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Improving Engineering Education through Utilization of Virtual Reality

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Abstract

Traditional methods (TM) for delivering engineering education are not aligned with rapid technological development. Engineering basic workshops as a fundamental course for engineering students are commonly provided through traditional education methods and depend mainly on understanding both the theoretical concepts and practical tasks. Simulation as advanced technology is trending where applications of virtual reality (VR) can be used as an effective teaching tool in education and boost the students' engagement in the courses. This study focuses on improving the traditional learning method used in mechanical engineering basic workshops by utilizing VR. A time study was conducted for both traditional and VR methods to identify the time required to complete all tasks. A facility layout redesign for the current workshop lab was proposed along with a direct cost study. It was found that the use of VR allowed students to understand the course experiments, achieved significant improvement in students' performance, and enhanced the learning experience for engineering students.

Introduction

Engineering education is a demanding field that requires mastering complex concepts and skills. Traditional learning methods should be changed as students struggle with theory concepts and lack hands-on experience. Virtual Reality (VR) is a rapidly developing technology with the potential to reform engineering education. It offers a unique solution by providing immersive learning experiences in a safe environment. which allows students to practice practical skills. VR has been proven to enhance learning outcomes in various engineering disciplines by improving student engagement and motivation. In addition, VR enhances spatial visualization and problem-solving skills by allowing students to interact with 3D models and simulations. Students can practice the necessary skills and avoid dealing with dangerous equipment or performing hazardous tasks.

Several studies have shown promising results of VR in providing practical engineering education. Most of these studies have concentrated their findings on the Impact of VR on student learning outcomes in engineering manufacturing, improving student learning outcomes in engineering design and increasing student engagement in engineering mechanics (Wang et al., 2019; Shih et al., 2020; Wu et al., 2022). Engineering education can benefit from VR in terms of creating simulations of real-world environments, allowing students to explore and learn in ways that are more interesting than traditional methods (TM). Han (2023) highlights the potential of VR in engineering education, which includes multi-sensory stimulation, guided learning, and accelerated cognitive processes. It provides students with immersive, hands-on learning, and interactive learning experiences. Engineering students could be challenged to design and build a bridge in VR, or to operate a machine in a virtual factory. This could be achieved by creating a unique learning experience and motivating students to learn in a safer environment with less time required to do the experiments and few resources needed compared to the traditional method of learning (Wang et al., 2019). Thus, VR technology is used to simulate these practices in a safe environment.

Indeed, VR has the potential to be a powerful tool for improving engineering education as it can help students learn more effectively, efficiently, and prepare them for the challenges of the engineering profession. Engineering education focuses mainly on math and science courses, with specific purpose of teaching students how products are created and understanding product processes. The workshop basics course includes practical knowledge of various manufacturing processes, including metal forming, pattern making, rolling, extrusion, metal machining, drilling, and milling. The workshop basics course introduced by the mechanical engineering department and used to teach fundamental knowledge of major machinery used in most industries. The course depends mainly on understanding practical skills. Thus, all students are supposed to experience working on those machines. However, the machines are limited, expensive, and costly to maintain. The main issues with the current engineering lab are:

- A lack of some mechanics machines due to limited space of lab.
- Increased machine costs and maintenance.
- Students were unable to experiment on the machines due to some safety concerns
- Limited space for students to perform experiments

Moreover, there are many different harmful parts in the workshop, which can harm students. Since students usually take this core course in the first year, they are not familiar with dealing with such dangerous machines. This makes it difficult to teach them practically within the lab class time.

There has been no research that explained the utilization of VR technology in engineering education, specifically in workshop basics course. Hence, this research aims to enhance the course deliverables by simulating the lab experiment practices through VR and to prepare the students with the necessary practical skills for the market. This can enhance students' experience and allow them to conduct scientific experiments in a safer environment and reduce the costs of establishing new labs.

The research is divided as follows: First, an introduction to VR is described. Second, a review of VR in engineering education is presented. Third, the research methodology and the details of the administrated survey are explained. Forth, the research findings with the students' and instructors' perspectives on using VR in the engineering lab are discussed. The last section provides a conclusion and directions for future research.

Literature Review

VR technology, first introduced in the 1960s, allows users to interact with three-dimensional environments using electronic devices, simulating computer-generated images or environments (Freina & Ott, 2015). Research on VR implementation in education shows high student engagement, which leads to increased awareness and knowledge. However, several research presented the limitations of VR such as high costs, time constraints, and validation test (Gartner, 2023). According to Abulrub et al. (2011) VR has the potential benefits in engineering education as VR provides students with immersive and interactive learning experiences that can help them to better understand and apply engineering concepts. Zavalani and Spahiu (2012) highlight the potential of VR in transforming engineering education by providing interactive, engaging learning experiences, enhancing students' spatial reasoning, and curiosity skills.

The virtual theatre was introduced by Ewert et al. (2013) as a platform for engineering education. The virtual theatre is a system that allows users to freely explore a virtual environment using a head-mounted display, a data glove, and an omnidirectional floor. This system provides a more realistic and intuitive experience than traditional engineering education tools, such as textbooks and diagrams.

A study conducted by Alhalabi (2016) compares the effectiveness of three virtual reality (VR) systems: Corner Cave System, Head Mounted Display (HMD) system, and HMD standalone device) with traditional teaching methods in engineering education. A total of 120 engineering students were involved in the study and randomly assigned to one of four groups. The study found that VR systems can enhance students' achievements in engineering education. Sudents in the VR groups reported higher levels of motivation and engagement than students in the No-VR group.

Win et al. (2018) review the use of VR in engineering assembly education and present the advantages and disadvantages of VR, as well as the VR hardware requirements. One of the main advantages of VR in engineering assembly education is that VR can provide students with immersive and interactive experiences that would not be possible in a traditional classroom setting. Another advantage of VR is that VR simulations can be designed to provide students with different levels of difficulty and to highlight their strengths and weaknesses. The study represents the disadvantages of using VR in engineering assembly education, which are VR headsets can be expensive and difficult to maintain and VR can cause some users to experience motion sickness. The manufacturing industry is rapidly evolving, with new technologies such as 3D printing, additive manufacturing, and the Internet of Things (IoT) becoming increasingly prevalent. This evolution is leading to a new paradigm known as Industry 4.0, which is characterized by a shift towards more intelligent, sustainable, and interconnected manufacturing systems.

Many studies showed that VR can improve engineering education and promote manufacturing sustainability in the context of Industry 4.0. For instance, Salah et al. (2019) present a case study of a VR-based engineering education program at the university. The study concludes that VR-based engineering education has the potential to reform the way that engineers are trained and provide students with immersive and interactive learning experiences to succeed in the manufacturing industry of Industry 4.0.

Lanzo et al. (2020) examine studies on the use of virtual environments in engineering education, finding increased use and benefits in cognitive and skill-based learning. However, limitations like unrealistic scenarios and small sample sizes suggest further investigation.The advantages of VR technology in engineering education as reported by Jindal et al. (2023) include enhanced understanding, improved performance, reduced costs, and equal opportunities for students with special needs and distance learning. Han (2023) explores the potential of VR in engineering education, highlighting its potential as a promising assistive technology in the future. The gaps and trends of VR were studied by Oje et al. (2023) and suggest the need for cognitive and socio-cognitive theories, multimedia design, and pedagogical principles.

Method

The research is to focus on improving the traditional learning method used in mechanical engineering basic workshops by utilizing VR. A methodology framework is designed to develop the research stages, as shown in (see Figure 1).

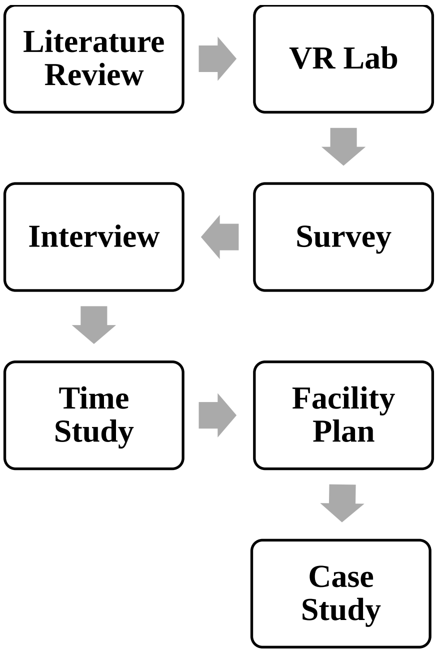

Figure 1. Research Framework

The first phase of the framework is to conduct a literature review, identify gaps, and understand VR applications. Then, the journal articles were summarized to obtain a comprehensive understanding of using VR in engineering education. After reviewing the literature, an initial VR application was developed for the proposed lab to investigate the acceptance level of the instructors and students who used VR and TM in the lab. The second phase involved creating a virtual reality simulation for the basic workshop lab using a game development engine called (Unity), aiming to replicate a real lab environment and demonstrate its functionalities. Then, a realistic 3D machine model was used to simulate the real-life operations of a drill press machine used by students (see Figure 2).

The simulation accurately represented 3D models of drill press machines, allowing students to experience heavy and expensive equipment without significant costs. The simulation aided students in performing the experiment in an interactive and safe environment. The simulation was initiated using Unity and set up for VR headset device, implementing 3D models and followed by scaling them to fit the scene, and working on machine model movements as shown in (see Figure 3).

Figure 2. Drill Press Machine

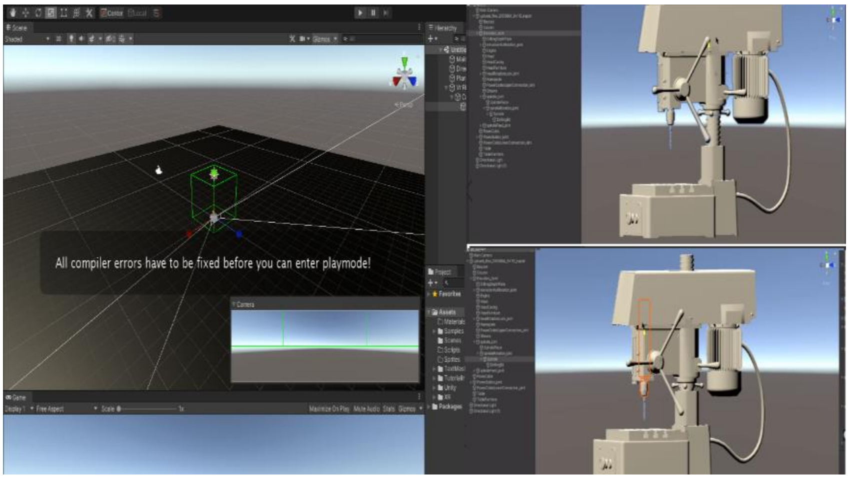

Figure 3. Setting up the drill press machine

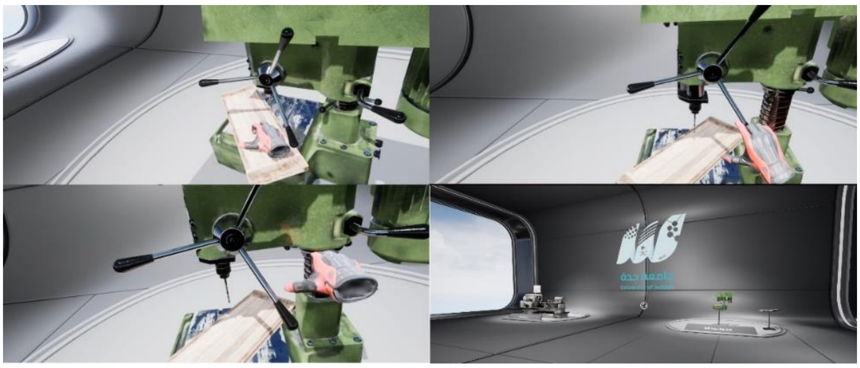

Figure 4. The improved visualization of VR Simulation

The VR simulation was improved by adding more visualization features so students could perform tasks more accurately, quickly, and efficiently (Figure 4). In addition, the VR simulation, set in 6 degrees of freedom (6DOF), allows students to perform experiments freely and use their full bodies.

The third stage involved collecting data on students' perspectives of using VR in engineering lab. The survey included a set of questions to and used to assess students' perspectives of using VR technology in basic workshops course (table 1). It was administrated to over 200 undergraduate engineers as well as engineering professions. The total numbers of responses obtained were 142 (a response rate of 71 percent).

The survey results indicated that (85 percent) of the participants were engineering students, and (89 percent) of them were aged 18-24. It was found that (57 percent) of the students were from the industrial & systems engineering department.

Table 1. Survey Results

Profile	N	%
Major		
Engineering Students	121	85%
Engineering Profession	21	15%
Age		
18-24	126	89%
25-30	15	11%
Engineering Major		
Industrial & Systems Engineering	81	57%
Mechanical Engineering	31	22%
Electrical Engineering	17	12%
Chemical Engineering	13	9%
VR Understanding level		
Excellent	11	8%
Very Good	24	17%
Good	91	64%
Weak	9	6%
Very Weak	7	5%
VR Safety		
Very High	17	12%
High	102	72%
Neutral	14	10%
Low	6	4%
Very Low	3	2%
Practice VR		

Profile	N	%
Yes	37	26%
No	105	74%

The survey results revealed that (64 percent) of participants have a good understanding of VR applications whereas only (72 percent) believe that the VR is safe. The participants responses indicated that (24 percent) did not practice VR on all machines. Overall, the survey highlights that most students were excited to use VR in the basic workshop lab and reported that VR simulations would enhance students' understanding of engineering topics, and make the course safer for students.

The fourth phase involved interviewing instructors to understand their perspectives on VR technologies in engineering education. Two instructors were interviewed to understand their background, teaching approaches, and their opinions on using VR technologies in the course. The course syllabus, learning outcomes, and objectives were discussed. The instructors normally used a TM method that involved a theoretical approach, with short videos provided instead of practical practice. The VR was found to be satisfactory, with two instructors stating it could achieve the course outcomes, while one suggested combining the TM with VR technologies for optimal results. After assessing the instructor's perspectives on using VR, logical models were created with students and instructors' involvement, and the physical model was tested for efficiency. A simulation modeling was implemented, allowing participants to experiment with machines in a safe environment.

The fifth phase involved a time study to determine the average time students spend on a virtual machine, with a 25% allowance for each method. This helped identify bottlenecks and obtain student feedback, distinguishing between manual and virtual machine operation. A time study was conducted following a procedure by Kanawaty and George (1992). The procedure includes three main steps: observing the work. Breakdown operation, and measuring time of each task (see Figure 5).

Figure 5. Time Study Procedure

The work was observed using a video of a drill press machine operation, then analyzed the actual process and represented it in a VR lab simulation. After that, the process was listed and a breakdown of the whole operation tasks was made. The experiment involved five undergraduate students. They were given instructions by the lab supervisor to experiment, following previously mentioned procedures. The experiment process was recorded using video, timer, and visual observation to identify potential issues. A time study was conducted using Excel to analyze the data, as shown in (see Table 2).

Table 2. Time Study Sheet for TM

Time Study Sheet (Physical Machine)								
Operation Name	Cycle Time (Second)					Average	Average	SMV with
	Student 1	Student 2	Student 3	Student 4	Student 5	(Second)	(Minute)	Allowanc
Give machine introduction	15	15	15	15	15	15	0.25	0.31
Give Safety and machine basics	22	22	22	22	22	22	0.37	0.43
Put material between vice	7	7	6	6	9	7	0.12	0.18
Secure material into the vice	11	8	9	9	11	9.6	0.16	0.22
Turn on the machine	3	4	4	4	7	4.4	0.07	0.14
Pull down the feed handle	23	22	21	20	21	21.4	0.36	0.42
Turn off the drill press	3	4	3	4	4	3.6	0.06	0.12
Put down the worktable	31	32	31	31	32	31.4	0.52	0.59
Grab chuck key	7	9	8	9	8	8.2	0.14	0.20
Loosen the chuck	12	12	11	12	11	11.6	0.19	0.26
Remove drill	10	11	10	9	8	9.6	0.16	0.22
Put another drilling tool	32	37	42	31	29	34.2	0.57	0.63
Lift the work table	29	28	30	27	26	28	0,47	0.53
Turn machine back on	6	6	5	5	5	5.4	0,09	0.15
Pull down the feed handle	21	22	22	22	19	21.2	0.35	0.42
Pull up the feed handle	10	9	11	12	11	10.6	0.18	0.24
Turn off the machine	7	5	6	4	5	5.4	0,09	0.15
Put down the worktable	30	27	26	24	25	26.4	0,44	0,50
					Total	**275**	**4.58**	**5.72**

Standard Minute Value (SMV)		
SMV	4.58	Minute for Physical Mahine Practice
SMV with Allowances	5.72	

Expected Allowences		
Allowances	4	Seconds

After that, the experiment was conducted using VR technology. The data was recorded as shown in (Table 3).

A comparison was made between VR and TM and It was indicated that students spend half of the time on VR compared to TM as shown in below (see Figure 6).

The Standard Minute Vale (SMV) was calculated for both VR and TM. It was indicated that VR method is 55.59% faster than TM as shown in the below (see Figure 7).

The sixth phase involves redesigning the facility layout to improve course delivery. The facility layout problem (FLP) is a strategic design problem that involves arranging cells within a defined area to minimize material flow costs. It involves specifying the temporal coordinates, orientation, and pickup and drop-off points of each cell, thereby enhancing system efficiency and flexibility. The measurements of machine size and lab area were identified to obtain the optimal design using AutoCAD software. The main entrance of the lab was redesigned to provide wide space, while the VR needed circulation and maneuvering for easy access.

Table 3. Time Study Sheet for VR

Time Study Sheet (VirtuL Reality Practice)								
Operation Name	Cycle Time (Second)					Average	Average	SMV with
	Student 1	Student 2	Student 3	Student 4	Student 5	(Second)	(Minute)	Allowanc
Give machine introduction	8	8	8	8	8	8	0.13	0.17
Give Safety and machine basics	10	10	10	10	10	10	0.17	0.20
Put material between vice	3	4	5	5	7	4.8	0.08	0.12
Secure material into the vice	4	6	6	7	9	6.4	0.11	0.14
Turn on the machine	2	3	3	3	5	3.2	0,05	0.09
Pull down the feed handle	3	5	6	6	9	5.8	0.10	0.13
Turn off the drill press	2	2	3	3	4	2.8	0.05	0.08
Put down the worktable	8	12	10	14	15	11.8	0.20	0.23
Grab chuck key	2	4	3	5	6	4	0.07	0.10
Loosen the chuck	5	8	7	9	11	8	0.13	0.17
Remove drill	4	7	8	9	12	8	0.13	0.17
Put another drilling tool	4	7	6	7	9	6.6	0.11	0.15
Lift the work table	7	10	9	9	11	9.2	0.15	0.19
Turn machine back on	2	3	3	2	5	3	0.05	0.09
Pull down the feed handle	4	5	5	5	8	5.4	0.09	0.13
Pull up the feed handle	3	6	5	4	8	5.2	0.09	0.12
Turn off the machine	3	5	4	4	7	4.6	0.08	0.11
Put down the worktable	5	6	8	8	13	8	0.13	0.17
					Total	**114.8**	**1.91**	**2.54**

Standard Minute Value (SMV)		
SMV	1,91	Minute for Virtual Reality Practice
SMV with Allowances	2.54	

Expected Allowences		
Allowances	2	Seconds

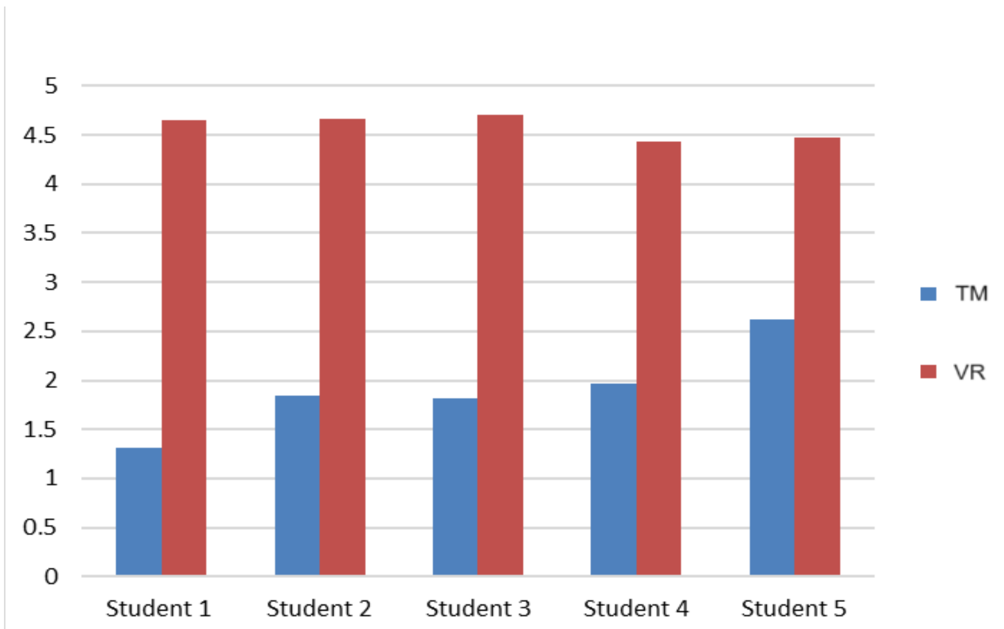

Figure 6. Time Study TM & VR

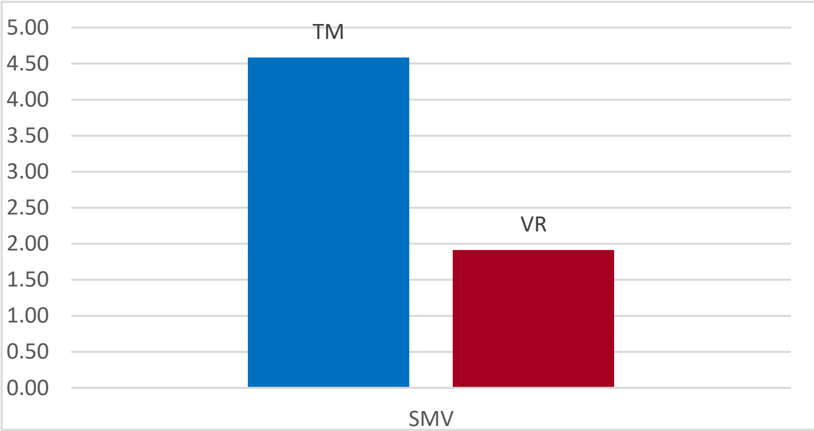

Figure 7: SMV for TM & VR

The last phase involved a cost study to identify the direct costs of traditional and VR method tools and to explore how VR can benefit students. An identification of the names of the four machines in the lab was made. This includes lathe machine, drill press machine, milling machine, and welding machine. The main components of VR were identified, which include VR headsets, screens, PCs, life span, and models. The total cost for the beginning and the cost every 10 years for both VR and TM was calculated and shown in (see Table 4).

Table 4: Total cost TM & VR

Direct cost for VR	Price (SAR)	Direct cost for TM	Price (SAR)
VR device Oculus rift S (life span 5 years)	1,816	Lathe machine	15000
PC HP pavilion, VR ready (life span 5 years)	3,800	Drill press machine	4000
Screen BenQ 24 inch (life span 10 years)	450	Welding machine	7500
Drill press machine 3D model	24	Milling machine	22500
Lathe metalworking machine 3D model	24	Lathe machine maintenance per year	2000
Welding machine 3D model	13	Lathe machine tools per year	1500
Corded milling machine 3D model	169	Lathe machine raw materials per year	1500
Total cost for the beginning	6,295	Drill press machine maintenance per year	1000
Cost every 10 years	11,682	Drill press machine tools per year	500
		Drill press machine raw materials per year	500
		Milling machine maintenance per year	2000
		Milling machine tools per year	1500
		Milling machine raw materials per year	1500
		Welding machine maintenance per year	1000
		Welding machine tools per year	1000
		Welding machine raw materials per year	1000
		Total cost for the beginning	58000
		Cost every 10 years	150000

Discussion

The literature showed that VR is an immersive technology that allows students to experience a simulated environment. Advancements in technology have raised the need to utilize VR in engineering education. The VR simulation represents 3D models of drill press machines, which allowed to experiment virtually. The following observations were noted. The use of VR in engineering lab is cheaper than the traditional method in the long run.

In addition, the traditional method may have some upfront costs that are not included in the initial cost, such as the cost of developing training or renting facilities. Moreover, the cost of VR hardware and software may decrease over time, making virtual reality even more cost-effective in the future. The effectiveness of virtual reality training can vary depending on the specific training program and the learners' individual needs. Indeed, VR is a promising new training method that can offer several advantages over traditional methods, including cost-effectiveness, improved engagement, and increased safety.

Conclusion

Utilization of VR technology in engineering education showed valid and positive results. As an educational tool, VR technologies have revealed usefulness for providing a better understanding, more practical environment while minimizing costs, time, and waste within a safe and harmless for students. The research aims to improve the traditional learning method used in basic workshops course by utilizing VR.

The research covers literature review, and virtual reality simulation for the drilling press machine. A survey was conducted to identify potential issues and to explore the acceptance levels with the TM and VR. Interviews with workshop lab instructors and students were conducted to understand their perspectives. In addition, time study, cost study, and facility layout redesign were used, indicating VR could enhance learning experiences.

It is recommended to develop VR-based training modules for specific engineering disciplines. This could include modules on other engineering courses such as machine design, fluid dynamics, and structural analysis. Incorporate VR into engineering design and prototyping processes is crucial to allow engineering students test and refine their designs in a virtual environment.

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