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A Systematic Literature Review of Virtual Reality in Engineering Education:
The Lack of a Common Evaluative Methodology

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ABSTRACT

Virtual reality (VR) has proven to be a flexible tool used to simulate unusual scenarios, with the purpose of improving the training of future engineering professionals. Currently, a large number of articles referring to VR in education are published, so this review is necessary to give guidance to those researchers interested in the subject. In this review, 3 unknowns were resolved: 1) focusing areas of VR in engineering education 2) leading nations and 3) funding importance. 74 articles downloaded from the Web of Science database were reviewed using the PRISMA guide. It was found that VR is applied in a wide range of subjects focused on engineering in general. Taking a deeper look, computer science is the area that is receiving the most attention from VR. In addition, the United States is the country leading these investigations and the importance of financing is also seen in the present research. Finally, the lack of a common evaluative methodology was analyzed, as well as the problems of massification of VR and the impact of this technology on student´s motivation

KEYWORDS:

Engineering Education, Funding Importance, Leading Nations, Literature Review, Methodology, PRISMA, SLR, Student´s Motivation, Virtual Reality, VR problematics

INTRODUCTION

It is not only its increasingly access that is serving to expand the use of Virtual Reality (VR) in multiple areas, is also the evolution of its capabilities, which allows to create a greater immersion that scholars are using to facilitate the learning process (Krokos et al., 2019; Loup et al., 2016; Reiners et al., 2014; Zawacki-Richter & Latchem, 2018).

This tool has shown an exceptional ability to simulate multiple situations, becoming not only an invaluable educational aid for students, but also for those professionals who seek to create specific scenarios to treat people with chronic diseases such as agoraphobia (Castro et al., 2014) and anxiety (Anderson & Molloy, 2020), training future surgeons without endangering the life of a patient

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(Fourman et al., 2021), helping radiologists in their diagnoses (Yoon et al., 2018) or teaching nuclear plant safety (Henrique Da Silva et al., 2015).

VR has been recognized by multiple researchers around the world as an excellent didactic aid, which have created new opportunities to explore its use in the education and training area where its implementation is increasing. This interest has created a great amount of information that can be intimidating, especially for those who want to get started in VR applied to learning.

In order to help those researchers who want to know the state of VR applied to engineering education, this Systematic Literature Review was made, where 3 questions are resolved. The first is to know in which area of engineering VR is being used as an educational aid. The second is to know which countries are conducting the greatest number of investigations on the present topic and third, to know if these investigations are receiving financial aid. As additional information, journals with the highest number of publications and the type of the analyzed publications are presented. Also, it is analyzed the lack of a common methodology to evaluate Virtual Reality applications, as well as the motivational increase experienced by students who use this technology. Finally, a discussion was created after having reviewed all the scientific documents, in order to acknowledge those aspects that slow its massification.

The use of VR as a tool for learning does not seem to stop, so it is necessary to know its aspects, in order to guide future generations of researchers and create better environments for future engineering students

VIRTUAL REALITY CAPABILITIES TO SIMULATE SCENARIOS

VR represents an invaluable teaching aid, due to its ability to simulate high-risk scenarios, or situations that would be extremely difficult to emulate in real life (Gazzotti et al., 2021; Lopez et al., 2021; Vásquez-Carbonell & Silva-Ortega, 2020; Zhang et al., 2020). An example of this is the use of virtual environments to train nuclear engineers in the measurement of the ration, and thus avoid the dangers that can arise in a real situation (Hagita et al., 2020).

Surgeons are also using this technology to improve their techniques and thus avoid practice on a patient, who can be affected by a bad decision or involuntary error, an error that can be infinitely less catastrophic in a virtual environment (Jin et al., 2021; Yan et al., 2021). VR in surgery is also used to lessen the emotional and physical burden of novice surgeons, as a pre-surgery practice and as a method to assess surgeons' capabilities (Jin et al., 2021).

Psychologists and psychiatrists have found in VR a complementary tool to medicines and therapeutic sessions. Due to its capability to simulate certain scenarios, mental-health care professionals have used this tool to create Exposure Therapy (ET). These therapies have been shown to be as effective as face-to-face ET (Anderson & Molloy, 2020). What is known now as Virtual Reality Exposure Therapy (VRET), has proven its effectiveness without the need for a "real" exposure in which the patient simply would not dare. Another example of VRET is the study of Castro et al (2014), where it was shown that the groups treated with VRET showed clinical improvements over traditional therapies, including better adherence of patients to treatment, and the motivation to continue them.

Another example of the didactic capacity of VR is its use to train people in the use of certain machinery, which would normally present risks, either for the student or for the environment. The use of tractors in the rural sector of Europe is considered a great cause of fatalities. In order to solve this problem, the use of virtual reality simulators has been proposed, where operators can review and repeat the required procedures and avoid any injury. This method has proven to be effective and positive (Ojados Gonzalez et al., 2017).

These educational benefits of VR are due to its ability to produce a required scenario. However, to achieve this, 3 aspects must be considered and properly managed. The first one is *Immersion* which is understood as the ability of a system to provide an adequate stimulus to a user´s senses so that he is convinced of being in a different place than his physical body is. This aspect is strongly connected with the technology because electronic devices are responsible for providing stimulus to a user. The more advanced these are, the more detailed stimulus will be generated, which would increase the immersion. The second one is *Perception* and it can be understood as the user´s sensation of being in a virtual environment, of being present in that simulated reality and being convinced of it. This can be achieved by creating a scenario as detailed as possible, which includes a representation of the user (generally called "*Avatar*") that is the closest to what a person identifies as himself. Finally, the third aspect is *Interactivity* and it is the ability to be able to interact with that virtual environment and obtain a response through this interaction like the sensation of the wind, or the feeling of the vibration from the fall of an object (Biocca, 1992, 1997; Cipresso et al., 2018; Jensen & Konradsen, 2018; Slater, 2009; Vásquez-Carbonell & Silva-Ortega, 2020). These aspects are summarized in Table 1.

Difference between Virtual Reality (VR), Augmented Reality (AR) and Mixed Reality (MR)

In 1965, Ivan E Sutherland proposed the bases of VR; he mentions a simulated world that had the same characteristics of the real world. This could be achieved by stimulating the senses of a user using different electronic elements (Cipresso et al., 2018; Sutherland, 1965). In contrast, Augmented Reality (AR) does not try to replace a user's world or environment, but to enrich it, creating a combination of reality with virtual elements, such as texts, 3D-graphics and images. To achieve this, items such as electronic glasses and cell phones are the main used resources (Prendes Espinosa, 2014). Another very popular technology is Mixed Reality (MR), term that was coined in 1994 by Paul Milgram and Fumio Kishino in 1994 (Milgram & Kishino, 1994) and refers to the fusion of real and virtual elements.

Each technology has its merits and its disadvantages that must be analyzed in order to choose the correct device and carry out an appropriate implementation. In a surgical scenario, VR would be an excellent tool for practicing and improving surgeons' skills as no patient would be required, only the technology that provides compelling feedback and simulates a "real" surgery. However, AR can be used in surgery, to help a professional with information in real time, like a patient's condition and medical history, and thus carry out the medical proceeding with greater chances of success (Fourman et al., 2021). Lastly, if a surgeon wants a better visual understanding of the preoperative process, like the part of the body to operate, MR can display a holographic reconstruction with all the proper information (Reis et al., 2021).

METHODOLOGY

The Systems Engineering Program of the Universidad de la Costa created a project with the intention to analyze the progress and characteristics of multiple ICT tools, such as Virtual Reality and Augmented Reality in engineering education. Three key questions were defined, and a Systematic Literature Review (SLR) was executed since it has consolidated as an excellent aid in order to synthesize the information and thus, provide a clearer prospect on a certain subject amidst the growing information that daily emerges, eliminating the difficulty of finding answers, especially for those just getting familiar with a determinate topic (Gough et al., 2012). The purpose of this work is to answer the following three unknowns:

Table 1. Aspects in VR

Aspects in VR	
Immersion	Users believe they are in a different place than their body is.
Perception	The user feels that his representation in the virtual environment is adequate.
Interactivity	The user gets adequate feedback from this virtual world.

1. What are the recent research areas of VR applied to engineering education?
2. Which nations are leading the investigations of VR applied to engineering education?
3. Is research on VR applied to engineering education receiving funding?

To carry out this process, the PRISMA guide was used, which is a recommendation to ensure the quality and repeatability of systematic reviews (Liberati et al., 2009). This guide was started once the subject to be discussed was identified, which is VR applied to engineering education.

SEARCH STRATEGY

Once the area was established, the keywords were chosen, through the collaboration of VR and bibliography review professionals, in order to search and find the information. The first defined words were "Virtual Reality" and "Education" +" Engineering". Additional words were "Training", "Learning", "Education" and "Engineer".

The chosen database was Web of Science (WoS), due to its interdisciplinary nature, that contains documentation belonging to other databases, such as ScienceDirect and IEEE, and scientific documents based on technology and Human-Computer interactions that are indexed on regular basis; documents that belongs to respected journals (Lasda Bergman, 2012; Purnell & Quevedo-Blasco, 2013).

DOCUMENTS SELECTION

In order to find out the recent investigative areas of VR in engineering education, the search was limited to documents produced from 2019 onwards. When conducting the search, 2930 articles were found in the WoS database. This period of time coincides with the launch of new electronic devices for access to VR and Software Development Kits (SDK), such as Oculus Rift S, HTC Vive Cosmos, Varjo VR-2 and Oculus Quest 1 & 2.

Inclusion / Exclusion Criteria

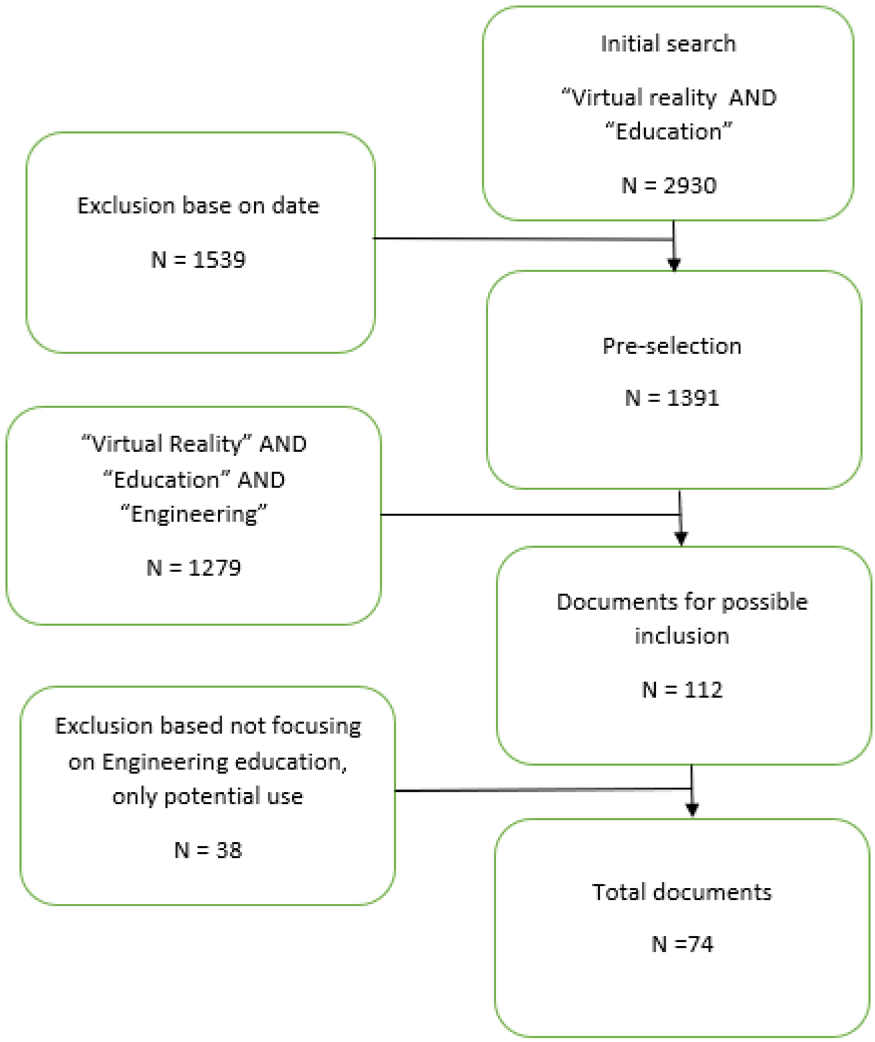
Once the keywords and the database where to perform the search had been chosen, the first search was carried out, and the result was 2930 documents on VR in education. The first filter of the search was carried out, which was to choose only the documents published from 2019 to date, which resulted in 1391 papers. The second filter was the use of the Engineering keyword in the documents obtained, which reduced the amount to 112.

At this point, the review of each article begins, to verify that they meet the inclusion criteria shown in Table 2. This was done with a group of 3 independent researchers (including the author) where a 100% selection agreement was achieved among all participants leaving a total of 74 articles for review. All this process can be seen in Fig 1.

Table 2. Inclusion/Exclusion Criteria

Inclusion / Exclusion Criteria	
Inclusion	**Exclusion**
Documents published 2019 onwards	Documents before 2019
Use of VR as educational or training tool	Use AR as educational or training tool
VR is used for engineering education or engineering training	VR with possible applications in engineering education
Peer – Review document approved for publication	

Figure 1. Flow diagram of the Systematic Review



DATA FOR ANALYSIS

In order to resolve the questions raised in this article, the components of each scientific document were studied to create an analysis matrix, and those where: 1) Document Type 2) Publishing Journal 3) Authors 4) Country where the investigation were carried out 5) Funding & Funding Institutions 6) Year 7) Used Keywords 8) Research Area and 9) Outcome (Positives and Negatives). The selection of these data was analyzed and chosen by the main author and two expert investigators on the subject. Initially, they worked together to prepare a document that included the steps to carry out the review. The preparation of the mentioned document was supported by the experience of the researchers, the PRISMA guide and the recommendations of other authors to carry out an accurate SLR. This document was carefully reviewed by each participant in this work, to correct any inconsistency that could alter the result. Steps to follow, document selection diagram, experiment outcome, author´s recommendation and the necessary data to solve the research questions were established, among other data that could lead to a transcendental finding.

Results

First question: What are the recent research areas of VR applied to engineering education?

Once the articles with which the systematic review would be carried out were obtained, they were downloaded and stored in a personal database. The analysis of each document was carried out in order to carry out a correct categorization of these.

This categorization, identified as Research Area, is provided by WoS webpage. The author's task, along with the mentioned researchers, was to acknowledge and assert that the research areas were correct or could have additional categories. After the analysis by the group of researchers, it was concluded with a 100% agreement that the areas of the articles were adequate, so the research group proceeded in the analysis. It is important to highlight that each article may belong to more than one research area.

Of the 74 downloaded papers, 41 (55.40%) are focused on the use of VR in teaching or training an engineer in a specific area, or how VR affects the educational processes of this student population making this the research area with the highest scientific production. The flexibility of VR as an educational tool is used in several engineering careers, such as railway engineering (Yang et al., 2020), bioengineering (Singh et al., 2020) and engineering applied to construction (Noghabaei et al., 2020) just to name a few, and the literary analysis confirms it. In second place, it was found that the documents applied to education that is the basis for the formation of engineers, such as programming, geography and physics education, among many others. This area is present in 26 articles (35.13%). In third place is VR applied to computer science engineers with 25 articles (33.78%). Closing the first five positions are Construction & Building Technology (civil engineers) with 7 documents (9.46%) and Materials Science (material engineer) with also 7 documents (9.46%). In total, 18 research areas were identified, and Table 3. shows each of these, along with the number of scientific documents associated with this

Second Question: Which nations are leading the investigations of VR applied to engineering education?

The researcher, supported by two experts, undertook the task of analyzing the affiliation of each author in order to find in which country the documents were created. It is very common for papers to be developed among researchers from institutions located in different parts of the world. Completed the data analysis, it was found that the articles contained in the author's database were produced in institutions located in 36 different countries. The United States is the nation with the largest production of scientific articles on VR in engineering education. Authors from this nation created or co-created 24 (32.43%) of the 74 documents contained in the downloaded DB. In a distant second position is China from where 7 (9.46%) articles are credited. In third position is Taiwan with 6 (8.11%) articles. Completing the first five positions are Turkey and Australia respectively, with 5 (6.76%) and 4 (5.40%) documents for each nation. In Table 4, the first 10 publishing nations can be seen.

Third Question: Is research on VR applied to engineering education receiving funding?

To solve this question, each article was carefully analyzed, not only to know if it received any type of financing, but also to identify all those institutions that participated, because it is very common for the financing of an article to be accredited to more than one organization, either public or private. Of the 74 documents analyzed, 43 (58.11%) mentioned having received some type of financial assistance. In total, financial aid is reported by 65 organizations around the world.

Table 3. Research areas

Research Areas	No. of Articles	%
Engineering	41	55.40%
Education & Educational Research	26	35.13%
Computer Sciences	25	33.78%
Construction & Building Technology	7	9.46%
Materials Science	7	9.46%
Physics	6	8.11%
Science & Technology	6	8.11%
Chemistry	5	6.76%
Environmental Sciences & Ecology	4	5.40%
Remote Sensing	3	4.05%
Telecommunications	3	4.05%
Biophysics	1	1.35%
Electrochemistry	1	1.35%
Imaging Science & Photographic Technology	1	1.35%
Information Science & Library Science	1	1.35%
Metallurgy & Metallurgy Engineering	1	1.35%
Physical Geography	1	1.35%
Public Administration	1	1.35%

Table 4. Countries

Institution	Mentions	%
United State	24	32.43%
China	7	9.46%
Taiwan	6	8.11%
Turkey	5	6.76%
Australia	4	5.40%
Italy	4	5.40%
Mexico	4	5.40%
Spain	4	5.40%
Germany	3	4.05%
Greece	3	4.05%

The organization that provided the most financial assistance was the NSF, which is credited with providing financial contributions to 8 (10.81%) VR investigations in engineering education. This entity is located in the United States. This was followed by Writing Lab, TecLabs, located in México, who financed 4 (5,40%) investigations on the aforementioned topic. The European Commission is mentioned as a financial contributor in 3 (4.05%) investigations. Although this is a multinational

Table 5. Funding

Organization	Mentions	%	Location
National Science Foundation (NSF)	8	10.81%	United States
Writing Lab, TecLabs, Tecnológico de Monterrey, México	4	5.40%	Mexico
European Commission	3	4.05%	Europe (Belgium)
Erasmus+ Programme of the European Union	2	2.70%	Europe (Belgium)
Fundamental Research Funds for the Central Universities	2	2.70%	China
Ministry of Education, Culture, Sports, Science and Technology, Japan (MEXT)	2	2.70%	Japan
Ministry of Science and Technology in Taiwan (MOST)	2	2.70%	Taiwan
National Natural Science Foundation of China (NSFC)	2	2.70%	China
AFRI ELI Grant from the USDA National Institute of Food and Agriculture	1	1.35%	United States
Australian Research Council	1	1.35%	Australia

organization, its headquarters are located in Belgium. The Erasmus + Program of the European Union is mentioned twice (2.70%), and like the European Commission, it is a multinational organization based in Belgium. Closing the first five positions is the Fundamental Research Funds for the Central Universities, from China, with 2 (2.70%) financial aid mentions. Table 5 shows the first 10 institutions, with their respective location.

Additional Information

Although this work focused on answering 3 questions, additional information was found that could serve as a guide to researchers on the topic of VR applied to engineering education. These are types of publication and publishing journals.

Type of Publication

Once the database with the downloaded articles had been analyzed, it was discovered that 64 (86.49%) of the total documents corresponded to Research Articles, 9 (12.16%) corresponded to Reviews and only 1 (1.35%) corresponded to Conference Proceedings. As an additional finding, 73 (98.65%) of the 74 papers were written in English and only 1 (1.35%) in Spanish.

Journals

All downloaded documents were published in 45 different Journals. The journal that published the largest number of documents in the downloaded sample was Computer Applications in Engineering Education, which is shown as responsible for publishing 9 (12.16%) of the 74 total documents. It was followed by International Journal of Interactive Design and Manufacturing – IJIDEM with 6 (8.11%) publications, Applied Sciences-Basel with 5 (6.76%) publications, Sustainability with 4 (5.40%) publications and IEEE Access with 3 (4.05%) publications. Table 6 shows the 10 journals with the highest number of publications.

THE LACK OF A UNIFIED METHODOLOGY TO ASSESS VR APPLICATIONS

After analyzing the downloaded documents, it was found out that 71.62% of them had carried out an assessment process, to evaluate the effectiveness of the proposed VR application/method. The most

Table 6. Journals

Journals	Mentions	%
Computer Applications in Engineering Education	9	12.16%
International Journal of Interactive Design and Manufacturing – IJIDEM	6	8.11%
Applied Sciences-Basel	5	6.76%
Sustainability	4	5.40%
IEEE Access	3	4.05%
International Journal of Engineering Education	3	4.05%
Information	2	2.70%
Journal of Architectural Engineering	2	2.70%
Journal of Computer Assisted Learning	2	2.70%
Journal of Construction Engineering and Management	2	2.70%

Table 7. Assessment method

Assessment method	Uses	%
Survey	17	32.07%
Questionnaire	9	16.98%
Pre-test and Post-test	8	15.09%
Interview	5	9.43%
Pre-lesson and Post-lesson survey	5	9.43%
Data Analysis	3	5.66%
Grading System	3	5.66%
Test	3	5.66%
Video analysis	3	5.66%
Application usage	2	3.77%

used assessment method was the Survey, being used in 32.07% of the studies. Questionnaires was the second most used method, used in 16.98% of the studies. It was followed by Pre-test and Post-test (15.09%), Interview (9.43%) and Pre-lesson and Post-lesson survey (9.43%). Table 7 shows the most used assessment methods. Studies may have used more than one assessment method (combining a survey and a grading system, as an example).

Until the elaboration of this document, there is no method to evaluate the effectiveness of VR applications considered as the most efficient or the most accurate by the research community. As a consequence of this, the measurement of the effectiveness of a virtual environment and its impact on the educational aspects of a student varies immensely in the present review. As table 7 shows, studies tend to carry out an evaluation of the effectiveness of the applications using a questionnaire or survey mainly. While this in itself may provide relevant and important information, it is safe to say that there is still some disposition of the evaluator’s subjectivity. An example of this is the study of Miller et al (2021) that found that some users might not find VR environments interesting at all, which could lead to subjective responses on surveys and interviews.

A suggestion to evaluate the benefits of VR in engineering education would be the use of pre-test and post-test (which was implemented by some studies), in addition to the analysis of user iterations in a virtual environment and a post-lesson interview. Additionally, it would be prudent to carry out a student characterization, to verify if his subjectivity can affect the result of the test.

This does not mean that all investigations did not apply an evaluative standard. Shu & Huang (2021), in their work about VR in maker education, use the Maker Pedagogical Content Knowledge (MPCK) guide to evaluate material knowledge. Try et al. (2021) used Analytic Hierarchy Process (AHP) as a guide to assess their work, Kamińska et al. (2021) support his assessment method with a System Usability Questionnaire (SUQ) and Dayarathna et al. (2020) used as a pilar the NASA Task Load Index (NASA-TLX). However, only 7.55% of the examined studies mentions the use of a specific assessment method.

Another consequence of the lack of an accepted evaluation methodology is the great variation of participants or testers in the studies. As can be seen in Table 8, (recollection of the 5 studies with the largest number of participants, as well as the 5 studies with the smallest number of participants), the range of testers found in the literature review was very wide, with the minimum being 2 students, and the maximum being 1,259. On many occasions, a low sample could not show the reality or provide a complete answer of a certain application in VR and its educational effectiveness.

With the increasing use of VR in engineering education, this seems to be the right time to discuss the possibility of creating a unified evaluation method that establishes the necessary parameters that lead to the culmination of an adequate experiment.

Table 8. Studies with the highest and lowest number of participants or testers

Study	No. of testers	Autor(s)
Evaluation of Virtual Reality Based Learning Materials as a Supplement to the Undergraduate Mechanical Engineering Laboratory Experience	1259 Students	(Syed et al., 2019)
Workforce Development Through Online Experiential Learning for STEM Education	342 Participants	(Mohammadi et al., 2020)
Impact of Virtual Reality on the Visualization of Partial Derivatives in a Multivariable Calculus Class	312 Students	(Kang et al., 2020)
A Study on the Impact of STEAM Education for Sustainable Development Courses and Its Effects on Student Motivation and Learning	303 Students	(Hsiao & Su, 2021)
Immersive VR for Organic Chemistry: Impacts on Performance and Grades for First-Generation and Continuing-Generation University Students	224 Undergraduate Students	(Miller et al., 2021)
Real-Time Interaction and Cost Estimating within Immersive Virtual Environments	20 Participants	(Balali et al., 2020)
Comparison of Building Design Assessment Behaviors of Novices in Augmented- and Virtual-Reality Environments	19 Students	(Hartless et al., 2020)
Design of a bi-manual haptic interface for skill acquisition in surface mount device soldering	10 Subjects	(James et al., 2019)
Learning methodology based on weld virtual models in the mechanical engineering classroom	7 Students	(Rodríguez-Martín & Rodríguez-Gonzálvez, 2019)
Enterprise architecture learning through virtual reality software prototype. Case Study	2 Students	(David et al., 2020)

VR & Student Engagement

Although many investigators have multiple definitions for student's engagement, it can be understood as a student's intention or commitment to complete a task, and his dedication to acquiring the skills that allows him to achieve this (Fredricks et al., 2004; Inan & Inan, 2015).

As Fredricks, Blumenfeld & Paris (2004) mentions, there are 3 components for the definition of Student´s engagement: Behavioral engagement, emotional engagement and cognitive engagement. The use of virtual reality has shown to stimulate the cognitive interest of the students, over traditional methods, such as the accompaniment of an instructor and explanation / instructional videos (Try et al., 2021).

Thanks to virtual reality, researchers have proven that virtual reality is a perfect tool to increase student motivation, either in combination with traditional methods or as a replacement for some of them (David et al., 2020; Violante et al., 2019; Yamaguchi et al., 2020) and helping them to retain knowledge (Hartless et al., 2020). In the present review of the literature, it can be affirmed that the idea that VR provides multiple benefits is further strengthened.

Multiple applications with different levels of immersion have been analyzed and tested to verify the increase in student´s engagement. Violante et al, (2019) created a 360° interactive virtual video, which increased interest, attention and concentration in students. Likewise, (Lee & Shvetsova, 2019) carried out a comparative study between two courses in a South Korea University, to analyze the impact of VR based-teaching. Among their many findings, it was found that VR can motivate students to increase their practical skills. A similar result was obtained by Salah et al. (2019). In their 2019 work, the authors found that creating an educational methodology supported by VR allows for better results in understanding a subject, having high rates of student satisfaction, and carrying out practices in less time, with fewer errors, compared to traditional teaching methods. Abichandani et al (2019) created a VR system to teach the fundamental aspects of Photovoltaic cells to undergraduate students. The system not only increased their knowledge in solar energy, but it also increased their engagement as well. The results of an experiment carried out by Chen et al (2021), found that their VR System can increase the interest of students in computer hardware. However, it is advisable to make a thorough analysis of VR and the best way to implement this technology, since not all students could be attracted by this technology, find it interesting (Miller et al., 2021), or if the use of haptic elements is necessary to increase the intention of use by the students (Seifi et al., 2020).

Challenges for VR Massification

Undoubtedly, VR is a flexible tool (Cunha et al., 2022; Soret et al., 2021) with the ability to simulate multiple scenarios (Fedorko, 2021). The prices of these devices have dropped over time, and their features tend to improve, increasing the immersion of a user in virtual environments. Many companies have evidenced this, so the VR-related market is expected to grow (Flavián et al., 2019; Meißner et al., 2020; Radianti et al., 2020). Another factor that is contributing to the spread of VR are smartphones with GPUs, allowing them to render 3D graphics (Agliamzanov et al., 2020; Sermet & Demir, 2022).

However, access to these technological tools is still very limited, not only for ordinary people, but also for multiple educational institutions. The costs of hardware, as well as software is still very high, which restricts its implementation, mainly in developing countries (Fransson et al., 2020; Kumar et al., 2021; Laurell et al., 2019), and that is without taking into consideration additional costs, such as the adaptation of the place of use, the training of the developers and the validation of the virtual environment, just to name a few (de Regt et al., 2020; Kumar et al., 2021; Pellas et al., 2020). As a result, the achievements and educational innovations made possible by this technology are impossible to replicate and most importantly, implement in the vast majority of cases.

Because VR can be considered a niche technology (especially among the older population) (Radianti et al., 2020), its understanding is still low in teachers and trainers. Although these actors know the concept of VR, very few have been users of it, and even less as a didactic tool. This results in a certain apathy to the use of this technology. It is known that there are population groups that are reluctant to technological changes (Anderson, 2018; Anderson & Molloy, 2020; Jayasekara & Fredriksson, 2021; Zhou, 2021), therefore it is necessary to work on future generations, making them participate in the implementation of virtual environments in engineering education. Likewise, many educational developments in VR are carried out without considering collaborative environments, which limits the student´s group interactions (D'Errico, 2021).

Another well-known problem is that parts of the population have adverse effects on the use of virtual reality devices. The mainly known are motion sickness (also known as Cyber sickness), Photo-sensitive seizures and Clinical deterioration (Anderson & Molloy, 2020; Pöhlmann et al., 2022; Villena-Taranilla et al., 2022; Xi & Hamari, 2021). This represents a limitation to expand the use of this tool in the educational field.

Additionally, the incorporation of teachers in the development of VR software is a vital aid. These are not only responsible for their use to apprentices; they are also capable of evaluating whether they meet the educational needs of the students. It is a very common problem nowadays, that many computerized programs and/or applications do not have a correct evaluation by the corresponding professionals, which leaves in doubt their quality and educational value (Crompton & Burke, 2018; Jensen & Konradsen, 2018; Papadakis et al., 2018; Vásquez-Carbonell, 2021). It is important to remember that VR is not inherently educational and depends on proper development to fulfill the educational purpose. Table 9 resumes the challenges for VR massification found in the literature review.

CONCLUSION

Virtual Reality has proven its value, thanks to his immeasurable ability to simulate different situations and environments, where apprentices can carry out their training and learning. This ensures careful monitoring by a teacher, as well as the repeatability of the required exercise, without subjecting users to hostile environments that may cause harm to themselves (like a simulation for nuclear waste management) or harm to another person (like a surgery simulation).

In this work, 3 unknowns have been answered. The first of them, What are the recent research areas of VR applied to engineering education? is responded by stating that researchers are applying VR to specific areas of engineering and/or how it can affect the educational processes of engineers in training. This provides a broad answer, since it does not seem to identify a specific engineering, but it is necessary to remember that each article may have one or more areas. For this reason, combinations of areas can arise, such as engineering and computing, or engineering, education and construction, to say a couple of examples. The first specified engineering that we can find is the one called Computer Sciences, being assigned as the area focused on 25 articles (33.78%). The positive side is that VR is being applied in multiple engineering companies and institutions, which indicates that multiple areas of knowledge have found in this tool an excellent didactic aid. The second question, Which nations are leading the investigations of VR applied to engineering education? have a straight answer:

Table 9. Challenges for VR massification

Challenges for VR massification	
Prices	Prices for VR-related elements are still very high, limiting his massification.
Low understanding	Low use and understanding of VR-tools by educators.
Cultural elements	Parts of the population are reluctant to use it (including educators).
Adverse physical effects	Some users suffer from motion sickness, photo-sensitive seizures and clinical deterioration
Lack of collaborative design	VR developers are not design environments for collaborative activities
Software issues	Lack of proper software development (Integrated work Educator-Developer)

the United States is where the majority of the investigations are being created. Of the downloaded sample, 32.43% of the documents were created in the North American nation. This marks a significant difference with the second place, which is China, where 9.46% of the documents came from. The last question, Is research on VR applied to engineering education receiving funding? also has a clear answer: Absolutely. Of the total documents analyzed, 58.11% reported having received some type of financial aid in their investigation. This indicates that those investigations related to the subject dealt with in this work have a high possibility of receiving some type of financial aid, while the research generates knowledge that helps expand VR applied to engineering education

It is important to remember that this tool requires a joint work with all those involved or benefited from its use. Teachers, developers, researchers, testers and students, all must participate actively so the virtual environment created meets its educational objective.

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