Conceptual Origins, Technological Advancements, and Impacts of Using Virtual Reality Technology in Education

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Abstract

Educators of the 21st century have to be techno-friendly to cater to students' needs who embrace the latest technologies. Using visual-based methods like PowerPoint presentations, videos, animation, etc., has helped the students retain information compared to the traditional methods. One of the breath-taking advancements in visualizing technology is Virtual Reality (VR). This paper provides an overview of Virtual Reality (VR) technology and its applications in education. During this study, to better understand VR's contributions to education, a systematic review of the literature was conducted from Scopus, IEEE, and Google Scholar databases. The paper aims to highlight the core concepts, the origination of the technology, its impact, associated problems, and future directions of VR concerning education and the methods considered by notorious researchers. Identified gaps in the chosen literature works were also highlighted, and suggestions to overcome the identified gaps were summarized.

Keywords

Virtual Reality, VR, History of VR, Virtual Reality in Education, VR in Education.

Introduction

Education has embraced digital devices to increase the teaching-learning process's effectiveness. Technology is omnipresent in every student's life these days. Their exposure to the recent advancements of technology demands a difference in their learning process too. Students of this iGeneration (or iGen) have come across several learning aids, including the projectors, online tools, interactive quizzes, movies, and so on. These days, due to the rapid advancements in technology, students could witness virtual environments that are not possible in regular classrooms (Schunk, 2012). Immersive simulations that are multi-informational can create a strong visual impact called Virtual Reality or, in simple terms, VR (Yu et al., 2019).

While the term VR has gained a lot of attention in recent days, (Nguyen et al., 2019) concluded that Virtual Reality and Augmented Reality (AR) are not just hype. Various researches have been conducted to explore the possible use of VR in different fields. Educators, developers, and researchers show a significant interest in using VR for educational purposes. At the same time, researchers focus on identifying possible solutions for the existing limitations of the technology. Papers published in recent years show the increased attention paid towards this research area.

The focus of this study is on the application of VR in education. The following research questions were defined:

RQ1: What is VR, and how did it evolve?
RQ2: What are the specific features of the studies about Virtual Reality in education?
RQ3: What are the impacts of VR on education?
RSQ3.1: What are the positive impacts of using VR in education?
RSQ3.2: What are the negative impacts of using VR in education?

Conceptual Origins (RQ1: What is VR, and how did it Evolve?)

It is essential to draw attention to the origination of the concept "Virtual Reality" to understand the technology. This segment of the paper focuses on the conceptual origin of the term VR, underlying theories, its growth, and theories relevant to VR's usage in education.

Definition(s) of VR

The term Virtual Reality was defined by different authors as follows:

It simulates a computer-generated 3-dimensional world that includes interactive objects with a sense of spatial presence (Bryson, 2013).

We are creating a strong effect of existence even when nothing exists (Bakr et al., 2018).

It creates a feeling of mental immersion into a 3-D world that tracks the user's position/actions and response in the form of feedback (Sherman & Craig, 2018).

Technology allows the user to experience a virtually recreated story through a head-mounted display (Shin, 2018).

As shown in Figure 1 (Burdea & Coiffet, 2017), VR is a combination of three I's. I.e., I^3 = Interaction + Immersion + Imagination.

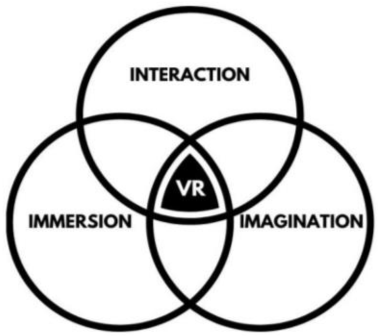

Figure 1 Three I's

Key Elements of VR

Virtual Reality comprises four key elements (Sherman & Craig, 2018), as shown in Figure 2.

Any VR application is considered to be a full-fledged application if that comprises of the four key elements. Satisfactory results are obtained by choosing the hardware and software configurations that complement VR's four key elements.

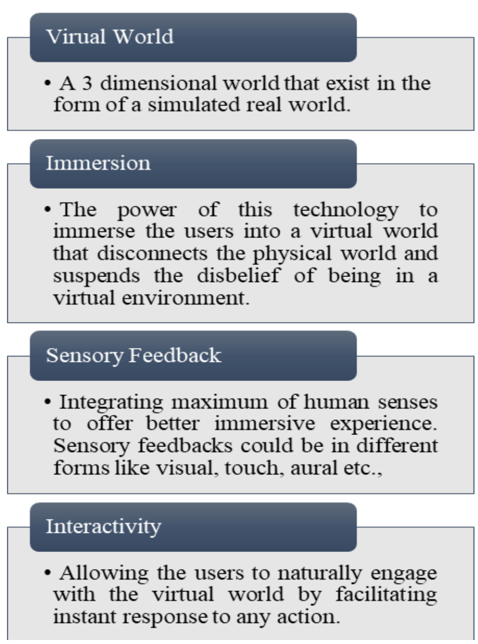

Figure 2 Key Elements of VR

History of VR

Over the years, VR technology has never stopped surprising the world. Since 1838, several milestones depict this technology's growth until this modern digitalization era, as detailed in Table 1.

Table 1 Milestones of VR

Milestone	Year	Description
Stereopsis	1838	Stereopsis is one of the concepts behind the working of VR headsets. It represents the user's ability to view through each eye that perceives horizontal differences.
Link Trainer	1929	This is the very first version of a flight simulator that was designed for training military pilots, which later became a prototype for the concept of VR.
Pygmalion's Spectacles	1935	Stanley G. Weinbaum included in his story, a pair of glasses that could simulate smell and touch in addition to the sight and sound. The story highlighted that a character was in the story instead of regular projection on a screen.
Telesphere Mask	1960	A head-mounted display that had miniaturized cathode-ray tubes fully immersing the user into the 3-D world.
Sensorama	1962	Sensorama is first of its kind multi-sensory VR device that could create a real immersive feeling with stereoscopic screen, stereo speakers, rotating chairs, odor sprayers, and fan-generated wind.
The Ultimate Display	1965	In this ultimate display, a realistic virtual word displayed through an HMD that includes 3-Dimensional sound and force feedback.
The Sword of Damocles	1968	Despite having a couple of HMD systems earlier, this is considered to be the first VR HMD that connects to the computer, with the ability to track user movements.
GROPE	1971	GROPE is considered first-ever force feedback gloves with the skeletal structure invented at the University of North Carolina.
VIDEOPLACE	1975	An artificial lab, inside which the user experiences virtual environments without wearing an HMD or gloves.
VCASS – Flight Simulator	1982	Visually Coupled Airborne Systems Simulator is a helmet that displays 3-D superimposed over the real-world content, which was used in training the pilots using flight simulators.
Naming Virtual Reality	1984	VPL Research Inc. was the first company to sell VR goggles and gloves to the public, and they also called this field a VIRTUAL REALITY.
Eye Phone	1988	Eye phone is a specially designed goggles and gloves that allow the users to see and interact with objects in the virtual space.
Virtual Wind Tunnel	1990	A VR technology that provides an opportunity to explore fluid flow simulations in different timing could be controlled by visualizing tools – Specifically used in aerodynamics.
Virtuality	1991	This is a gaming HMD that is accompanied by joystick and multipayer network units.
CAVE	1992	A room that comprises display units on all the side walls with rear projectors typically resembles a movie theatre that gives an immersive experience.
Virtual Vietnam	1997	An application that was developed to treat the veterans which allow the user to ride a combat helicopter.
SAS Cube	2001	Almost similar to CAVE, this room allows the users to experience stereoscopic projections. This technology is comparatively thrice the time cheaper than CAVE.
Street View	2007	Google Earth VR, which is made available for specific VR headsets through which 360º view of the selected street can be experienced.
Oculus Rift	2012	Oculus rift is a prototype HMD released in 2012 for the gaming platform that emerged with excellent build quality and standards.
Google Cardboard	2014	Simple, cardboard-made VR solution that turns a compatible mobile handset into a VR headset.
HTC Vive	2016	HMD with room-sized tracking allows users to move around and interact with the objects in the 3-D environment.
Oculus Half Dome	2018	A new update from Oculus offers a higher comfort level for viewing and physical movements because of the non-moving parts of the HMD.
Oculus Quest	2019	With touch controllers and 6 degrees of freedom, Oculus launched Oculus Quest.
Oculus Quest 2	2020	The advanced version of Oculus Quest was released with advanced touch controllers and the highest resolution display ever.

VR Hardware

The most common way of displaying VR content to the user is through Head Mounted Displays (HMDs). An HMD is a tailor-made device that can fit on the forehead, including a pair of lenses and a built-in display unit. Different varieties of HMDs are available in the market, each with its processing power and efficiency. Table 2 juxtaposes some of the popular HMDs available in the market.

Table 2 Analysis of HMD's

Product	Pros	Cons	Pricing
Oculus Quest	• Easy to configure • No cables • No need for a computer or a laptop • Display Panel: OLED • Display Resolution: 1440 x 1600 per eye • Refresh Rate: 72Hz • DOF: 6 • FOV: 90^{o}	• Average graphics quality • Smartphone required for preliminary setup • Content from Oculus store only can be accessed • Weighs about 570grams • Lights leakage occurs through the nosepiece	• $399 for the 64GB model • $499 for the 128GB model
Oculus Rift S	• Insight Tracking • Connection established through cables • Requires a computer / Laptop • Display Panel: LCD • Display Resolution: 1280 x 1440 per eye • Refresh Rate: 80Hz • DOF: 6 • FOV: 115^{o}	• Average graphics quality • It cannot be used by simplest PCs or laptops • The design is too heavy • Less efficient controller tracking • No HDMI port – Only display port is available	• $299
HTC Vive	• Better head tracking than Oculus • Can track up to 15x15ft • Smoother graphics • Display Panel: Dual AMOLED • Display Resolution: 1080 x 1200 per eye • Refresh Rate: 90Hz • FOV: 110^{o}	• Absent of in-built audio feature • Must be connected to PC all the time • Size is bulky and heavy • Expensive • Large area required	• $2379 for PRO version

* DOF: Degree of Freedom

* FOV: Field of View

Cost Comparison of HMDs

Figure 3 Price history of Oculus Rift S

Figure 4 Price history of Oculus Quest

Figure 5 Price history of HTC Vive

The cost analysis from September 2020 to March 2021 of the famous headsets shows the demand for VR headsets and increased pricing of advanced models (Figure 4 & 5). As shown in Figure 3, Oculus Rift S has drastically reduced its cost because of the same brand's availability of advanced headsets. While HMDs are commonly in use for educational purposes, several other types of VR systems, as projected in Figure 6, are adapted from (Kalawsky, 1996). Some VR systems are fundamental, and hence they do not require specialized hardware to display or execute the content. In contrast, the advanced systems require appropriate hardware and software corresponding to the use.

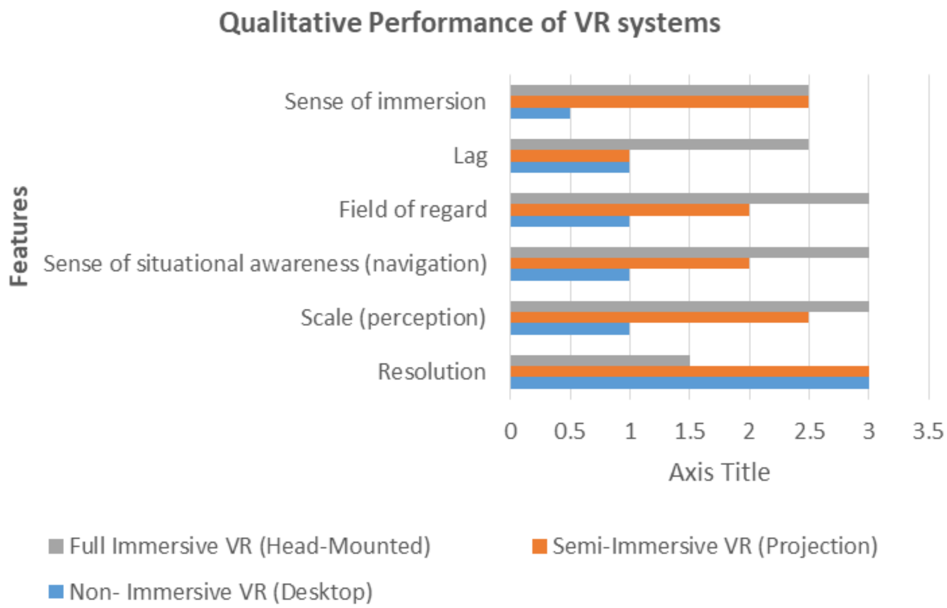

Figure 6 Analysis of VR systems

VR and Education

The word education loosely refers to how the facilitation of resources, knowledge, skills, or positive qualities are promoted. The primary objective of education is to help students prepare for life, work, and citizenship by developing knowledge and skills essential for society. VR is considered a critical learning aid in this digitally advanced era (Leo Willyanto Santoso, et.al., 2021). To authenticate the connection between the learning paradigms and VR, it is essential to analyze the key factors behind the learning paradigms like behaviorism, cognitivism, constructivism (Schunk, 2012), connectivism (Siemens, 2014), and experientialism (Kolb & Kolb, 2012). Key learning paradigms of Virtual Reality are illustrated in Figure 7 and explained in Table 3.

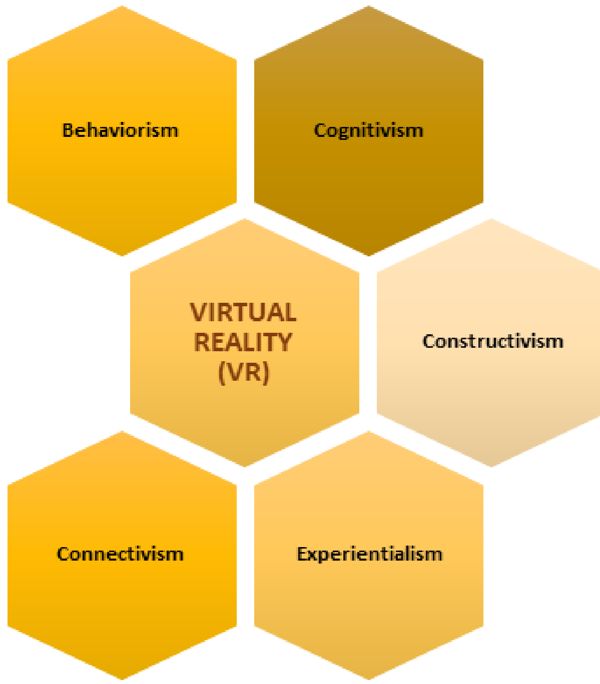

Figure 7 Learning Paradigms

Table 3 Explanation of Learning Paradigms

Categories	Explanation	Reference
Behaviorism	This category is one of the oldest and most popular theories in education. It insists that learning happens through observation from the environment through which one's behavior changes.	(Clark, 2018)
Cognitivism	This category allows users to add new information to their existing knowledge.	(Schunk, 2012)
Constructivism	A learning process in which the learners act as information constructors.	(Fosnot, 2013)
Connectivism	A continuous learning system in which the learners gain knowledge outside the traditional setting with the help of technology tools.	(Siemens, 2014)
Experientialism	Learner's personal experience contributes the most for knowledge acquisition, whereas the teacher acts as a facilitator.	(Kolb & Kolb, 2012)

Related Works

There are thousands of researches carried out in the field of VR and education. For this study's scope, papers that are published on or after the year 2016 are taken into consideration.

Methods

Potentially relevant studies on VR in education were identified using the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) framework.

Search Strategy

For this study's scope, articles were identified by conducting a systematic literature review from Scopus, IEE, and Google Scholar. Notification service was enabled for all the chosen databases so that the recent articles published in the same domain are not missed out. To be more specific, a combination of keywords was used to keep the results more closer to the target study. Table 4 depicts the keywords used to search from databases. In addition to the keywords, restrictions were set to limit the search results, as shown in Figure 8.

Table 4 Search Keywords

Database	Search keywords	Results
Scopus	"virtual reality" OR "VR" AND educat* OR teach* OR learn* OR train* AND university OR "higher education" OR college OR school AND NOT "machine learning" OR "deep learning" AND NOT "artificial intelligence" OR "neural network" AND NOT rehabilitation OR therapy AND PUBYEAR > 2016	976
IEEE	((((((("All Metadata":virtual reality) AND "All Metadata":education) NOT "All Metadata":machine learning) NOT "All Metadata":deep learning) NOT "All Metadata":artificial intelligence) NOT "All Metadata":neural network) NOT "All Metadata":rehabilitation) NOT "All Metadata":therapy)	112
Google Scholar	allintitle: (Virtual Reality AND education | training | school)	736
Total		1824

Inclusion and Exclusion Criteria

Using the Systematic Reviews and Meta-Analyses (PRISMA) framework to identify potentially relevant studies on VR in education, the search returned a total of 1824 documents. To find a suitable method for the inclusion and exclusion of articles, the KH coder is an appropriate method. It provides a dynamic analysis of qualitative data with text mining tools (Coder, 2017). When the regular method of scrutinizing the obtained results with filters like citations.

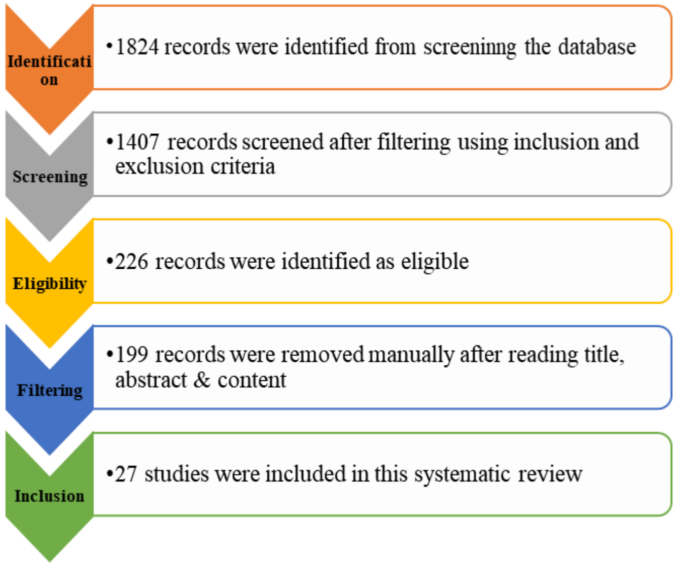

Figure 8 Inclusion and Exclusion Criteria

Literature Review (RQ2: What are the Studies' Specific Features about Virtual Reality in Education?)

The learning process has to be interactive, challenging, motivating with quality. There are several models used in implementing such novel technology in the classroom. It's found that using three-dimensional media (Suleman et al., 2019) that VR has been widely used as a practical learning media. Chemistry teachers, students, peer reviewers, media experts, and material experts have assessed the media in VR learning content with Android-based application and awarded it as useful with 78% potential.

A similar study in a chemistry experiment using Leap motion and Head-mounted display (Han et al., 2017) was used to create a wireless transmission technology with a server and client connectivity (Beavis & Ward, 2019) in conveying learning information to students. In another experimental chemistry study, leap motion was used to make the human avatars interact with objects in the virtual environment to carry out experiments. It is observed that a high level of tracking accuracy is required to perform such experiments (Han et al., 2017).

The physics tool VERT is a simulation environment to train radiotherapy concepts. Complex concepts such as dosimetry practices are also taught in this method to the trainees rather than clinical Linac availability. VERT also offers blended learning in the classroom. VERT potentially helped the trainees handle the radiotherapy tools (Leong et al., 2018). VERT – Virtual Environment for Radiotherapy Training was used in a study and was proven effective because it was used in the classroom without waiting for a patient (Beavis & Ward, 2019).

A study was conducted to demonstrate to students the usage of the Infrared spectrometer and its purpose in analyzing the resulting spectrum with Samsung Gear VR's aid under the faculty supervision (Dunnagan et al., 2020). The students in this study have volunteered themselves with curiosity. This study's uniqueness is that the VR instructional learning is made available for Google Cardboard and Gear VR with IOS and Android support. An increase in students' motivation to attend labs is found as a result of this study.

57 Students from the western United States were recruited (Van Der Linden & Van Joolingen, 2016) to participate in the VR biology class to learn about the work of human bloodstreamz. The study proved that the students involved in VR learning have improved motivation, engagement, and interest in learning.

A study conducted at the University of Texas at Tyler (Coyne et al., 2018) with 18 pharmacy students to assess team-based learning using Steam VR software and Vive headset proved that 94.4% are interested to learn in such a team-based learning environment. It also conveyed that VR is fun, engaging, and immersive.

LIRKIS - an advanced technology lab (Sobota et al., 2016) with VR and other advanced immersive interfaces such as Oculus Rift, MS-Kinect, CAVE (Cave Automatic Virtual Environment), and Optitrack for motion capture is used to educate disabled students to explore new possibilities.

Chemistry and Biology require a to carry out a lot of procedures for which VR is proved to be effective (Al-Awadhi et al., 2017; Parong & Mayer, 2018). Compared to Power Point presentations, VR motivates and increases the interest to learn, but at the same time, PowerPoint presentations were proven to show high scores in their tests.

Study results indicated that the use of VR to teach solar energy shows a significant growth in students' knowledge and engagement (Abichandani et al., 2019). This study followed a self-guided discovery method where the teacher's participation is limited.

For subjects like organic chemistry, it is reported that the students turned out with a high degree of satisfaction with almost no barriers to using the system (Dunnagan et al., 2020).

In a study about gravitational force concepts, the researchers used virtual simulation to achieve increased student involvement and results (Pothumani et al., 2019). The research did not focus on the type of VR tools used, leaving less scope for other researchers to take it further.

Google expeditions VR system was introduced to a group of middle school children, and their experiences were accessed using a set of questionnaires. The results showed a significant increase in the group scores that used VR than the traditional instructional method group (Bowen, 2018).

In a specific research, CAVE (Cave Automated Virtual Environment) was used in choosing between two different building layouts (Bakr et al., 2018). This study suggests that VR is a tool that enhances the visual perception and competence of children.

Newton's laws of motion are one of the key concepts in physics, and researchers have attempted to teach this concept with the help of VR games. Students who played VR game was highly motivated than the students learned using the traditional method (Van Der Linden & Van Joolingen, 2016).

Several categories of learning content framework were identified during the coding process, as given in Table 5.

Table 5 Learning Content Framework

Type	Description
Analytical	Whether the application of VR will enable students to develop analytical skills such as data collection and interpretation, programming, or complex decision-making
Practical Experience	Where the use of VR tries to help students understand and accept procedures like how to carry out surgery or firefighting procedures
Communication and Team-Building	If VR seeks to enhance students' potential to collaborate as a team or develop their leadership abilities (for example, to introduce themselves to a recruiter), it is meant as communication.
Domain-Specific Knowledge	A subject where deeper understating of the concepts are explained with the help of VR

Positive Impacts of using VR in Education (RSQ 3.1: What are the Positive Impacts of Using VR in Education?)

In the educational context, VR is usually preferred to simulate a classroom or lab. Experiments that involve high difficulty levels or dangerous methods are safely presented with VR (Christou, 2010). VR plays a vital role in the education and training industry. Implementation of a learning setup for each course or subject requires a lot of funding and space. Virtual Reality has bridged this gap by creating custom course content for each learning environment. VR has its advantage by improvising students' psychomotor, cognitive skills.

Practical Learning than Traditional Book Learning

There are certain hiccups in traditional classroom learning where most of the theoretical information was not conveyed to students due to the absence of technology or inadequate practical learning setup, fixed by adapting Virtual Reality. This technology is about taking the learners into the virtual world to experience the education content through virtual 3 dimensional or 2-dimensional objects. The study (Kamińska et al., 2019) proved that certain traditional book learning methods were replaced with VR and have changed the level of interest among students.

Easy Understanding of Complex Concepts

Subjects such as science and mathematics involve a deeper understanding of concepts found as hard to explain in classrooms (Monita & Ikhsan, 2020). Whereas with the help of VR, the students' effortlessly understood difficult concepts through experiential learning. Students considered VR as a roadmap for future implementation of the learned content.

Undivided Attention in Learning

In the old-fashioned classroom learning, students get bored and tired of the books' theory content, where the same method of black and white learning method is followed throughout the year. A novel virtual learning environment such as virtual Reality would bring students' undivided attention in classroom learning and the subject (Elkoubaiti & Mrabet, 2018).

Enhances Creativity of Students

Practical learning in the classrooms with VR aid enhances students' creativity (Elmqaddem, 2019). Applied learning promotes a way to explore and implement new ideas in several domains, promoting their learning and increasing their creativity.

Teachers' Skill Level Improvement

Teachers could practice their classroom sessions such as time management, students' management and classroom engagement in VR before attending their real classroom sessions, it's evident in the studies that by using VR (Dong, 2016), they could potentially avoid the mishaps which happen in the regular classroom while handling the subject and preparing themselves to face such calamities.

Easy Retrieval of Learned Theories

As per the study (Dong, 2016), Rather than hearing and listening, 90% of information red in the human mind through physical movements. Virtual Reality provides an option to interact with the virtual 3d objects, the learned content registered in the human mind, and retrieved easily.

Increased Interactivity with a Sense of Satisfaction

A sense of learning complex subject just for exams without comprehension results in dissatisfaction and frustration for the learner. Virtual Reality blurs the line between complex and easy concepts and makes the user learn with clear understanding and satisfaction and increase in autonomy (Schunk, 2012).

Communication Barrier

Communication acts as a barrier between students and teachers due to different cognitive levels (learning, selecting, organizing and integrating). These concepts were embedded in the virtual reality learning environment where selective cognitive learning methodologies were imparted with autonomy (Parong & Mayer, 2018).

Collaborative Learning

Social learning is proved to be a positive learning environment where students of different needs with different learning styles come together to support and guide each other in creating collaborative learning.

Negative Impacts of Using VR in Education (RSQ3.2: What are the Negative Impacts of using VR in Education?)

Cost

Cost is one affecting factor in VR technology, where the implementation of complete VR hardware is not affordable to a commoner. To convert an education laboratory into a VR-enabled one, a huge sum of amount has to be invested by the stakeholders. Though such huge capitalization is invested, experts with deep technical knowledge are limited to operate the same. Since the technology is new and evolving daily, a saturation point has not been met yet.

Opting the Right Device

Several VR devices are available in the market; finding a suitable recommended VR device for each tailored learning environment is yet found to be complicated. There are limitations to each hardware and software. One classroom's needs and requirements may not be fulfilled by the hardware and its supporting software (Yu et al., 2019). As the technology has not grown to the fullest of its potential, where there are changes in VR hardware and software, adapting to one specific device and software is still troublesome for the teachers (Schunk, 2012).

Teacher Readiness & Training

To inculcate the use of virtual Reality in classroom learning, the trainers need to be trained in the hardware and software to accept to convert traditional class and lab environment into a VR enabled classroom. Training the teachers from a non-IT background is a challenge.

Associated Sickness

Visual fatigue is one such major drawback found with users in using VR devices. The students and learners have experienced motion sickness during and after virtual learning. This visual discomfort is caused by the difference between the Real-world and the virtual world's visual display. The difficulty in focusing, far and near vision issues are created due to visual fatigue. Sleepy, nausea, dizziness are other effects of motion sickness. (Nolin et al., 2016) have proved that fatigue and eye-strain are the most common effects of VR usage, whereas burping and nausea are the least ones.

Discussion

This detailed analysis shows that the students are very interested in using virtual reality technologies that clearly show that VR is a promising technology. Most of the studies were focused on the students' interest, motivation, and engagement. Simultaneously, the problems associated with the usage of this technology, the factors affecting the adaptation of this technology are not explored in detail. It is clear that the use of VR in education is still in the experimental stage in some countries, and still, there is scope for improvement in the methods of adopting this technology.

The identified studies reveal that VR tool motivates and increases the engagement of students. Almost 80% of the studies have received funding to carry out the research meaning that they have obtained the required resources. No significant research was identified focusing on lower economic countries or under developing countries where investment in VR technologies and the readiness to accept the technology are a challenge. The majority of the studies focused on engagement and motivation rather than long-term academic performance.

All the studies were conducted for a certain period, but there is no specific methodology to integrate VR into regular teaching-learning practice. Mapping the learning theories with the VR content is found missing in the majority of the studies.

Virtual Reality technology is a vast and advanced area explored by numerous researchers across the globe. The studies' implications show that if the educational institutions' stakeholders carefully choose the required VR content for the courses, they can achieve good results. It is also wiser to start with low-end VR devices rather than investing a huge amount on the infrastructure until teachers and students get familiar with the usage.

Conclusion and Future Work

One of the major hindrances to adopting VR technologies is identified as the cost associated with the purchase of equipment, software, maintenance, training the teachers, and requirement of physical lab spaces. To overcome the cost issue, mobile labs can be set up, which doesn't require a huge investment to construct a lab, buy the software and hardware, spend on training the teachers, or even spend on the maintenance up-gradation.

Since technology is rapidly growing, the availability of resources is also expanding. Teachers can make use of the free resources related to their subjects, probably with low coast mobile-enabled VR devices like Google cardboard before they could step up for a huge investment.

The continuation of this work will focus on surveying the institutional heads and teachers to identify their level of readiness to adopt this technology. Also, trials will be carried out to study the efficiency of VR concerned with the specific subject.

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