Developing VR Technologies for Engineering Education

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***Abstract*— This research explores the development and evaluation of a Virtual Reality (VR) Learning and Practical Hub aimed at improving mechanical engineering education at a Faculty of Engineering. A survey was conducted with students across various academic levels to identify essential engineering concepts and practical sessions for VR integration. The VR application was refined through pilot tests, incorporating student feedback. A final evaluation was performed by comparing traditional and VR-based practical sessions, measuring student engagement, productivity, and interest. The results indicate that VR has significant potential to enhance learning experiences in engineering education.**

Keywords*— *Virtual Reality (VR), Engineering Education, Virtual Learning Environments, Immersive Learning, Pedagogical Approaches, Educational Technology, digital learning

I. Introduction

Virtual Reality (VR) has rapidly evolved into a prominent technology with significant implications for various fields, including engineering education. Traditional engineering education often presents challenges due to the complexity of the material. Students may find it difficult to fully grasp concepts when learning about machinery through only presentation slides, images, and videos. Additionally, the heavy workload often limits students' ability to review past academic work, affecting their understanding and retention of complex subjects.

Engineering education typically comprises theoretical lectures and practical lab sessions. However, access to modern machinery and equipment used in industry is often restricted during these lab sessions. Supervised sessions limit students' opportunities for experimentation, as unauthorized configurations might damage costly equipment. Increased familiarity with testing and components is crucial for engineering students, and VR technology offers a promising solution to overcome these constraints.

VR provides an interactive, computer-generated environment that allows users to engage with an artificially constructed world as though they were physically present [1]. By creating virtual labs, VR technology addresses the issue of limited access to physical resources, providing immersive experiences that facilitate the teaching of complex topics and concepts. A survey conducted by the Career Office at Lodz University of Technology revealed that 50% of mechatronics graduates feel unprepared for their future professional roles [2], underscoring the need for educational tools that better prepare students for their careers.

Research comparing VR-based teaching with traditional methods has demonstrated that students using VR achieved significantly higher marks, with some studies showing a 32.4% increase in performance [3]. This highlights the potential of VR to revolutionize engineering education by offering a more engaging and effective learning experience. VR creates an immersive experience through interactive computer simulations. Key elements of VR include a virtual environment, which defines objects and their interactions, and virtual presence, which provides the sensation of being in a place through physical or psychological immersion. Additionally, VR systems offer sensory feedback, primarily visual with occasional haptic elements, and allow for interactivity, enabling users to influence the virtual world and adjust their viewpoint [4].

Through the integration of VR into engineering education, students can bridge the gap between theoretical knowledge and practical application, ultimately enhancing their preparedness for the engineering challenges of the future.

II. Literature Review

Virtual Reality (VR) technology has significantly impacted engineering education, evolving from early concepts to advanced applications. VR's integration involves both hardware and software components that facilitate its use beyond entertainment, extending into educational settings. Current research highlights VR's role in enhancing learning experiences and aligning with educational objectives. Studies have shown that VR can improve student engagement and performance while addressing challenges related to its adoption. Additionally, emerging trends and future advancements in VR-enhanced education are being explored.

A. Historical Evolution of VR

The concept of Virtual Reality (VR) began in 1957 with Morton Heilig's Sensorama, an early multi-sensory experience. In 1968, Ivan Sutherland developed the first head-mounted display linked to a virtual environment, introducing three-dimensional vision. Myron Krueger's interactive VR environments in the early 1970s, including the Video Place system, allowed for multi-user interactions. The term "virtual reality" gained popularity in the 1980s through cultural references like William Gibson's Neuromancer and the film Tron. The 1990s saw the development of the CAVE (Cave Automatic Virtual Environment), which provided immersive experiences using screens, electromagnetic sensors, and surround sound. The 2010s brought major advancements with Palmer Luckey's Oculus Rift, HTC Vive's motion controllers and positional tracking, and Sony's PlayStation VR. Today, VR is transformative across various fields, including medicine, entertainment, education, and design [4], [5].

B. VR Hardware and Software

The functionality of VR technology relies on various hardware and software components. Key hardware elements include VR headsets, input devices, sensors, controllers, and connecting equipment. For instance, the HTC Vive headset features a wired connection with two lenses, a screen, and integrated sensors such as a gyroscope, accelerometer, and laser position detectors. It also includes built-in features like a headphone jack, front camera, microphone, and Bluetooth connectivity. The system utilizes wireless controllers with programmable buttons and a touchpad, and lighthouses (base stations) that use infrared lasers to track the headset and controllers within an area of up to 12.25 square meters.(m^2) Additionally, a connector box links the headset to a computer or TV. In terms of software, VR content is developed using tools such as Unity 3D, Unreal Engine, and 3D modelling software like 3ds Max. VR development platforms, including OpenSpace and ENTiTi, alongside programming languages such as JavaScript, C#, and C++, are essential for creating immersive VR applications [2], [6], [7].

C. Applications of Virtual Reality

Virtual Reality (VR) has found applications across various fields, enhancing experiences and functionalities in multiple domains. In marketing and sales, VR offers interactive virtual showrooms, allowing customers to explore and engage with digital prototypes of complex products [8]. Flight and driving simulators utilize VR to provide a risk-free environment for training pilots and drivers, which would be unsustainable through traditional methods [9].

In the medical field, VR is used for surgical training, enabling surgeons to practice procedures and enhance their skills in situations where live practice is not feasible [10]. VR has also been applied in tourism promotion, offering immersive experiences to showcase destinations [11]. Additionally, VR-based exposure therapy has been explored as a treatment method for anxiety disorders and depression [12].

D. Virtual Reality Applications in Engineering Education

VR has made significant strides in engineering education, offering enhanced visualization and immersive experiences across various disciplines. VR enables immersive design reviews, allowing engineers and students to assess digital models in a virtual environment, which improves the evaluation of size, proportion, aesthetics, ergonomics, and spatial relationships [13]. It also facilitates interactive assembly and disassembly, providing step-by-step visual guides that help engineers practice and ensure proper fit and alignment before handling physical prototypes [14]. Additionally, VR creates controlled environments for simulation and training, allowing users to develop skills and confidence through virtual interactions with equipment and emergency scenarios [15]. Furthermore, VR supports fire safety training by immersing students in emergency situations, enabling them to practice proper responses without real-world risks [16].

E. Virtual Reality Curriculum Intergration

Integrating VR into engineering curricula significantly enhances educational productivity across various disciplines. In mechanical engineering, VR provides an immersive experience for understanding complex machinery and prototypes, allowing students to interact with and grasp mechanical systems virtually. It also enriches practical demonstrations by facilitating interactive engagement with mechanical systems, thus improving comprehension of mechanical concepts. For electrical engineering, VR enables virtual simulations of electrical panel services, offering students the opportunity to practice and troubleshoot electrical systems without physical constraints. In civil engineering, VR enhances the visualization of structural designs and construction projects, presenting complex designs in an immersive manner that surpasses traditional 3D models. Additionally, VR supports software testing and development in computer engineering by facilitating the creation and evaluation of software applications in virtual environments, fostering innovation in immersive web and mobile applications.

F. Student engagement and performances

The impact of VR technology on engineering education is evident through its effects on student engagement and learning outcomes. Research and experiments highlight its positive influence. In an interview with 60 students following a VR-based session, participants rated various aspects of their experience on a scale from 1 to 5, where 1 is the lowest and 5 is the highest [2]. The aspects evaluated included the overall experience, the tool's usefulness for presenting exercises, its effectiveness in transferring knowledge, the realism of the presented device, and the students' preference for using the VR system in classes. The results indicated that most students rated these aspects highly, demonstrating strong positive interest in incorporating VR into engineering education.

G. VR Challenges and Limitations

Despite its potential, VR technology faces several challenges. High costs and technical requirements can be prohibitive, and there is a significant need for content development. Users often experience motion sickness and health issues like eye strain. Additionally, there is a steep learning curve, limited content availability, accessibility concerns, and a lack of standardization and interoperability, which impede widespread adoption.

H. Future Trends and Innovations

VR is increasingly integrated with technologies like AR, MR, and XR, with future advancements set to enhance engineering processes [17]. Upcoming VR technologies will enable global real-time collaboration in shared virtual environments, improving efficiency and creativity among engineers. Additionally, VR's integration with digital twin technology will allow engineers to monitor and optimize physical products using real-time sensor data. Advancements in VR, such as gesture recognition, voice commands, and haptic feedback, will further enhance human-machine interactions, making the design process more intuitive and improving overall system usability.

III. METHODOLOGY

A. Research Design

This research focused on developing a Virtual Reality (VR) application designed as a practical and educational hub for mechanical engineering. The application was intended to facilitate university practical sessions, conduct educational sessions, and provide distance learning opportunities through VR headsets. The research followed an experimental approach, which included several key steps. Initially, a survey was conducted to identify relevant mechanical engineering concepts and practical tasks suitable for VR integration. Based on the survey data, user needs were assessed to guide the application development. The VR application was developed in alignment with these identified needs. Finally, the application was tested and refined based on user feedback to ensure its effectiveness and usability.

B. Data Collection and Data Analysis

Data for the development of the VR application were collected through a Google Form-based survey administered to engineering faculties at government universities in Sri Lanka. The survey included seven questions addressing various aspects such as the year of study, prior VR experience, challenging mechanical engineering concepts or topics, practical sessions suitable for VR demonstration, essential VR features for enhancing learning, challenges in understanding mechanical engineering concepts, and anticipated benefits of VR in mechanical engineering education. A total of 58 responses were collected.

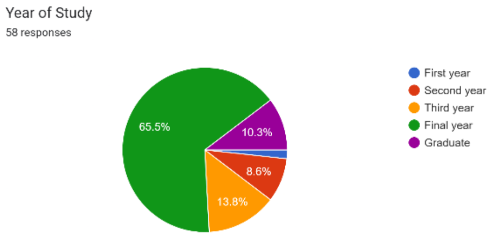

Fig. 1. Results of survey – year of study

Based on the survey results and their relevance to the curriculum, specific mechanical engineering concepts were identified. Notably, "thermodynamic concepts" emerged as significant. Among practical sessions, the "thermal conductivity of liquids" was selected as the most suitable for initial VR integration. This selection was based on factors such as the complexity of designing and developing the VR application, the level of immersive engagement it offers, learning outcomes, and its relevance to students according to their academic year.

C. Development tools and Environment

Selecting the appropriate software and hardware is crucial for the development of a VR application. This project utilizes a combination of game engines, VR application development software, photo editing tools, and video editing/animation software. The primary hardware component is a VR headset.

The Unity development platform was chosen for the creation of the VR application due to its robust support for VR experiences and interactive 3D content. Adobe Photoshop and Adobe Premiere Pro were utilized for photo and video editing purposes, respectively. After careful analysis, the Meta Quest VR headset was selected as the preferred VR device for its compatibility and performance.

To create the necessary 3D models, SolidWorks and SketchUp software were employed, allowing for detailed and accurate modelling of practical apparatus and virtual environments.

D. VR Application Design

The design of the VR application was informed by survey results indicating a preference for immersive and interactive learning experiences, particularly simulations of complex operations. The "VR Learning and Practical Hub" application was structured into several distinct virtual environments: a Practical Room for conducting experiments, a Classroom for learning theoretical concepts, a Workshop for specialized training sessions, and an Exam Room for quizzes aimed at enhancing knowledge and experience. The initial implementation focused on creating a virtual laboratory for the "Thermal Conductivity of Liquids" practical.

Fig. 2. VR environment design using Unity

Fig. 3. Inside view of virtual lab in VR application

Before implementing the practical activities, standard procedures and apparatus were reviewed. The GUNT WL 422 apparatus [18] and its accompanying computer software were used as references to design the VR practical. The objective was to enable the experimental determination of the thermal conductivity of water and to compare these results with standard values.

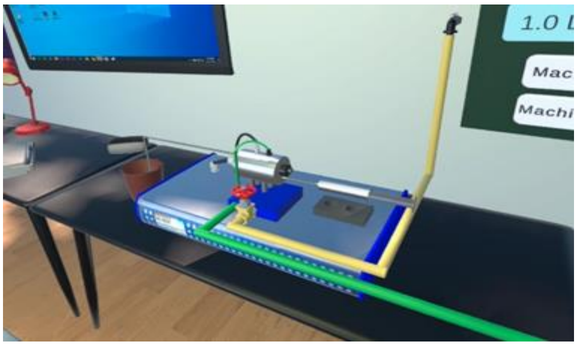

Fig. 4. WL 422 Virtual apparatus

E. VR Application Testing and Improving

Upon completion of the initial version of the VR application, a pilot test was conducted with a small group of users to evaluate the functionality and user experience. Based on the feedback received, several optimization processes were implemented to enhance performance. These included optimizing frame rates (FPS), reducing draw calls, minimizing polycount, optimizing textures, and implementing anti-aliasing. Additionally, new light map settings, including baked and real-time lighting, were tested and applied to further improve the visual quality and realism of the VR environment [19].

IV. Results and Discussion

This study evaluated the productivity, interest, and engagement of students using both traditional and VR-based methods for practical sessions. The evaluation was carried out in two phases with quizzes administered to ten students who participated in both types of practical sessions.

In the first phase, students completed a traditional practical experiment followed by a hard copy quiz (first quiz). This quiz assessed various aspects, including overall satisfaction with the practical method, clarity of instructions, engagement level, ease of equipment setup, comfort, and suggestions for improvement. The feedback gathered highlighted several areas of satisfaction and areas needing improvement in the traditional method.

The second phase involved students engaging in a VR-based practical session covering the same experiment. Following this session, a second quiz was administered to compare the VR-based method with the traditional approach. The quiz questions focused on effectiveness in understanding the concept of thermal conductivity, clarity of instructions, engagement level, ease of use, and personal preference between the two methods.

The results from the second quiz showed a clear preference for the VR-based method. Students reported that the VR method was more effective in understanding the concept of thermal conductivity due to its immersive and interactive nature. They found that instructions within the VR environment were clearer and that the experience was more engaging compared to the traditional method. Additionally, students rated the VR method as more intuitive and easier to navigate.

Figs. 5 and 6 illustrate these findings, with a majority of students preferring the VR-based method for both effectiveness and personal preference. The data indicate that VR technology can significantly enhance student engagement and comprehension in practical sessions.

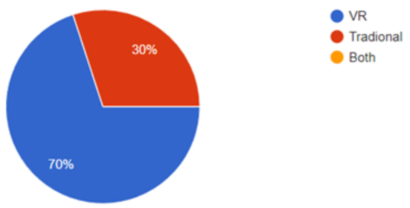

Fig. 5. Results of second quiz – More effective method for users

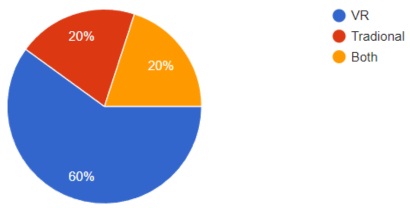

Fig. 6. Results of second quiz – Personal preference for the conducting practicals

These results suggest that integrating VR technology into practical sessions could lead to improved learning outcomes and greater student satisfaction. The immersive nature of VR seems to offer a more engaging and effective means of understanding complex concepts compared to traditional methods.

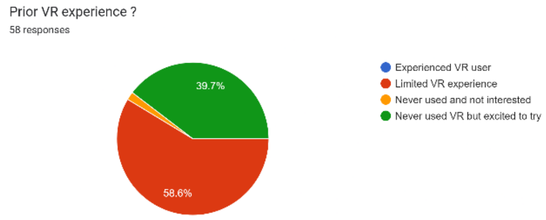

Fig. 7. Results of survey – Prior VR experience of users

The survey data (Fig. 7) indicate that users, regardless of their prior VR experience, responded positively to the use of VR in engineering education. This supports the notion that VR can significantly enhance practical learning experiences. A comparative analysis with existing VR studies shows both similarities and unique features of this application. Strengths of the VR sessions include their immersive and interactive nature, which enhances learning.

For users, the primary cost is the purchase of a compatible VR headset, such as the Meta Quest series, and if the application is priced, users would need to pay for the app. On the developer's side, expenses include hardware such as high-performance computers necessary for running VR development software, as well as costs for VR engines, 3D modeling software, editing tools, and VR assets. These expenses are essential for the development and deployment of VR applications.

While the pilot test provided valuable insights, the small sample size of ten students may limit the generalizability of the findings to the broader population of engineering students. Expanding the study to include a larger and more diverse group of participants from multiple universities would enhance the reliability and applicability of the results. Additionally, increasing the number of students participating in the final quiz evaluation could further refine the understanding of the VR application's impact on learning outcomes.

V. Conclusion

In 2016, VR and AR hardware sales reached approximately $700 million [2], underscoring the significant growth potential of these technologies. Major tech companies like Samsung, HTC, Sony, Microsoft, Google, and LG have introduced commercial VR solutions, reflecting a global trend towards more immersive experiences. This trend highlights the importance for educational institutions to integrate advanced technologies, particularly in engineering education.

Despite the growing interest, the adoption of VR remains limited. To fully harness its potential, ongoing development and investment in VR technologies are crucial. As evidenced by this research, VR offers substantial benefits, including improved engagement, enhanced understanding, and the development of practical skills. Integrating VR into educational curricula provides a more immersive learning experience, allowing students to explore foundational concepts and complex scenarios interactively. VR's accessibility features promote inclusivity, offering diverse opportunities for educators through virtual labs, simulations, and collaborative spaces.

Additionally, recent studies indicate that 87.2% of individuals aged 16–24 demonstrate a high awareness of VR technologies, with 72% of school students expressing a strong preference for using VR as a medium of learning [20]. These findings underscore the critical and timely need to implement and focus more on VR technologies, ensuring their integration into educational systems to meet growing demands and maximize their potential.

The incorporation of VR not only enhances the learning process but also equips students with practical skills and problem-solving abilities essential for their future careers. It fosters innovation, creativity, and adaptability—key traits of successful engineers. The findings suggest a strong user preference for VR-based practical sessions due to their effectiveness, ease of use, and clarity of instructions.

Students provided valuable suggestions for improving the VR application. Some mentioned the need for additional time to familiarize themselves with the VR headset before conducting practical sessions. There were also suggestions to extend the duration of the practical, allowing for more in-depth exploration. Enhancing the realism of the graphics and eliminating lag was another area highlighted for improvement. A few students expressed a preference for using the VR-based method as a pre-lab activity to better understand the practical before engaging in the traditional method. Others preferred a combination of both methods, so they could repeat the experiments as often as needed to reinforce their understanding. Additionally, there were suggestions for improving the haptic feedback to make the experience more immersive. A few negative incidents were reported, with some users experiencing headaches after prolonged VR use. This suggests the need to manage session duration and explore ways to reduce physical discomfort during extended VR sessions.

Looking ahead, future directions may involve integrating Mixed Reality (MR), which combines Augmented Reality (AR) and VR features, to further enhance the educational experience. Potential advancements could include real-time demonstrations supported by Artificial Intelligence (AI) and the development of VR/MR-compatible educational materials. AI-driven practical instructors and cloud-based systems could offer practical guidance and data-driven improvements, providing limitless opportunities for users. Future work will focus on addressing the limitations identified in this study, further refining the VR experience to ensure more comprehensive results and maximize its potential in engineering education.

In summary, VR technology represents a dynamic frontier in engineering education, merging hands-on training with immersive learning to prepare students for future challenges. Educators must navigate this evolving field to ensure students acquire the knowledge and skills needed in a rapidly changing environment. Future research comparing VR and traditional learning methods will further validate the effectiveness of VR in enhancing educational outcomes.

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