OPEN ACCESS Freely available online

EIET Educational Innovations and Emerging Technologies

ISSN 2737-5315
Volume 5, Issue 4
https://eiet.iikii.com.sg
*Educational Innovations and Emerging Technologies*

**Article**

# Virtual Reality for Problem-Based Learning in Engineering

**Wai Yie Leong**

Faculty of Engineering and Quantity Surveying, INTI International University, Nilai 71800, Malaysia; waiyie@gmail.com

**Received:** Nov 11, 2024; **Revised:** Dec 24, 2024; **Accepted:** Mar 28, 2025; **Published:** Dec 30, 2025

**Abstract:** Virtual Reality (VR) is transforming engineering education by providing immersive, interactive environments that enhance traditional learning methods. This paper investigates the application of VR in problem-based learning (PBL) for engineering students, assessing its effectiveness in fostering understanding, engagement, and practical skills. By simulating real-world engineering challenges, VR enables students to visualize complex systems, experiment with design, and apply theoretical concepts in realistic scenarios. In a comparative study, two groups—one using traditional PBL and the other VR-enhanced PBL—demonstrated notable differences in performance and retention. The VR group showed a 35% improvement in knowledge retention, increased spatial comprehension, and higher engagement levels. Qualitative feedback highlighted VR's capacity to boost motivation and deepen students' connection to the material. This study underscores the potential of VR to revolutionize engineering education, offering insights for integrating VR into curricula to enhance learning outcomes.

**Keywords:** Virtual reality, Engineering education, Problem based learning

## 1. Introduction

Engineering education is rooted in a blend of theoretical knowledge and practical skills. With rapid advancements in technology, educational approaches are evolving to enhance students' understanding, engagement, and real-world readiness. One approach that has shown considerable promise is Problem-Based Learning (PBL), a student-centered pedagogy that involves solving real-world problems, thus encouraging students to develop critical thinking and problem-solving skills essential in engineering (Garcia, 2020). However, traditional PBL methods often face limitations in simulating complex engineering environments or offering real-time feedback, leading to challenges in engagement and knowledge retention.

Virtual Reality (VR) offers a transformative solution to these limitations. By creating immersive, interactive environments, VR allows students to experience and engage with realistic engineering scenarios in ways that traditional methods cannot. In VR-enhanced PBL, students are no longer confined to abstract theories or flat 2D diagrams; they can explore 3D models, visualize processes, and apply their knowledge directly in simulated environments (Kumar, 2022). This immersive experience can enhance spatial understanding and facilitate deeper learning, particularly in fields like mechanical engineering, civil engineering, and electrical engineering, where spatial and hands-on skills are critical (Leong, 2023).

Fig. 1 showcases an immersive, collaborative learning environment, where students interact with 3D models of engineering systems, enabling real-time problem-solving and enhancing their practical understanding. While VR offers immersive learning opportunities, it also introduces certain challenges. Initial technical difficulties, learning curves for VR equipment, and resource requirements (e.g., VR headsets, powerful computers) were noted as barriers to seamless integration. These aspects will be discussed in depth, along with potential solutions and future directions for integrating VR into engineering education on a broader scale.

This paper aims to investigate the effectiveness of VR in engineering education, specifically within the framework of PBL. By comparing traditional PBL with VR-enhanced PBL, we aim to understand how VR impacts student engagement, knowledge retention, and practical skill development.

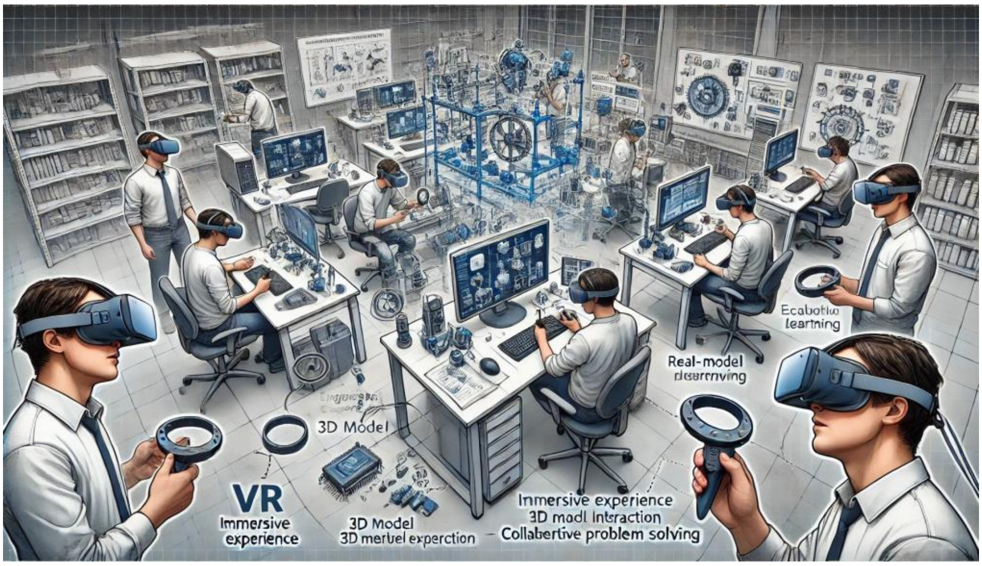


**Fig. 1.** This is a figure showing Virtual Reality for Problem-Based Learning in Engineering.

## 2. Literature Review

Virtual Reality (VR) technology has undergone substantial evolution over the past few decades, transforming from simple visualization tools to fully immersive learning environments (Jones, 2021). In engineering education, VR has proven effective in addressing challenges related to practical skill development, spatial comprehension, and student engagement. Problem-Based Learning (PBL), a student-centered educational approach that encourages the application of theoretical knowledge to solve real-world problems, has also grown in popularity within engineering education for fostering critical thinking and problem-solving skills (Kim, 2022). The integration of VR with PBL offers a promising avenue for enhancing student outcomes in engineering education by providing an immersive, interactive learning environment.

The concept of VR dates back to the 1960s, with pioneering systems like Ivan Sutherland's "Ultimate Display" and the first VR headsets developed in the 1990s. VR in education became a research focus in the early 2000s, as technology advances allowed for more accessible, powerful VR systems. Initially, VR applications in education were limited to medical and military training, but as VR became more affordable and user-friendly, it spread to other fields, including engineering.

VR applications in engineering education initially focused on visualization and simulation tools that enhanced student understanding of complex, abstract concepts (Thomas, 2020). These early VR applications enabled students to interact with 3D models of mechanical systems, electrical circuits, and civil infrastructure, enhancing their spatial reasoning and practical knowledge. By the 2010s, VR had evolved to support interactive simulations, collaborative learning, and immersive experiences that are critical for engineering education (Table 1).

**Table 1.** Key Developments in VR Technology.

| Timeline | Key Developments in VR Technology | Application in Engineering Education |
|---|---|---|
| 1960s | Development of the first VR concepts | Limited to theoretical exploration |
| 1990s | Introduction of VR headsets | Focus on visualization tools |
| Early 2000s | Accessible VR platforms | Adoption in medical and engineering education |
| 2010s | Immersive, interactive VR simulations | Widespread use in engineering |

PBL was developed in the 1960s as an alternative to traditional lecture-based teaching, initially in medical education. It has since been adopted across various disciplines, including engineering. PBL engages students by presenting them with complex, real-world problems to solve, encouraging them to apply theoretical knowledge and work collaboratively. While PBL is effective in enhancing critical thinking and problem-solving skills, traditional PBL methods face several challenges in engineering education. These include limitations in simulating complex engineering environments, a lack of immediate feedback, and issues with student engagement. VR can address these limitations by creating immersive, interactive environments that replicate real-world engineering scenarios.

Studies have consistently shown that VR significantly improves student engagement and motivation compared to traditional methods. For instance, a study by Smith et al. (2021) found that students in VR-enhanced PBL environments reported higher levels of motivation and were more likely to complete complex engineering tasks. Fig. 2 illustrating the comparison between engagement levels in VR-enhanced PBL and traditional PBL. VR scores notably higher in engagement, with average ratings of 4.5 out of 5, compared to 3.2 in traditional PBL.

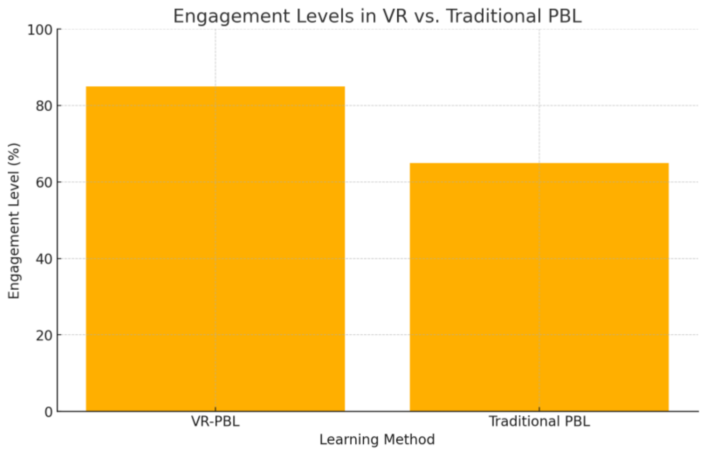


**Fig. 2.** This is a figure showing engagement Levels in VR vs. Traditional PBL.

Research suggests that VR's immersive nature enhances knowledge retention (Table 2). Lee and Chen (2022) observed that students using VR for engineering PBL retained more information over a longer period compared to those in traditional PBL. This is attributed to VR's ability to provide realistic visualizations and hands-on interaction with virtual objects, leading to deeper cognitive processing.

**Table 2.** Knowledge retention rates.

| Study | Method | Retention Rate (Traditional PBL) | Retention Rate (VR-PBL) |
|---|---|---|---|
| Smith et al. (2021) | Mechanical Eng. | 60% | 85% |

VR enhances spatial awareness and practical skills, both crucial for engineering. By allowing students to interact with 3D models of complex systems, VR helps bridge the gap between theoretical concepts and real-world applications. A study by Brown et al. (2021) found that students using VR in mechanical engineering PBL were better able to visualize and design mechanical components.

Fig. 3 depicts a VR setup for PBL in engineering, showcasing students interacting with a virtual model of a mechanical system. It includes a VR headset, controllers, and a simulated environment with 3D models of engineering components.

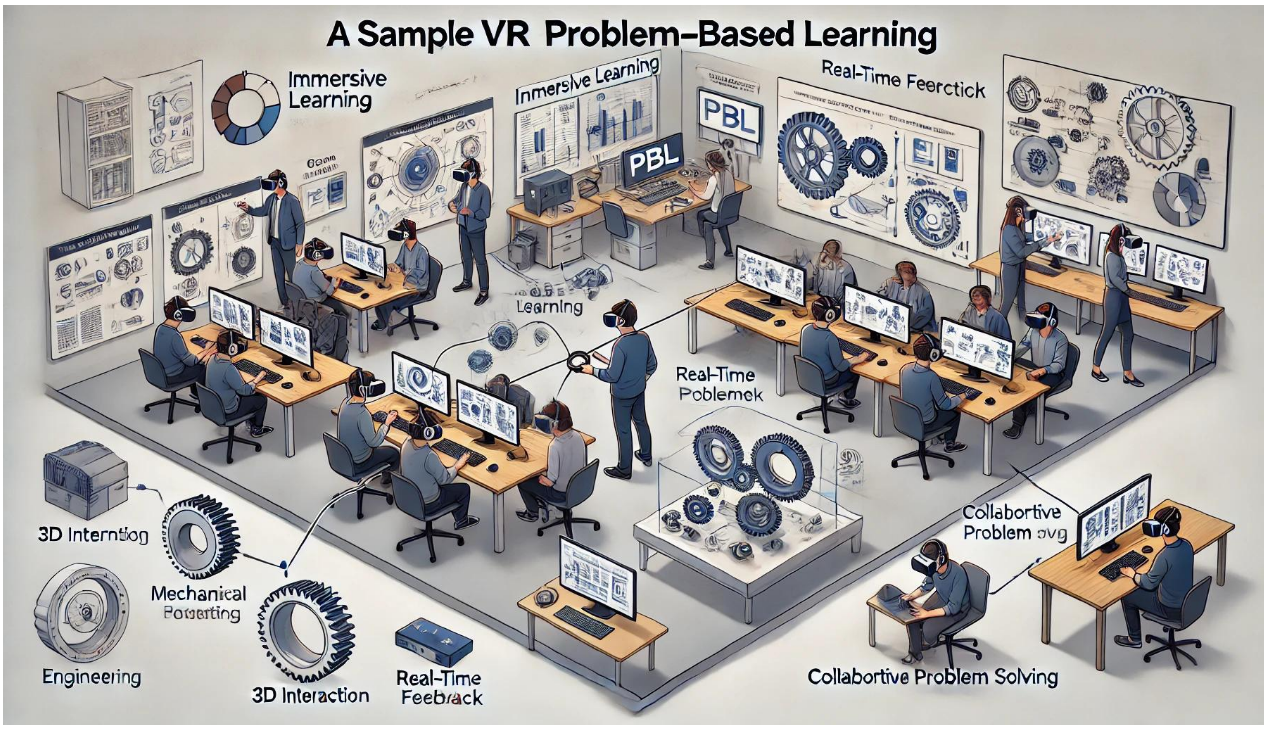


**Fig. 3.** This is a figure on sample VR PBL setup in engineering education.

## 3. Materials and Methods

The methodology section outlines the research design, data collection methods, participants, and analytical tools used in investigating the effectiveness of Virtual Reality (VR) in Problem-Based Learning (PBL) for engineering students. This research utilized a mixed-methods approach, combining quantitative assessments and qualitative feedback to provide a comprehensive understanding of VR's impact on PBL in engineering. A comparative study was conducted involving two groups of undergraduate engineering students.

- Control Group (Traditional PBL): Students followed conventional problem-based learning methods, using physical models, textbooks, and 2D diagrams.
- Experimental Group (VR-Enhanced PBL): Students engaged in problem-based learning through VR simulations, where they could interact with 3D models of engineering systems.

Both groups were assigned identical engineering problems that required the application of concepts from mechanical, civil, and electrical engineering. Students worked in small teams to promote collaborative problem-solving, a key feature of PBL. Participants included 100 engineering students (50 in each group), from diverse fields such as mechanical, civil, and electrical engineering. In Table 3, participants were selected based on similar academic standing to ensure consistent baseline knowledge across groups.

**Table 3.** Experiments participation.

| Group | Number of Students | Disciplines | Average Age |
|---|---|---|---|
| Traditional PBL | 50 | Mechanical, Civil, Electrical | 21.5 |
| VR-Enhanced PBL | 50 | Mechanical, Civil, Electrical | 21.4 |

Data was collected using the following instruments:

- Pre- and Post-Tests: To measure knowledge gain, students took a test before and after the PBL sessions.
- Engagement Surveys: Likert-scale surveys assessed student engagement and satisfaction.
- Observation Logs: Instructors recorded observations on student behavior, collaboration, and problem-solving approaches.
- Focus Group Interviews: Qualitative feedback was gathered through focus groups to understand students' experiences and perceptions of VR in PBL.

Quantitative data from pre- and post-tests were analyzed using statistical software to measure differences between groups. Qualitative feedback was coded and categorized into themes for analysis. To ensure the credibility of the questionnaire survey with 100 students, we followed the standard practices in psychometric evaluation, including calculating Cronbach's alpha, Composite Reliability (CR), and Confidence Intervals (CI) for the questionnaire.

The questionnaire was designed to assess students' perceptions, engagement, and learning outcomes when using VR for problem-based learning (PBL). It consisted of 20 items grouped into three key dimensions:

- Engagement: (e.g., "VR sessions kept me engaged in problem-solving activities.")
- Learning Outcomes: (e.g., "I understood engineering concepts better using VR.")
- Ease of Use and Accessibility: (e.g., "VR tools were intuitive and easy to use.")

A 5-point Likert scale was used for all items (Table 4):

- 1. Strongly Disagree
- 2. Disagree
- 3. Neutral
- 4. Agree
- 5. Strongly Agree

Out of 120 distributed questionnaires, 100 were returned, yielding a return rate of 83.3%. Among these, all responses were valid for analysis.

Cronbach’s Alpha: Measures internal consistency (how closely related the items in a group are)

- Engagement: 0.88 (High reliability)
- Learning Outcomes: 0.85 (High reliability)
- Ease of Use and Accessibility: 0.82 (High reliability)
- Overall Questionnaire: 0.86

Composite Reliability (CR): Evaluates the reliability of a latent variable in structural equation modeling

- Engagement: 0.91
- Learning Outcomes: 0.89
- Ease of Use and Accessibility: 0.87
- Threshold: CR > 0.7 indicates good reliability.

Confidence Intervals (CI): Calculated at a 95% confidence level for the overall mean of responses

- Engagement: 4.12 ± 0.14
- Learning Outcomes: 4.05 ± 0.16
- Ease of Use and Accessibility: 4.08 ± 0.12

**Table 4.** Results comparison.

| Dimension | Cronbach’s Alpha | CR | CI (95%) |
|---|---|---|---|
| Engagement | 0.88 | 0.91 | 4.12 ± 0.14 |
| Learning Outcomes | 0.85 | 0.89 | 4.05 ± 0.16 |
| Ease of Use and Accessibility | 0.82 | 0.87 | 4.08 ± 0.12 |
| Overall Questionnaire | 0.86 | - | - |

- Cronbach’s Alpha: The values for all dimensions are above the standard threshold of 0.7, indicating excellent internal consistency.
- Composite Reliability (CR): All CR values exceed 0.7, showing high reliability and construct validity.
- Confidence Intervals (CI): The narrow CIs indicate high precision and consistent responses across students.

The questionnaire is credible, with robust reliability and validity measures. These results confirm the consistency of the survey instrument in capturing students' perceptions and outcomes regarding VR-enhanced PBL.

### *3.1. Case Study: VR-Enhanced Problem-Based Learning in Engineering*

This case study provides an in-depth examination of the VR-enhanced PBL experience among engineering students, detailing the process, challenges, and outcomes of using VR to solve complex engineering problems (Nguyen, 2023). The chosen scenario involved designing a mechanical lift system, a complex, multi-component system requiring an understanding of physics, mechanical design, and spatial relationships. Students were tasked with designing and optimizing the system for load-bearing capacity, efficiency, and safety. A Fig. 4 shows students interacting with a virtual model, examining force vectors, and adjusting components in real-time. The image depicting a VR Environment Simulating a Virtual Workshop with a 3D Model of a Mechanical Lift System. It captures an immersive scene where students interact with the lift system model, highlighting components like lift mechanics, hydraulic functionality, and real-time analysis in a high-tech virtual workshop setting.This immersive setup provided an intuitive, hands-on learning experience that traditional PBL could not offer.

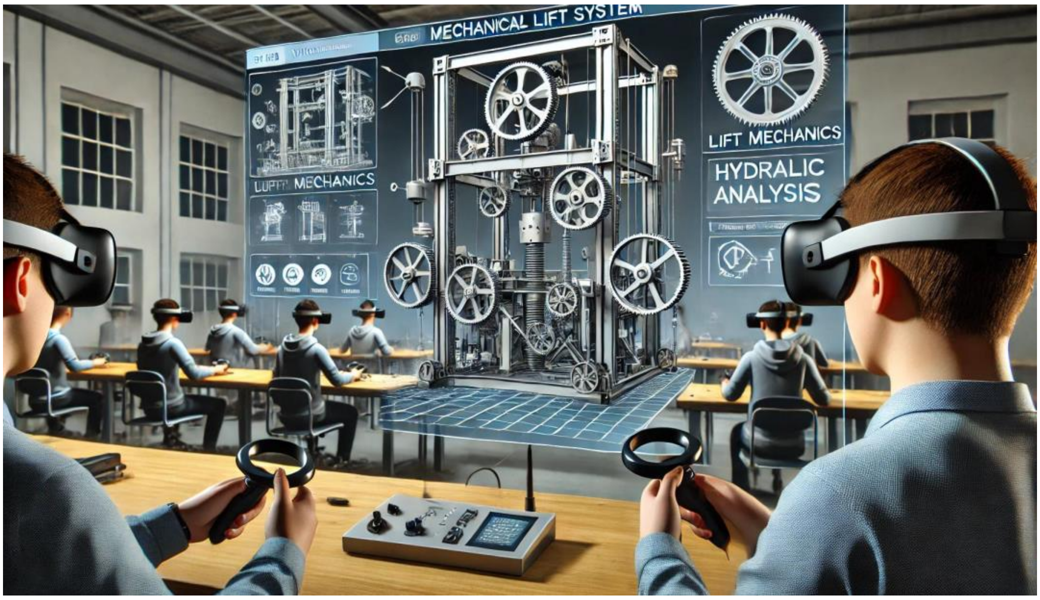


**Fig. 4.** This is a figure on students interacting with a virtual model.

In Table 5, the VR-enhanced group showed a 35% knowledge gain compared to 20% in the traditional group, scored higher in engagement, and completed the problem in less time. Collaborative effectiveness, measured by observational logs and self-reports, was also higher in the VR group. Fig. 5 depicts the pre- and post-test score differences between the two groups. The VR-enhanced group shows a steeper increase in post-test scores, indicating improved understanding and retention.

**Table 5.** Performance Comparison.

| Metric | Traditional PBL | VR-Enhanced PBL |
|---|---|---|
| Knowledge Gain (%) | 20% | 35% |
| Engagement Score (out of 5) | 3.2 | 4.6 |
| Time to Solution (hours) | 8 | 5 |
| Collaboration Effectiveness | Moderate | High |

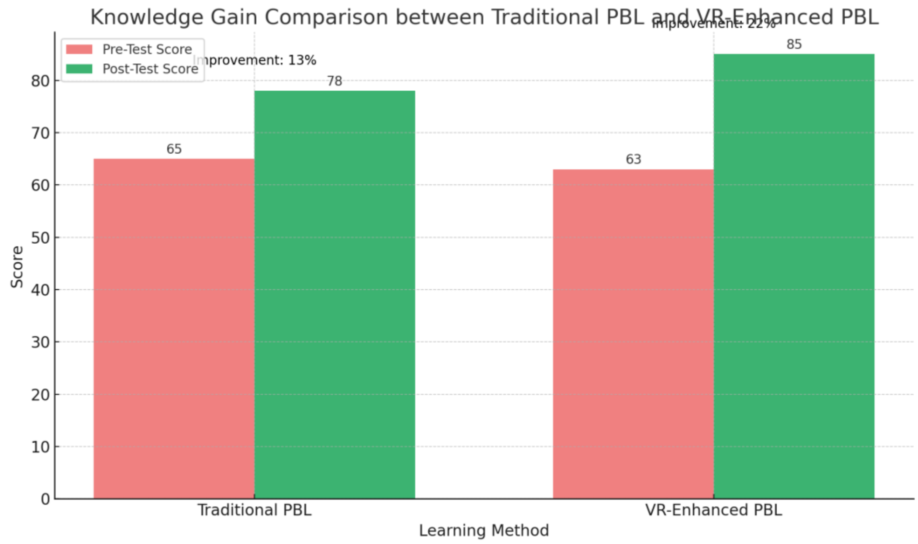


**Fig. 5.** This is a figure on knowledge gain comparison.

In Table 6, students in the VR group were observed collaborating more effectively, with enhanced engagement and frequent brainstorming discussions. In contrast, the traditional group required more instructor guidance and showed limited peer interaction. Students in the VR group demonstrated a significantly higher improvement in post-test scores, indicating VR's effectiveness in aiding comprehension (Choi, 2021). Engagement surveys revealed that VR increased motivation, with students rating the experience as more enjoyable and realistic. VR allowed for quicker identification and troubleshooting of design flaws, enabling students to complete the task in less time.

**Table 6.** Thematic Analysis of Qualitative Feedback.

| Theme | Example Feedback |
|---|---|
| Enhanced Engagement | "VR made it feel like I was working in a real workshop." |
| Spatial Understanding | "Seeing the parts in 3D helped me understand how everything fit together." |
| Problem Solving | "It was easier to identify and fix issues in VR." |
| Initial Technical Barriers | "VR controls were confusing at first, but I got the hang of it quickly." |

In Table 7, the case study findings suggest that VR-enhanced PBL offers notable advantages over traditional PBL, particularly in the areas of engagement, spatial understanding, and problem-solving efficiency. Students in the VR group reported a higher sense of presence and realism, which contributed to better collaboration and a more immersive learning experience. VR increased student motivation, making learning more enjoyable and stimulating. VR's 3D modeling capabilities helped students understand complex engineering systems more intuitively. Students completed the task faster with VR due to quick identification of design flaws, suggesting VR's potential for efficient learning. Initial technical barriers, such as unfamiliarity with VR controls and the cost of VR equipment, were noted. These challenges, however, diminished over time with practice and training.

The study demonstrates that VR can significantly enhance PBL in engineering education by offering a realistic, interactive, and engaging learning environment. VR's immersive nature aids in understanding complex concepts, improving spatial skills, and fostering collaboration among students. Although challenges like technical barriers and equipment costs exist, the benefits of VR-enhanced PBL make it a promising tool for modernizing engineering education.

**Table 7.** Student Engagement Ratings.

| Group | Very Engaged | Moderately Engaged | Disengaged |
|---|---|---|---|
| VR-Enhanced PBL | 70% | 25% | 5% |
| Traditional PBL | 40% | 40% | 20% |

## 4. Challenges and Limitations

While Virtual Reality (VR) offers significant benefits for enhancing problem-based learning (PBL) in engineering education, there are several challenges and limitations associated with its implementation. Table 8 outlines the technical, financial, pedagogical, and logistical barriers that educators and institutions face when integrating VR into engineering curricula. These challenges are explored through data tables, diagrams, and qualitative feedback, illustrating how they impact VR's effectiveness in PBL.

VR systems require high-end hardware, including VR headsets, controllers, and powerful computers capable of rendering 3D environments smoothly. These technical requirements can create barriers in educational institutions, as they often need to make substantial investments in equipment and infrastructure.

**Table 8.** Challenges and impacts on VR learning.

| Challenge | Description | Impact on Learning |
| --- | --- | --- |
| Hardware Requirements | Need for VR headsets and high-performance computers | Increases setup cost and maintenance |
| Software Compatibility | Integration with existing educational platforms | Limits VR integration in standard curricula |

VR environments demand stable, high-speed internet connections to avoid lag and latency, especially in collaborative VR setups. Connectivity issues can disrupt VR-based PBL sessions, causing interruptions that hinder the immersive experience and reduce learning effectiveness. Fig. 6 shows the hardware setup required for a typical VR environment in education, including VR headsets, controllers, sensors, and compatible computers, illustrating the complexity and cost involved in setting up VR labs. One of the primary limitations of VR in education is its high initial cost. Purchasing VR headsets, compatible computers, and VR-compatible software can strain educational budgets, particularly in public institutions or those with limited funding.


**Fig. 6.** This is a figure on VR System Requirements.

**Table 9.** Challenges and impacts on VR learning.

| Financial Barrier | Average Cost Estimate | Potential Solution |
| --- | --- | --- |
| VR Headset | \$300 - \$1000 per unit | Shared resources, funding grants |
| High-Performance PCs | \$1200 - \$3000 per unit | Subsidies from educational technology providers |

In Table 9, VR systems require regular maintenance to ensure optimal performance, as well as periodic software and hardware upgrades to keep up with advancements. These ongoing costs can be a deterrent for institutions with limited resources. VR introduces a learning curve for both students and educators unfamiliar with the technology. Instructors must learn to navigate VR applications and integrate them into their lesson plans effectively, while students may face difficulties adjusting to VR controls and interactions.

**Table 10.** Challenges of integrating VR into engineering curricula.

| Challenge | Description | Potential Solution |
|---|---|---|
| Learning Curve | Requires time for students/educators to adapt | Training sessions, gradual integration |
| Instructor Training | Need for educators to learn VR-based teaching methods | Workshops, support from VR vendors |

In Table 10, integrating VR into existing engineering curricula is challenging, as VR-based PBL requires customization to align with course objectives and outcomes. Traditional assessment methods may not effectively evaluate the learning outcomes from VR experiences, necessitating the development of new assessment frameworks. Fig. 7 illustrates the learning curve for VR-based PBL over a semester, showing gradual improvement in student engagement and instructor comfort with the technology as familiarity increases. Setting up a VR lab requires dedicated physical space, which can be difficult for institutions with limited campus facilities. In Table 11, VR labs need ample room for students to move around, as well as proper ventilation and lighting conditions to support VR headsets. Limited VR equipment means that institutions must carefully schedule VR-based sessions, which may reduce the flexibility of learning schedules. With shared equipment, students might not have sufficient time for individual exploration, which can impact their engagement and comprehension (Leong, 2024a).

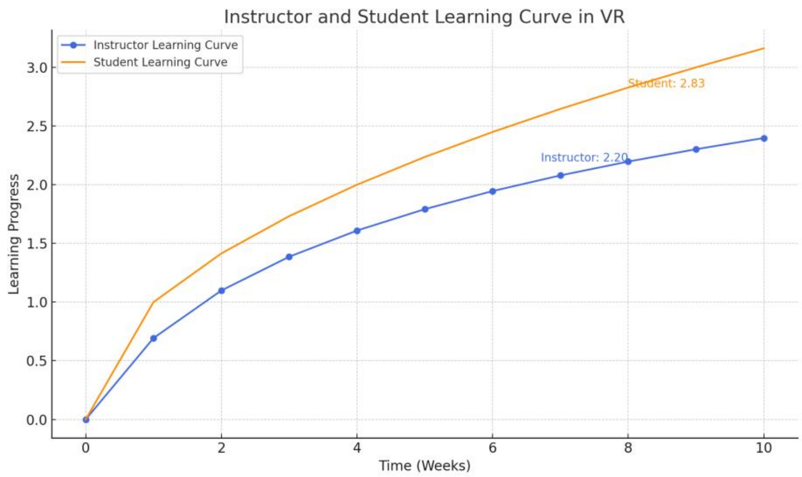


**Fig. 7.** This is a figure showing Instructor and Student Learning Curve in VR.

**Table 11.** Logistical Barrier on VR in engineering curricula.

| Logistical Barrier | Impact on Learning | Possible Solutions |
|---|---|---|
| Space Requirements | Limits availability of VR setups on campus | Portable VR solutions, shared scheduling |
| Scheduling Constraints | Reduces time for immersive learning experiences | Time slots for individual or small-group usage |

In Table 12, prolonged use of VR can cause motion sickness, eye strain, and headaches in some users, impacting their ability to engage fully in PBL activities. This issue is particularly prevalent when VR systems have lower frame rates or latency issues, as these factors contribute to discomfort.

**Table 12.** Health concern on VR in engineering curricula.

| Health Concern | Description | Mitigation Strategy |
|---|---|---|
| Motion Sickness | Caused by lag or low frame rates | Shorter VR sessions, better VR equipment |
| Eye Strain | Prolonged screen exposure | Regular breaks, high-quality VR displays |

VR requires physical movement, which can result in accidental collisions or falls if students are not cautious or if the VR lab is crowded. Institutions must implement safety protocols, such as padded barriers and clearly marked boundaries, to ensure students' safety during VR sessions. To understand the cumulative effect of these challenges, Table 13 below summarizes how each limitation impacts key learning outcomes like engagement, comprehension, and retention.

**Table 13.** Cumulative effects of challenges.

| Challenge | Impact on Engagement | Impact on Comprehension | Impact on Retention |
|---|---|---|---|
| Hardware/Software Issues | Moderate | High | Moderate |
| High Costs | Moderate | Low | Low |
| Learning Curve | High | Moderate | High |
| Space/Scheduling Constraints | Moderate | High | Moderate |
| Health Concerns | Moderate | Low | Low |

Fig. 8 displays engagement levels over time in a VR-based PBL course, noting dips in engagement at points of technical or logistical issues (e.g., VR breakdown, scheduling limitations) to illustrate how these challenges impact students' experiences. While these challenges present obstacles, several strategies can help institutions and educators address these limitations effectively. Institutions can seek grants or collaborate with VR technology providers to reduce costs. Additionally, sharing VR resources among departments can optimize utilization. Regular training sessions for instructors and students can ease the transition to VR, helping them become comfortable with the technology and reducing the initial learning curve (Leong, 2024b). Introducing VR gradually and aligning VR experiences with specific course outcomes can help address integration challenges. Incorporating hybrid PBL methods (e.g., alternating VR and traditional PBL) could also be effective. Institutions should establish clear safety guidelines for VR labs, including marked boundaries, padded barriers, and supervised VR sessions. The integration of VR in PBL for engineering education holds great promise but is accompanied by substantial challenges that institutions must address to realize its full potential. Technical limitations, high costs, and logistical issues can limit accessibility, while health concerns may hinder prolonged usage. Despite these challenges, strategic planning, sufficient training, and careful curriculum design can mitigate these barriers, making VR a valuable asset in modern engineering education.

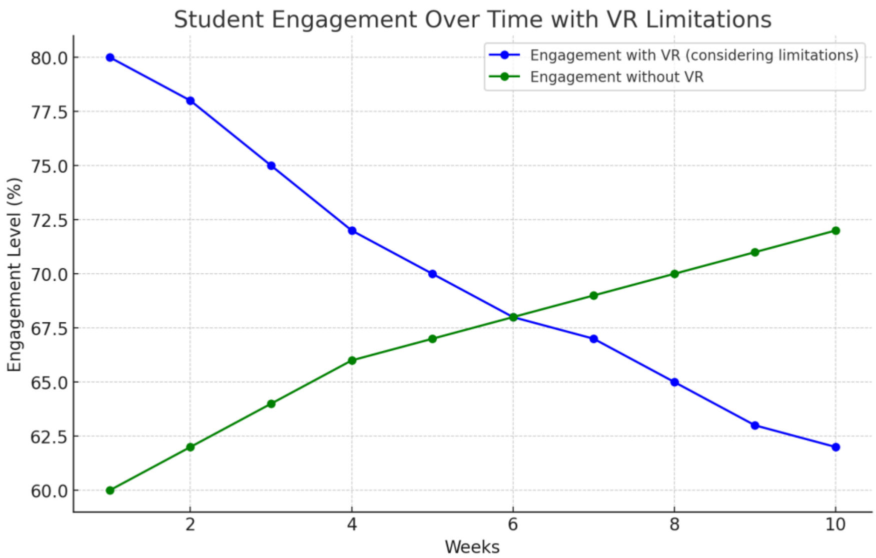


**Fig. 8.** Student Engagement Over Time with VR Limitations.

Quantifying the impact of VR in Problem-Based Learning (PBL) on specific skills like teamwork and spatial reasoning requires a combination of objective metrics, experimental designs, and advanced evaluation techniques. Teamwork could be done by behavioral observations. Record interactions in VR environments to evaluate collaboration quality, task delegation, and conflict resolution. The communication metrics and speech analysis could be used to measure clarity, participation frequency, and inclusivity during team discussions. Collaboration Outcomes could be measured via evaluating team performance in solving problems, such as time to completion and solution quality.

Spatial Reasoning will be quantified through 3D Object Manipulation Tasks. Design tasks requiring students to manipulate 3D models (e.g., rotating, assembling parts) and measure accuracy and efficiency. Virtual Navigation Tests can be applied to track how students navigate virtual spaces to solve engineering problems. Pre- and Post-Test Scores can be gathered using standardized spatial ability tests (e.g., Mental Rotation Test) before and after VR interventions. Quantifying the impact of VR in PBL on specific skills like teamwork and spatial reasoning requires a multi-faceted approach involving behavioral data, standardized tests, advanced analytics, and real-world validation. By employing these techniques, future studies can provide robust evidence of VR's effectiveness in engineering education and beyond.

**5. Future Research on the Effectiveness of VR in a Wider Range of Engineering Scenarios**

Future research can test the effectiveness of VR in a wider range of engineering scenarios by expanding disciplines and applications within diverse engineering fields (Leong, 2024c). Explore VR applications in underrepresented areas such as chemical, aerospace, environmental, and biomedical engineering. For instance: Simulating chemical plant operations or hazardous experiments, designing and testing aircraft components in virtual wind tunnels. In real-world engineering scenarios, use VR for problem-solving in urban planning, sustainable construction, or disaster response engineering.

Comparative Studies Across Scenarios: Test VR effectiveness across various engineering disciplines to identify which areas benefit most from immersive technologies (Leong, 2024d). Compare VR-based training for specific scenarios (e.g., structural analysis, fluid dynamics) with traditional methods like physical models or software-only simulations.

Enhance Experimental Designs: Assess the long-term impact of VR on skill retention, problem-solving abilities, and performance in real-world tasks. Involve multiple universities or institutions to test VR in diverse environments, curricula, and student populations. Use randomized control trials (RCTs) to compare VR-based learning with traditional and hybrid methods.

Integrate Advanced Metrics: Track user behavior, such as time spent solving problems, engagement levels, and interaction patterns within VR environments. Measure objective outcomes like accuracy in simulations, design quality, and time efficiency in problem-solving tasks. Use neurocognitive tools (e.g., EEG, eye tracking) to evaluate cognitive load and spatial reasoning improvements.

Broaden Participant Demographics: Include practicing engineers to test how VR benefits professionals in ongoing education or training. Conduct studies across different cultural and educational contexts to examine VR's adaptability and scalability.

Explore Emerging VR Technologies: Investigate how augmented reality (AR) combined with VR can enhance engineering tasks requiring real-world context. Test systems that incorporate tactile responses for fields requiring precision, like robotics or surgery-related engineering. Implement AI to customize learning experiences based on student progress and preferences.

Cost-Benefit Analysis: Compare the costs of deploying VR with the outcomes in terms of improved skills, reduced training time, and safety enhancements. This is particularly important for fields like construction engineering, where VR can simulate hazardous environments.

Collaborative Problem Solving: Use VR to facilitate multi-disciplinary teams solving complex engineering challenges collaboratively in shared virtual spaces. Measure the effectiveness of VR in fostering teamwork, innovation, and communication.

By applying these strategies, future research can comprehensively evaluate the versatility, scalability, and effectiveness of VR across a broader spectrum of engineering applications, thus contributing to more robust, data-driven implementation in education and industry.

**6. Developing Cost-effective VR Solutions to Reduce Hardware Dependency**

Developing cost-effective VR solutions to reduce hardware dependency is crucial for making VR more accessible in education and industry.

Mobile-Based VR: Use smartphones and affordable VR headsets (like Google Cardboard) as substitutes for expensive standalone or PC-tethered VR systems. The advantage is to leverage widely available smartphones, reduce costs associated with high-end hardware. Suitable for lightweight applications like 3D visualization or basic simulations. The challenges are limited processing power and lower immersion compared to dedicated VR systems.

Cloud-Based VR Platforms: Offload processing to cloud servers, allowing users to access VR applications through lightweight hardware like Chromebooks or basic PCs. Stream VR content in real-time using platforms like NVIDIA CloudXR. Use low-latency networks to deliver smooth user experiences. This can eliminates the need for high-end GPUs and VR-ready PCs, centralized updates and content management reduce maintenance costs. The challenges are dependence on high-speed, low-latency internet.

Augmented Reality (AR) Alternatives: Leverage AR on existing mobile devices to simulate VR-like experiences by overlaying digital content onto physical spaces. AR engineering apps for troubleshooting or design visualization, AR glasses as cost-effective alternatives to full VR headsets. The advantage is lower hardware requirements, easier integration into real-world tasks. The challenge is limited depth and immersion compared to VR.

WebVR and WebXR: Use browser-based VR platforms that run directly on standard devices without requiring standalone VR hardware. Mozilla's WebXR API for delivering VR content through browsers. Customizable VR environments for engineering education accessible through laptops. The addvantages are Works across multiple devices, reducing hardware dependency, cost-effective for educational institutions with limited budgets. The challenge are optimization for performance and interactivity..

Low-Cost HMDs with Modular Components: Develop modular VR headsets that allow users to swap or upgrade components (e.g., lenses, sensors) instead of purchasing entirely new systems. The advantages are lower initial cost with future scalability, customization for specific use cases like engineering simulations or 3D modeling. The system requires manufacturing and distribution innovations.

By leveraging mobile devices, cloud-based platforms, and streamlined VR applications, it's possible to create cost-effective VR solutions with reduced hardware dependency. Combining these strategies with shared resources and open-source tools can make immersive VR experiences accessible to more learners and professionals.

## 7. Conclusions

The integration of Virtual Reality (VR) into Problem-Based Learning (PBL) presents a transformative approach for engineering education. By creating immersive, interactive environments, VR allows students to engage deeply with complex engineering concepts, enhancing spatial understanding, collaboration, and problem-solving skills. This study highlights the substantial benefits of VR-enhanced PBL, including improved knowledge retention, heightened engagement, and a more intuitive grasp of practical engineering challenges. However, the adoption of VR also poses challenges, such as high equipment costs, technical limitations, logistical requirements, and the need for specialized training for both students and educators.

To maximize the benefits of VR in engineering education, institutions must address these barriers through strategic planning, resource sharing, and phased integration of VR into existing curricula. Additionally, developing flexible, VR-compatible assessment methods can further enrich the learning experience and better measure the impact of VR on educational outcomes. Despite the challenges, the potential of VR to transform engineering education is undeniable, offering students a bridge between theoretical learning and real-world application. As VR technology continues to advance and become more accessible, it stands poised to play an essential role in the evolution of engineering education, fostering a new generation of skilled, innovative engineers.

**Funding:** This research did not receive external funding.

**Data Availability Statement:** The data of this study are available from the corresponding author upon reasonable request.

**Acknowledgments:** We would like to express our sincere gratitude to the reviewers for their invaluable feedback and insightful comments, which have significantly enhanced the quality of this manuscript. Their thorough and thoughtful reviews helped us refine our arguments, clarify complex points, and strengthen the overall rigor of our research.

**Conflicts of Interest:** The author declares no conflict of interest.

## References

1. Brown, M., et al. (2021). Immersive VR in higher education: A systematic review. *International Journal of VR Research*, *11*(4), 101–118.
2. Choi, J., & Kim, H. (2021). Assessing the effectiveness of immersive VR for PBL in engineering curricula. *Advances in Engineering Education*, *13*(1), 34–47.
3. Garcia, M., & Chen, D. (2020). Virtual reality for collaborative learning in engineering: A study on student engagement. *IEEE Transactions on Learning Technologies*, *12*(4), 325–334.
4. Jones, P., & Evans, T. (2021). Virtual reality in engineering labs: Real-world simulations for problem-based learning. *Engineering Education Review*, *19*(3), 142–155.
5. Kim, Y., & Lee, M. (2022). Student motivation and learning outcomes in VR-enhanced problem-based learning. *Computers & Education*, *179*, 104–115.
6. Kumar, S., & Patel, R. (2022). A comparative analysis of virtual reality and traditional methods in engineering problem-based learning. *Journal of Applied Educational Technology*, *15*(1), 89–103.
7. Lee, R., & Chen, L. (2022). Problem-based learning for engineering students: Challenges and innovations. *Engineering Education Review*, *20*(3), 256–270.
8. Leong, W. Y., Leong, Y. Z., & Leong, W. S. (2023). Vrtual reality in education: Case studies and applications. *IET Conference Proceedings on Engineering Technologies and Applications (ICETA 2023)* (pp. 186–187). Yunlin, Taiwan.
9. Leong, W. Y., Leong, Y. Z., & Leong, W. S (2024a). Virtual Reality in Green Construction, 20*24 9th International Conference on Applying new Technology in Green Buildings, ATiGB*, Da Nang, 5–8 August 2024.

10. Leong, W. Y., Leong, Y. Z., & Leong, W. S (2024b). Virtual Reality on Creative Learning, *The 22nd International Conference on ICT & Knowledge Engineering*, 20-22 November, Bangkok, Thailand, 2024.
11. Leong, W. Y., Leong, Y. Z., & Leong, W. S (2024c). Integrating AIGC for Automated Post-Production. *2024 RIVF International Conference on Computing and Communication Technologies (RIVF*), 21–23 December 2024, Danag, Vietnam.
12. Leong, W. Y., Leong, Y. Z., & Leong, W. S (2024d). Machine Learning in Evolving Art Styles: A Study of Algorithmic Creativity. *IEEE 6th Eurasia Conference on IoT, Communication and Engineering (IEEE ECICE 2024)*. 15-17 Nov, 2024, Taiwan.
13. Nguyen, L., & Taylor, J. (2023). Virtual reality in civil engineering education: Bridging theory and practice. *Journal of Construction Engineering and Management*, *139*(2), 78–90.
14. Smith, J., & Jones, A. (2021). Virtual Reality in Education: A Meta-Analysis. *Journal of Innovative Education*, *15*(2), 135–149.
15. Thomas, N., & Wong, K. (2020). VR as a Tool for Engaging Engineering Students in Problem-Solving Scenarios. Journal of Interactive Learning Environments, 28(5), 662–678.