or adding graphical rendering of the user's hands and 3D sounds in the virtual environment [70] confused and distracted some of the VR users.

In VR's defence, we have found and agreed with studies that realise these drawbacks and suggest to simplify the virtual environment [71], reduce or completely eliminate supplementary devices such as haptic devices [72], and to carefully design the virtual environment inspired by the learning objectives rather than the aesthetics. Simplifying the virtual environment will limit the students' distraction from conducting the experiment/learning. For example, an experiment that allows the students to connect a simple electric circuit must have only the tools needed to accomplish the task. The environment may resemble an actual lab, but will be limited in size as well as what the environment has to offer. In that way, the student focuses on conducting the learning task while minimizing their distraction in the virtual environment. Adding to the example, eliminating the need for supplementary devices such as haptic feedback devices will reduce the complexity of conducting the learning task by the student. i.e., an HMD's camera can detect the student's hands and its movements, mimicking it in the virtual environment, instead of using a sophisticated haptic device. Finally, in VR's defence against the oculomotor and physiological dysfunctions, these are experienced by a small number of people. In addition, a controlled environment that does not involve fast moving objects, or fast-paced scenes, and which is carefully designed, will eliminate most of these dysfunctions. For the remaining few students who are experiencing maladies, an onscreen rendering of the virtual environment can be used.

There are plenty of VR development platforms such as Unity, Unreal Engine, OpenVR, Amazon Sumerian, Google VR for everyone, CRYENGINE, etc. They all serve different purposes in the VR application development and can be either used as standalone or in conjunction with one another. The 3D objects, animations, and motion graphics are created using many software as well, which differs based on the type of object being created. The most common software are Blender, 3DS Max, SketchUp Studio, Maya, etc. In terms of utilizing these tools in developing a VR application for engineering education, a framework must be developed with a robust workflow. However, this is beyond the scope of this paper. Regardless of the workflow, the development of a VR application for engineering education is time-consuming and requires expertise in the above software(s) and coding, as the design is crucial in eliminating the dysfunctions as well as students' distraction. The team must have sufficient coding knowledge in order to script the non-standard tasks that are not typical to these software, as they are mainly designed for VR gaming and not education.

8. Limitations

It is evident from the vast literature covered in this paper that VR is an excellent tool in engineering education. However, the VR application/lab will require a careful design that must be in line with the curriculum, learning objectives, and outcomes of the course. Not only that, but it also must include learning theories and approaches imbedded in the design to maximize the students' learning experience, cognition, and skills. Furthermore, the VR application/lab must be validated through testing on engineering students, and carefully analysing their feedback for continual improvement of the design, environment, and experiments offered. Hence, a dedicated team of experts must be available at the university or institution to work closely with the instructors on improving the VR experience. Such resources may not be available at the university/institute, adding extra responsibilities to the instructor and increasing their burden.

9. Conclusions

The use of VR is concluded to be beneficial to both the students and the university alike. The students' cognitive and pedagogical gains lead to an increase in their performance and grades. This is directly as a result of the VR application design that is focused on the learning objectives, alongside the integration of learning theories. In addition, the students' active engagement using VR is a student-centred approach and part of BLA, which is better than the passive and traditional learning approach. The university/institution benefits from cost reductions by replacing existing expensive laboratories with VR, reduced infrastructure requirement for lab spaces, safer lab working environment for the students, and a market-edge in terms of distance learning VR support and students with special needs. Although the technology has reported drawbacks, they can all be illuminated with proper design in mind.

In the bigger picture, VR is a cutting-edge technology in education that can transform the educational system. With the current COVID-19 Pandemic, and the requirement of social distancing and remote learning, the use of VR is an additional tool the value of which is likely to become even more evident in the coming years, rather than an education novelty. The race towards an optimal continuum of an outstanding education to university students will be heavily dependent on the use of technologies like VR, and the universities/institutions that are early adopters will have an edge and provide educational excellence and quality assurance to its students.

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