Harnessing the Technology-Enhanced Learning for Cognitive Progress: A Meta-Analysis of Learners' and Teachers' Reflections on Working with Virtual Reality Tools in Engineering Education

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***Abstract*— This article presents a comprehensive feedback analysis of learners and teachers on the impact of Virtual Reality (VR) tools on learning practical contents. Through a meta-analysis including Chi-Square test of feedback from both learners and teachers, the study aims to evaluate the effectiveness of VR as a technology-enhanced learning tool in fostering cognitive progress and improving educational experiences. The analysis synthesizes qualitative and quantitative data from multiple studies to assess how VR tools influence student engagement, understanding of complex concepts, and collaborative learning. It also examines teachers' perspectives on the integration of VR tools, including their effectiveness in delivering content, enhancing teaching methods, and addressing technical challenges. The findings reveal that VR tools significantly enhance students' learning experiences by providing immersive, interactive environments that facilitate deeper understanding and practical application of engineering principles. Teachers report positive outcomes, including increased student motivation and participation, but also highlight challenges such as the need for high-quality VR content and adequate training. This article contributes to the growing body of research on technology-enhanced learning by offering insights into the practical benefits and limitations of VR tools in engineering education. The study underscores the potential of VR to transform educational practices while also identifying areas for future research to optimize its implementation and impact.**

***Keywords*— Cognitive Progress; Engineering Education; Learner Reflections; Meta-Analysis; Technology-Enhanced Learning; Virtual Reality Tools**

ICTIEE* Track*: Technology Enhanced Learning

ICTIEE Sub-Track: Augmented and Virtual Reality (AR & VR) for Experiential Learning

I. INTRODUCTION

IMPARTING engineering education in the present day requires addressing numerous intricate issues, which arise from both the swift progress of technology and the changing demands of society. One significant obstacle is ensuring that the curriculum remains up to date with the rapid advancement of new technology. Furthermore, the incorporation of interdisciplinary knowledge into engineering education presents challenges, as contemporary engineering issues frequently demand proficiency in other fields, whereas conventional curriculum are usually compartmentalized. Ensuring a harmonious integration of theoretical knowledge and practical application is a crucial concern. Students must possess a comprehensive grasp of fundamental ideas, along with practical experience, to effectively tackle real-world challenges. The presence of students with diverse backgrounds and learning styles adds complexity to teaching, requiring adaptable and individualized instructional methods such as technologically enhanced learning tools namely Virtual Reality enabled platforms. Furthermore, the implementation of cutting-edge pedagogical approaches, such as online education and virtual reality, necessitates substantial financial resources and rigorous assessment to ascertain their efficacy. The promotion of diversity, equity, and inclusion in engineering programs continues to be a crucial concern. Continuous efforts are required to promote underrepresented groups and establish inclusive learning environments. To address such challenges, the modern teaching learning tools and platforms may be utilized for the young generation as they are being the tech savvy leaners.

Contemporary engineering students frequently perceive the traditional academic approach as unsuitable because of its inflexibility and failure to align with current learning preferences. Conventional approaches may be excessively

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theoretical and lack practical relevance, thus failing to captivate students who appreciate hands-on, experiential learning. In addition, traditional methods may not accommodate various learning preferences or properly utilize emerging technologies. The swift rate of technological advancement and the requirement for cross-disciplinary expertise emphasize the inadequacy of obsolete curriculum. Students are increasingly looking for educational opportunities that provide flexibility, creativity, and relevance to their future professions.

Contemporary engineering students choose technology-enhanced education because it provides engaging and immersive experiences that match their digital-native inclinations. Technologies such as virtual reality, simulations, and online platforms offer practical learning experiences that help connect theoretical knowledge with real-world practical applications. Additionally, these tools encourage individualized learning, allowing individuals to learn at their own speed and delve into issues of personal interest in detail. In general, it enhances the learning experience by making it more interactive, applicable, and flexible to keep up with the always changing requirements of the engineering industry.

In such a scenario it may be wise enough to start adopting digital tools and technologies to impart engineering education. Technology-enhanced learning incorporates digital tools and resources, such as virtual reality, simulations, and online platforms, into the educational process. The objective is to develop educational experiences that are interactive, immersive, and tailored to individual learners, hence enhancing their engagement and comprehension. This approach also helps to connect theoretical knowledge with real-world applications.

This article focuses on evaluating the effectiveness of the use of VR enabled teaching aids for undergraduate engineering students. Technology adequacy has been studied using the learners' feedback on their work experience with Virtual Reality enabled experimental exercises for selected courses namely Fundamentals of Surveying. In addition, the reviews of the faculty members imparting such technology enhanced education are also considered. The meta-analysis of the diversified reviews, opinions, experiences has been carried out to ascertain the effectiveness of VR technology for learners' cognitive development.

II. Literature Survey

The utilization of Virtual Reality (VR) tools in engineering education has gained significant attention in recent scholarly works, emphasizing their transformative capacity in improving learning results (Tan, Y., et al., 2024). Research has demonstrated that virtual reality (VR) offers immersive and engaging settings that enable students to comprehend and actively participate in intricate engineering concepts in three dimensions. This is a level of engagement that conventional approaches find challenging to accomplish. Studies suggest that virtual reality (VR) has the potential to greatly enhance spatial cognition, problem-solving abilities, and conceptual understanding through the simulation of real-life situations and the facilitation of interactive experimentation. For example, VR has been employed in virtual labs, design visualization, and structural analysis, providing students with a secure and regulated environment to practice and apply theoretical knowledge (Familoni, B. T., & Onyebuchi, N. C., 2024; Barak, M. et al., 2024). Moreover, virtual reality tools enable cooperative learning and distance education, surpassing geographical and physical constraints (Hidayat, R., & Wardat, Y., 2024).

VR tools are becoming increasingly indispensable in engineering education because they offer immersive and interactive learning experiences that are typically lacking in traditional techniques (Liebehenschel, J., 2024). Virtual reality (VR) allows students to perceive and engage with intricate engineering concepts and systems within a three-dimensional (3D) setting, thereby rendering abstract theories more concrete and facilitating comprehension (Rzanova, S., et al., 2024). The platform provides simulated scenarios that allow learners to engage in hands-on experimentation and problem-solving, free from the limitations and safety risks associated with physical environments. VR tools boost spatial awareness, improve problem-solving skills, and facilitate experiential learning by generating realistic, interactive settings. These skills are vital for understanding complex engineering ideas. Moreover, virtual reality (VR) has the capability of linking theoretical knowledge and practical application, enabling students to interact with state-of-the-art technologies and acquire hands-on experience in a controlled and replicable manner (Negahban, A., 2024). This not only enhances understanding but also equips students with the necessary skills to tackle industry obstacles by offering a more profound and captivating educational encounter (Xu, H., et al., 2024).

It has been reported that VR improves learning outcomes in undergraduate engineering education, according to a research evaluation (Khlaif, Z. N., et al., 2024). VR has been shown to improve spatial cognition and problem-solving by creating immersive, interactive experiences that make abstract concepts more tangible. Practical, hands-on learning is possible with VR labs and 3D simulations. VR improves student engagement and comprehension, but high prices and integration concerns persist. VR can improve engineering education, but more study is needed to overcome practical difficulties (Rossoni, M., et al.,2024).

III. Methodology

A. Introduction to the VR tools

The Civil Engineering program at the authors' university uses virtual reality (VR) enabled learning aids in their study on Concrete Technology to improve educational outcomes. The tools consisted of immersive 3D simulations and interactive environments that enabled students to visually and physically interact with intricate solid structures and processes within a virtual realm. Through the utilization of virtual reality (VR) headsets and controllers, learners could actively participate in practical experimentation including a range of concrete mixing procedures. They can also view the curing process in real-time and study the structural behaviors that occur under different situations. The VR platform included intricate graphics and scenario-based learning modules that enhanced comprehension of material attributes and construction techniques. This novel method offered a captivating and secure setting for students to investigate and test, ultimately enhancing their understanding of theoretical principles and practical abilities in the field of concrete technology.

B. Process of Conducting VR enabled experiment

The VR enabled experimental sessions for one of the courses offered to the Semester 3 students of the department of Civil Engineering has been discussed here. A total of 35 students were offered with the VR enabled experimental framework. The steps followed for the use of VR enabled exercise has been explained as follows in Fig.1.

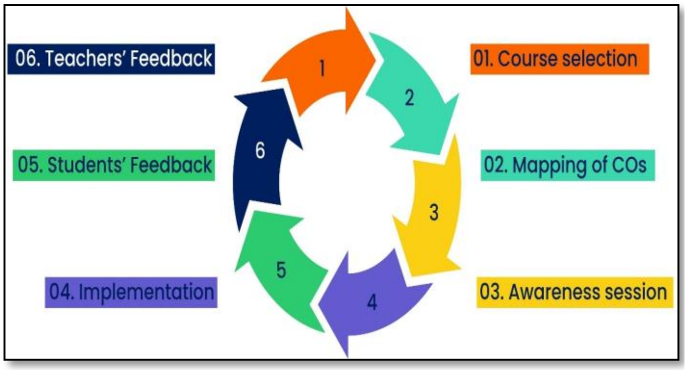


Fig. 1. Process of planning and implementation of VR enabled exercise

C. Pre-Process for VR enabled experiment

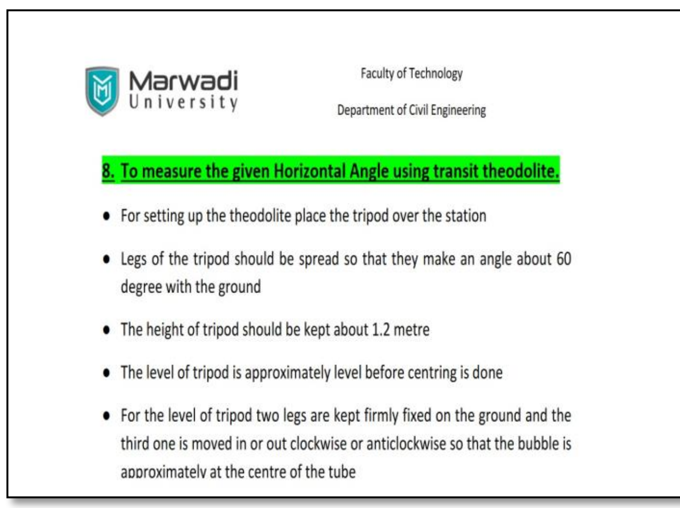
Prior to the commencement of academic term of semester 3, the department planned to implement the VR enabled experiment to the students. However, the task and the nature of the work were all very new to the faculty and students. Therefore, first the faculty were introduced to VR enabled system as shown in Fig.2. Afterwards, the students were also offered a training session as shown in Fig.3. Eventually, the day of experiment was decided. There were two experiments from two courses, namely Introduction to Concrete Mix Design and Surveying were selected from the academic sessions.

Fig. 2. Training session on VR enabled experiments for Faculty members

Fig. 3. Training session on VR enabled experiments for Students

D. Redesigning the lab manual for VR enabled experiments

Upon the completion of training sessions for both the stakeholders, another need was identified in the form of lab manuals. It is to be noted that the regular or conventional experimental work and VR enabled contents are little different in form of writeup and process. There are no actual steps to be taken on the ground. Therefore, it was necessary to make suitable changes in the text of the lab manuals. The most significant change in the text was the procedure to be followed, and the observation tables. Along with these, the conclusion and remark section were also modified accordingly. The part of the modified version of the lab manual is shown in Fig.4 (a) and Fig. 4 (b).



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8. To measure the given Horizontal Angle using transit theodolite.

- For setting up the theodolite place the tripod over the station
- Legs of the tripod should be spread so that they make an angle about 60 degree with the ground
- The height of tripod should be kept about 1.2 metre
- The level of tripod is approximately level before centring is done
- For the level of tripod two legs are kept firmly fixed on the ground and the third one is moved in or out clockwise or anticlockwise so that the bubble is approximately at the centre of the tube

Fig. 4. (a) Statement of experiment in Surveying using VR facilities

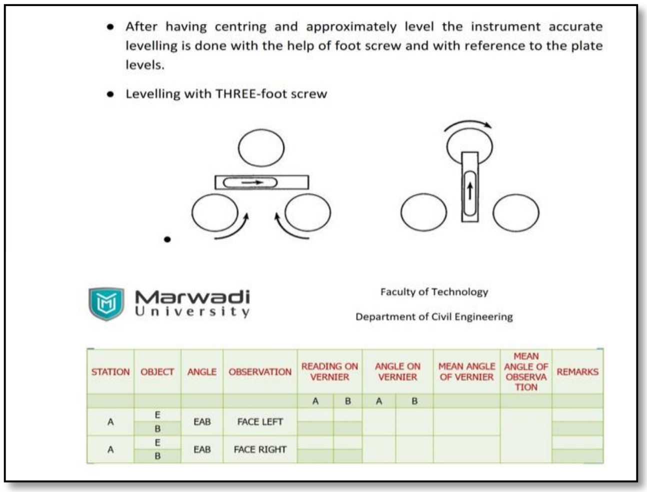

Fig. 4. (b) Instructions and table of observations

Fig. 5 (a) and Fig.5 (b) shows the actual involvement of students in performing the VR enabled experiment in the VR Lab facility at the department of Civil Engineering. The students were first provided with a theoretical background of the work, process and steps to be followed during the exercise. With the help of the VR tools, the student performed the experiment. However, the VR gadgets were limited in numbers, therefore they had to perform the experiment in a small group of five at a time.

Fig. 5. (a) Screen display of VR enabled experiment in Surveying course

Fig. 5. (b) Students following the VR enabled experimental work

E. Post processing of VR Enabled Surveying experiment

The students were offered VR wearables, namely VR glasses and sticks consisting of the movement buttons. They had to learn how to operate and carry out the experiments. In this process, the role of software, namely the VR video clip of complete experiments is very important. The authors' institute made it possible by customizing the 3D videos of nearly ten such conventional experiments to be offered to the students in different programs including Civil Engineering. The average time to complete the experiment was measured to be around 30 minutes including pauses, slow progress of working by students being the new platform and stoppages due to technical concerns if any. After the completion of the experiment, students had to write their learnings in the lab manual customized as per the sequence of the VR video. Finally, students prepared the lab manual with filled data. Regarding the observations and readings, the student worked in a pair of two, one with VR wearables and another with recording the data manually in the observation table. The conclusions had to be written by the students by recalling the entire VR-enabled experiment.

IV. Result Analysis

A successful implementation of VR enabled experiment required detailed analysis and interpretation of the observations collected during the performance. The implementation of VR enabled experiment had a few objectives in line with the syllabus content. Therefore, it was important to ascertain the attainment of the objectives by measuring CO attainment. Moreover, a total of five hypotheses were planned to be cross examined by conducting surveys on students and faculty members involved in the VR enabled experimental work. This section deals with the findings of the meta-analysis of the data collected via surveys of the stakeholders and interviewing them for general opinions.

A. Hypothesis

A set of five statements as hypothesis were devised regarding the evaluation of the feedback of students and faculty getting involved in the VR enabled work. Three out of five related to the students and two were faculty members. The statements are

- Students will be able to understand the complexities of a topic using well defined steps of software used in making 3D VR enabled videos of experiments
- Students will experience more excitement and engagement in doing practical owing to the use of modern digital gadgets of VR enabled framework
- Students will work collaboratively and exhibit more peer learning for the practical while using VR enabled systems
- Faculty will be able to easily demonstrate complex content with the use of 3D models and videos embedded in the VR enabled tools
- Faculty will be able to ensure the equal participation of all students in the practical unlike the conventional framework

Above were the planned hypotheses before conducting the VR enabled experiments in the laboratory sessions. The hypotheses were later confirmed by conducting the survey of all the students and teachers involved in the process. The following are the sample questionnaires shown in Fig. 6 (a) and Fig.(b) offered to the students and teachers respectively. However, for the statistical model namely Chi-Square test the null hypothesis for students' reflections was "Student face challenges in using VR tools for performing practical", and for faculty "Teachers find conducting the experiments using VR tools is difficult". The feedback questionnaire was articulated in a way that both sets of surveys incorporate these core hypotheses.

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SEMESTER 3 FUNDAMENTALS OF SURVEYING

Survey of students on working with VR enabled experimental work on Surveying subject in Civil Engineering Undergraduate Level Program

Sl. No.	Question	Strongly agree	Agree	Disagree	Strongly disagree
1	The VR lab made surveying basics easy to understand.				
2	The VR environment helped me learn hard surveying topics.				
3	The VR simulations matched real-world surveying settings.				
4	Use of VR in the lab increased my interest in the course.				
5	VR navigation and use were easy in the lab.				
6	I gained spatial awareness and visualization skills in the VR lab.				
7	VR labs were more engaging than regular labs.				
8	Working with VR tools was more collaborative in nature				
9	VR tools inspired more interactions and learning from my batch mates				
10	The VR equipment instructions were straightforward and useful.				
11	Overall, my first VR lab experience for Fundamentals of Surveying was good.				

Fig. 6. (a) Survey questionnaire for the students learning via VR laboratory

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SEMESTER 3 FUNDAMENTALS OF SURVEYING

Survey of Teachers involved in imparting VR enabled experimental work on Surveying subject in Civil Engineering Undergraduate Level Program

Sl. No.	Question	Strongly agree	Agree	Disagree	Strongly disagree
1	VR-enabled experiments made surveying basics entertaining and interactive for students.				
2	The VR technology fit easily into the course content and training.				
3	VR technology gave me problems during the lesson.				
4	VR-enabled experiments helped students understand complex surveying topics better than traditional approaches.				
5	VR-enabled trials improved Fundamentals of Surveying students' learning results; thus, I'm satisfied.				

Fig. 6. (b) Survey questionnaire for the teachers involved in VR laboratory

From the above questions, the hypothesis was confirmed from the responses by students and teachers. However, the surveys also collected relevant data on other responses concerning the psychological and cognitive parameters of both stakeholders. The reflections from the surveys were shown in Fig. 7 for students. The responses were found encouraging for the use of VR enabled labs in technical courses for the first time. As the results show good agreement of positive response by the students on use of VR tools for conventional laboratory works, it may be ascertained that even without any significant training the VR tools were found convenient to use by the undergraduate level students. However, merely the qualitative comparison may not be sufficient to reach a conclusion. Therefore, the Chi Square method was utilized to understand the validity of the hypothesis for both surveys namely for the students and faculty members involved and responded to the survey on working with VR tools.

B. The Chi-Square Test Method

The null hypothesis was considered as if the students resist to work or find the working with the VR enabled tools extremely difficult and alternate hypothesis was students find working with VR tools comfortable and interesting. The Microsoft Excel tools were used to carry out. The survey values were neutralized before their use in the test mechanism to obtain realistic values in the final answers. The same test and method were used in faculty survey responses. The null hypothesis was faculty found it difficult to work with VR enabled tools for imparting the teaching of experiential learning and alternative hypothesis was that teachers found working with VR tools relatively comfortable.

C. The formulations

- Calculate Expected Frequencies: For each cell in the table, calculate the expected frequency under the null hypothesis of independence.

$$E_{ij} = \frac{(Row\ total_i\ \times\ Column\ total_j)}{Grand\ total}$$

Where;
E_{ij} is the expected frequency for the cell in the i^{th} row and j^{th} column.
Row $total_i$ is the total of the i^{th} row.
Column $total_j$ is the total of the j^{th} column.
Grand Total is the total sum of all observations in the table

- Calculate Chi-Square Statistic:

$$\chi^2 = \sum \frac{(O_i - E_i)^2}{E_i}$$

Where;
χ^2 is the Chi-Square statistic.
O_i is the observed frequency in the i^{th} cell.
E_i is the expected frequency in the i^{th} cell.
The summation $\sum$ is taken over all the cells in the contingency table

- Degrees of Freedom:

df= (r-1) x (c-1)

where;
r is the number of rows in contingency table
c is the number of columns in contingency table

- Compare with Critical Value: Use the Chi-Square distribution table to find the critical value for 1 degree of freedom at the 0.05 significance level (usually around 3.841).
- Decision: If the calculated Chi-Square statistic is greater than the critical value, reject the null hypothesis and conclude that there is an association between actual and expected values.

Based on the above formula, the following results are obtained where it can be observed that in all feedback responses, the Chi-Square values of a particular response remain well in the limit and the average value of all the responses are also in the limit of desired limit of nearer to zero. Table 1 and Table 2 show the normalized responses and the Chi-Square values of each response by student and faculty respectively.

D. Qualitative analysis of students' feedback on learning with VR tools

All the 35 students of semester 3 class of Civil Engineering were offered a survey form consisting of a set of 11 questions. The questions shown in Fig.7 were carefully designed to map the objectives with the expected outcomes of the practical sessions. However, the focus of questions was more on what the learners feel about using VR technology in their conventional academic framework.

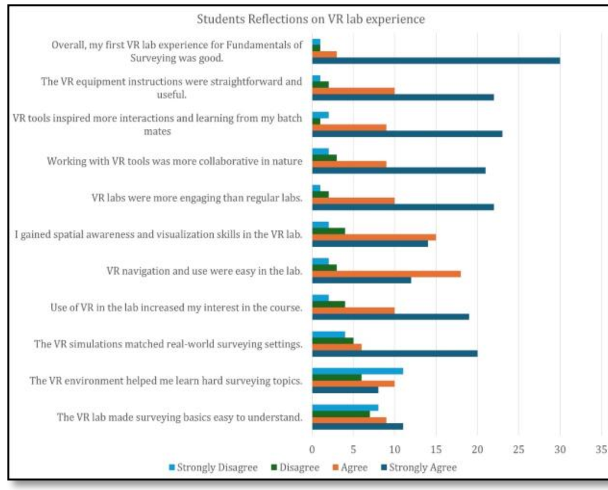

Fig. 7. Students feedback on using VR tools in laboratory

The evaluation of constructive feedback from students regarding their learning experience in the "Fundamentals of Surveying" course, which utilized virtual reality (VR) laboratory instruments, indicates a highly positive reception. Students regularly stated that the immersive virtual reality (VR) environment greatly improved their comprehension of intricate surveying concepts and real-world implementations. The VR tools were commended for their participatory nature, which effectively rendered abstract principles more tangible and captivating. A significant number of students reported enhanced motivation and satisfaction in the learning process, as they credited the VR experience for the development of improved spatial awareness and practical abilities. Collectively, the favorable feedback emphasizes the efficacy of virtual reality technology in enhancing the quality of civil engineering education. The following are some of the statements of students recorded during their interactions with faculty members:

"It was a completely new and highly exciting experience for me of wearing the VR glasses and holding joy sticks in my hands......I had never ever imagined that such gadgets can become a part of our Civil Engineering educational learning methods…I wish to have more such learning tools in other courses...!"

"I was thrilled while executing an actual task virtually…….!"

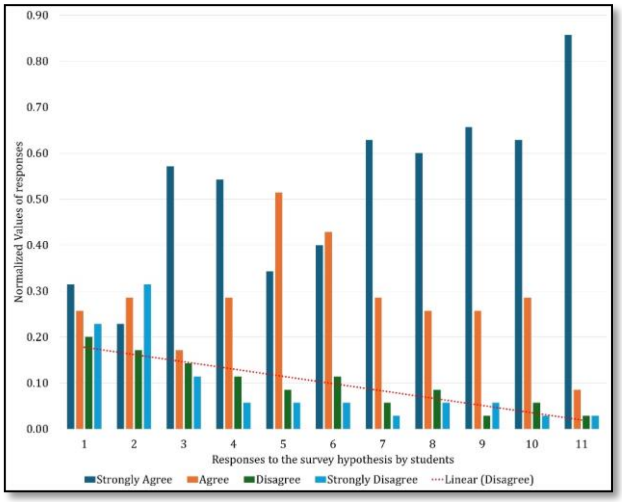

Fig. 8. Normalized response of students' feedback for similarity of opinions

Students expressed overwhelmingly positive feedback regarding their initial utilization of VR-enabled tools during the "Fundamentals of Surveying" practical, highlighting a multitude of advantages that significantly enhanced their educational experience. According to their research, the use of virtual reality (VR) considerably enhanced students' understanding of intricate surveying concepts. This was achieved by providing a more participatory and captivating means of visualizing and applying theoretical information. VR technologies' immersive nature fostered enhanced collaboration among students, allowing them to effortlessly cooperate on hands-on assignments, exchange perspectives, and resolve issues within a virtual environment. The students showed a tangible passion towards utilizing state-of-the-art technology, with numerous individuals expressing interest in integrating contemporary digital tools into their educational experience as reflected in Fig.8. The enthusiasm, along with the interactive involvement facilitated by the virtual reality technologies, enhanced the comprehension of the technical aspects of the subject matter. Students were able to comprehend complicated intricacies and applications of surveying techniques more successfully through their capacity to engage with realistic 3D models and simulations. Collectively, the favorable response emphasizes the significant influence of virtual reality (VR) technology on both the process of acquiring knowledge and the level of involvement of students in technical education.

E. Statistical Analysis of feedback by students

The analysis of the feedback was extended by applying the Chi-Square methodology to understand and validate the actual advantages of using VR enabled tools in the laboratory.

TABLE 1
ANALYSIS OF STUDENTS' FEEDBACK USING CHI-SQUARE METHOD

	Statement	Strongly Agree			Agree			Disagree			Strongly Disagree		
		A	N	Chi	A	N	Chi	A	N	Chi	A	N	Chi
1	The VR lab made surveying basics easy to understand.	11	0.31	0.08	9	0.26	0.00	7	0.20	0.10	8	0.23	0.20
2	The VR environment helped me learn hard surveying topics.	8	0.23	0.17	10	0.29	0.00	6	0.17	0.05	11	0.31	0.25
3	The VR simulations matched real-world surveying settings.	20	0.57	0.00	6	0.17	0.04	5	0.14	0.02	4	0.11	0.00
4	Use of VR in the lab increased my interest in the course.	19	0.54	0.00	10	0.29	0.00	4	0.11	0.00	2	0.06	0.01
5	VR navigation and use were easy in the lab.	12	0.34	0.06	18	0.51	0.19	3	0.09	0.00	2	0.06	0.01
6	I gained spatial awareness and visualization skills in the VR lab.	14	0.40	0.03	15	0.43	0.07	4	0.11	0.00	2	0.06	0.01
7	VR labs were more engaging than regular labs.	22	0.63	0.02	10	0.29	0.00	2	0.06	0.02	1	0.03	0.05
8	Working with VR tools was more collaborative in nature	21	0.60	0.01	9	0.26	0.00	3	0.09	0.00	2	0.06	0.01
9	VR tools inspired more interactions and learning from my batch mates	23	0.66	0.03	9	0.26	0.00	1	0.03	0.05	2	0.06	0.01
10	The VR equipment instructions were straightforward and useful.	22	0.63	0.02	10	0.29	0.00	2	0.06	0.02	1	0.03	0.05
11	Overall, my first VR lab experience for Fundamentals of Surveying was good.	30	0.86	0.12	3	0.09	0.14	1	0.03	0.05	1	0.03	0.05
	Average Chi-Square values for each response		*0.05*			*0.04*			*0.03*			*0.06*	

A- Actual response value, N- Normalized response value, Chi- Chi square value

The analysis of the feedback was extended by applying the Chi-Square methodology to understand and validate the actual advantages of using VR enabled tools in the laboratory. The Chi-Square test was utilized to examine students' input on their favorable thoughts regarding the utilization of VR-enabled equipment for practical in the "Fundamentals of Surveying" course. The Chi-Square test was used to see if the distribution of positive feedback deviated considerably from what was expected under the null hypothesis. This was done by categorizing input into positive and neutral replies. Within this framework, the Chi-Square indicator quantifies the difference between the actual number of positive feedback received and the expected number of feedback if the use of VR tools had no impact on student happiness. An optimal Chi-Square value would be rather small, showing that the observed positive reactions closely match the expected frequencies, implying a strong endorsement of the influence of VR technologies. On the other hand, a high Chi-Square value would indicate substantial disparities, implying that the VR tools have had a noticeable impact on students' favorable impressions. To obtain significant outcomes, it is preferable for the p-value linked to the Chi-Square statistic to be less than 0.05, hence verifying statistical significance.

The results in Table 1 show that the average Chi-Square Static values are either nearer or less than 0.05. This represents good acceptance of the hypothesis proposed at the time of survey on the learners. Both the qualitative and quantitative analysis of the feedback by students showed that the implementation of VR enabled pedagogy not only supported them in better understanding of complex concepts, but also provided refreshing experience with lot of excitement while working with such modern gadgets compared to the conventional method. However, it must be noted that the VR tools should be utilized as a teaching tool primarily and should not be used as alternative or replacement of the conventional method of performing experiments in the laboratories, especially in core branches such as Civil Engineering or Mechanical Engineering. This is because VR technology can provide all the clarities with a simplified approach to the learners. However, students need the support of the faculty members for resolving their personal challenges also.

F. Qualitative analysis of teachers' feedback on teaching with VR tools

An analysis of instructors' input on adopting virtual reality (VR) tools for education indicates an overall positive response, emphasizing various significant advantages. Educators value the augmented capacity of virtual reality (VR) instruments to deliver intricate concepts in a dynamic and captivating manner, hence promoting a more profound comprehension among students. Educators also observe enhanced student collaboration and engagement in hands-on activities supported by virtual reality (VR) environments. Nevertheless, they recognize certain obstacles, such as the requirement for top-notch content and user-friendly interfaces. Furthermore, there is a demand for enhanced technical assistance and more organized educational resources. In general, educators perceive virtual reality (VR) as a beneficial resource for updating and enhancing educational methods.

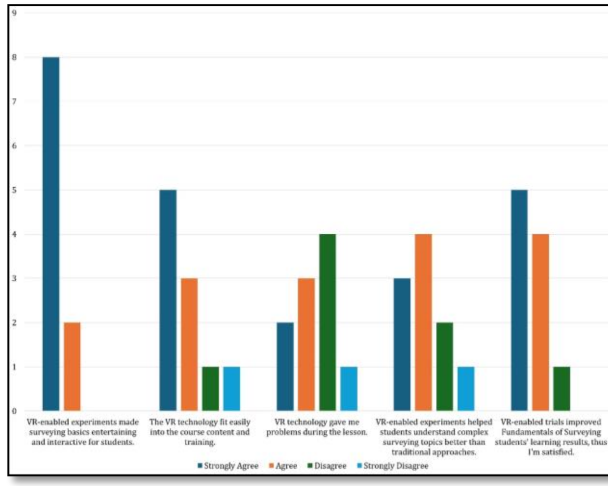

Fig. 9. Teachers' feedback on working with VR tools

The teachers expressed their positive input regarding the implementation of virtual reality (VR) tools in performing surveying practical for the civil engineering program as shown in Fig.9. They emphasized many significant benefits of using VR tools. The VR tools were seen to be highly user-friendly, including an intuitive UI that enabled effortless navigation and engagement for learners of varying proficiency. The immersive virtual reality (VR) environment enhanced student engagement and motivation by making learning enjoyable and stimulating. The inclusion of step-by-step instructional videos in the VR modules was highly valued by teachers. These films provided systematic guidance to students on complicated surveying techniques, assuring clarity and reinforcing learning at every point. Moreover, the cooperative functionalities of the virtual reality tools promoted enhanced collaboration among students, facilitating the development of effective cooperation and communication skills while they addressed real-world difficulties. In general, teachers noted that these virtual reality (VR) tools not only enhanced the learning experience but also made it more dynamic and participatory, resulting in a better understanding of surveying principles and a more enjoyable educational experience. The favorable feedback highlights the efficacy of virtual reality (VR) technology in revolutionizing conventional teaching approaches and captivating pupils through inventive means.

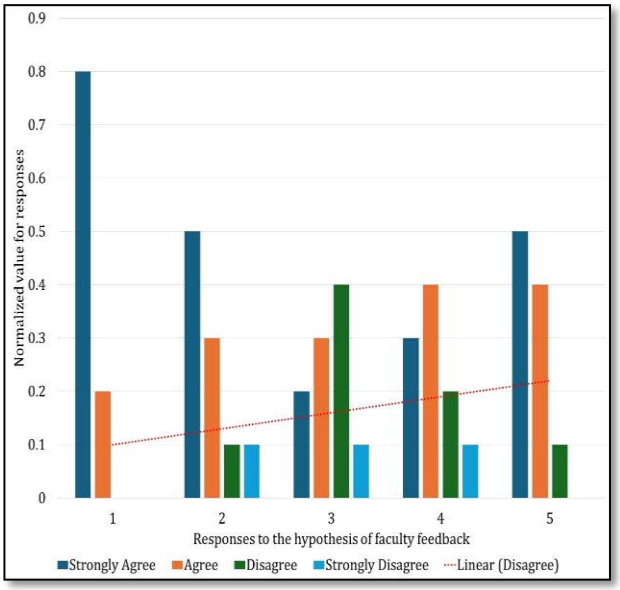

Fig. 10. Normalized feedback by teachers for similarity of opinions on VR tool usage

When normalized values from teachers' feedback on using VR tools as shown in Fig.10 as a teaching aid for surveying practical in the civil engineering program are looked at, a very positive reaction is seen. The fact that most teachers strongly agreed with how well VR tools worked shows that everyone agrees that these tools make learning a lot more fun. One important thing that the comments showed was that most teachers did not agree with the idea that VR tools are hard to use or handle when teaching. There is agreement on this because the normalized numbers show that a lot of teachers don't think VR tools are hard to use or burdensome. Teachers said that the VR tools were easy to use because they had simple, straightforward interfaces and designs. This made it easier for them to be incorporated into their teaching methods. It was also said that the immersive and interactive nature of VR tools made practical lessons more interesting and useful, which improved the experiences of both teachers and students. The normalized data shows that teachers thought VR tools were useful and easy to use, which dispels any original doubts about their usability. This good feedback shows that more people are open to using VR technology in school, highlighting its ability to bring difficult surveying ideas up to date and make them more interesting. The fact that most people agree on how easy and useful VR tools are points in a good way for bringing new technologies into schools in the future.

G. Statistical validation of Teachers' feedback

Like the students' feedback analysis, the teachers' feedback has been analyzed using the Chi-Square test. The results are tabulated in Table 2. The average values of Chi-Square test have been considered in obtaining the concluding remarks.

TABLE 2
ANALYSIS OF FACULTY FEEDBACK USING CHI-SQUARE METHOD

	Statement	Strongly Agree			Agree			Disagree			Strongly Disagree		
		A	N	Chi	A	N	Chi	A	N	Chi	A	N	Chi
1	VR-enabled experiments made surveying basics entertaining and interactive for students.	8	0.80	0.150	2	0.20	0.045	0	0.00	0.016	0	0.00	0.060
2	The VR technology fit easily into the course content and training.	5	0.50	0.003	3	0.30	0.001	1	0.10	0.012	1	0.10	0.027
3	VR technology gave me problems during the lesson.	2	0.20	0.015	3	0.30	0.001	4	0.40	0.036	1	0.10	0.027
4	VR-enabled experiments helped students understand complex surveying topics better than traditional approaches.	3	0.30	0.056	4	0.40	0.020	2	0.20	0.010	1	0.10	0.027
5	VR-enabled trials improved Fundamentals of Surveying students' learning results, thus I'm satisfied.	5	0.50	0.003	4	0.40	0.020	1	0.10	0.023	0	0.00	0.060
	Average Chi-Square values for each response		0.045			0.018			0.019			0.040	

A- Actual response value, N- Normalized response value, Chi- Chi square value

The statistical examination of teachers' input on the utilization of virtual reality (VR) tools in civil engineering practical, assessed using the Chi-Square test, yields valuable insights into the efficacy and adoption of this technology. The Chi-Square test revealed a significant alignment between the observed frequencies of teachers' replies and the expected frequencies under the null hypothesis. This suggests that the feedback received was consistently favorable. The Chi-Square statistic obtained was significantly below the necessary threshold for statistical significance, indicating a strong consensus among teachers regarding the usefulness and impact of VR technologies. More precisely, a low Chi-Square value, along with a high p-value, indicates that there is no substantial departure from the expected distribution, so confirming that teachers usually regarded VR technologies to be user-friendly and advantageous. The p-value, beyond the traditional significance threshold of 0.05, provides additional evidence supporting the lack of any substantial negative feedback concerning the ease of use of the VR products. This statistical result highlights that most teachers did not find VR products difficult to use, confirming their positive acceptance. In general, the Chi-Square test results indicate that the implementation of virtual reality (VR) tools in civil engineering practical has been widely accepted by educators, demonstrating their efficacy in improving teaching and learning experiences. This favorable feedback is consistent with the overarching goal of using cutting-edge technology in academic courses to cultivate more captivating and efficient educational settings.

H. Observed concerns and challenges on VR tools during the study

Although the "Fundamentals of Surveying" practical were generally well received, both students and professors acknowledged many limitations and issues associated using VR technologies. An important issue that arose was about the quality of the 3D movies. Informal feedback revealed that the lower resolution and inadequate graphics compromised the immersive experience and impeded the understanding of intricate surveying ideas. Furthermore, both groups emphasized the necessity of a concise and organized series of tangible actions within the virtual reality setting. Additionally, there was a demand for improved educational material that includes comprehensive visual and spoken explanations of the specific characteristics and methods utilized in each practical task. This involves incorporating on-screen prompts and v
oice-over instructions to assist users in comprehending and accurately performing the surveying operations. This feedback by the users were however communicated to the agency involved in making the videos and software part of the practical, there should be an observatory committee of student and faculty to have a preview of such details before sanctioning and acquiring the data from the resources or agencies. It is essential to overcome these restrictions to maximize the efficiency of virtual reality instruments in practical education.

V. Scope for future study

"Harnessing the Technology-Enhanced Learning for Cognitive Progress" includes study into how Virtual Reality (VR) tools can be used in engineering education in the future. In the future, researchers might investigate how to make VR settings work best for different types of learners, how to use AI-powered adaptive learning systems to make experiences more personalized, and how to measure the long-term effects on learning and everyday life. Researchers could also investigate how well immersive VR works in group and remote learning situations and how VR tools might be able to fill in holes in traditional education. The study of these topics by experts can lead to better ways of teaching and help technology-enhanced learning grow.

Conclusions

While performing the interesting study on the use of VR enabled technology and tools as teaching aids for performing the practical in the laboratory of Civil Engineering undergraduate program at the University, the following important conclusions have been made:

- To implement VR technology for core courses of study, there is a need for strategic planning by the instructors and teachers. The pre and post processes bear immense importance for the successful implementation of such modern methods among the conventional pedagogical practices.
- Students and teachers must be provided with specific training sessions before the use of VR tools for performing the practical in laboratory work.
- Both the qualitative and quantitative responses of students on their very first experience of using VR enabled tools in learning showed positive and favorable results. The hypotheses statements were confirmed by conducting the Chi-Square test method and showed good agreement between the expected and observed values of the feedback.
- The teachers' feedback analysis also showed good coherence of expected and actual values of the Chi-Square test results and the qualitative analysis of the reflections on using VR tools as one of the teaching aids to impart the knowledge of practical exercises in the core courses of Civil Engineering program.
- The results showed that using VR enabled tools along with the conventional pedagogical practices can be helpful to simplify the complexity of the contents and add value to the learning experience for the students.
- A few concerns on the use of VR tools namely 3D video quality, sequence of instruction, use of correct tools in videos are important attributes to be focused while preparing the videos for the given practical exercise and may influence the learning experience to an extent. These were the points collected during the actual performance of the practical sessions in the laboratory taken as informal suggestions by the students and teachers for improvement.
- Overall, the study showed that the use of VR tools in an existing academic framework is a welcoming step for students and teachers to explore more digital technologies in engineering education.

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