Scalable VR Solutions for Engineering Education: A Continuous Improvement Framework

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Abstract

The increasing use of technology in higher education, especially in resource-constrained environments, is reshaping how students engage with industrial experiences. Virtual Reality (VR) offers a solution to the challenges posed by growing class sizes and limited real-world access, supporting holistic Graduate Attribute Development and addressing global SDG challenges in engineering education.

This paper explores how VR can enhance student engagement with complex technological topics like Industry 4.0. It examines the effectiveness of a VR-based framework for improving student emotional responses and interest in technology, while assessing the scalability of such approaches for larger classes.

A pilot study was conducted with third- and fourth-year students participating in a voluntary virtual facility layout activity. Emotional response surveys showed that fourth-year students were more comfortable with the technology, as expected, but both groups reported increased interest in technological topics. The study uses a dynamic response evaluation model informed by these surveys, and the organizational distinction between development teams and lecturing staff enables the framework to scale effectively.

The findings demonstrate that VR can improve student engagement and comfort with emerging technologies, making it an important tool for resource-constrained environments. This framework provides a method for continuous improvement, quantifying the long-term impact of VR on engineering education curricula. By enabling adaptable, scalable learning experiences, it helps prepare students for complex engineering challenges and future technological changes, offering a valuable contribution to the ongoing evolution of engineering education.

Keywords: Virtual Reality (VR), Engineering Education, Industry 4.0, Emotional Response, Virtual Learning Environments, Continuous Improvement, Curriculum Development

1 Introduction

Engineering graduates are required to integrate Sustainable Development Goals (SDGs) and Industry 4.0 concepts into their skillsets. Additionally, the revised International Engineering Alliance (IEA, 2021) competency framework emphasizes holistic skills, including psychosocial and sociocultural awareness, with significant implications for undergraduate engineering education. A critical challenge for educators in supporting students cognitively, affectively and systemically (Tait, 2000) is bridging theory and practice, particularly as growing class sizes make traditional industrial site visits less feasible due to logistical and safety constraints (Dorfling et.al,2019). Large groups also limit meaningful student engagement, reducing the effectiveness of such visits.

Virtual reality (VR) offers a potential solution, aligning with the National Academy of Engineering’s Grand Challenges for advancing personalized learning (NAE, 2024). The declining cost and increased accessibility of stand-alone VR headsets, remote management tools, and free development platforms make large-scale VR labs viable for engineering education. Thoughtful integration of technology can enhance learning, particularly for underrepresented groups, by providing equitable exposure to emerging tools.

However, educators must implement technology strategically to avoid diminishing learning outcomes. Engineering education extends beyond technical tools to complex problem-solving, and poorly integrated technology may hinder progress. In diverse contexts like South Africa, where students have varying levels of technical exposure, careful adoption is crucial. While technology will inevitably reshape engineering education, its success depends on educators' ability to integrate it effectively.

2 Background (Lit Review)

The SDGs (United Nations, 2025) are playing a crucial role in shaping a more holistic approach to graduate development, particularly in the Global South. As industries and economies strive to meet sustainability targets, universities are recognizing the need to equip graduates with the skills to address complex, interconnected challenges. This shift emphasizes not only technical competencies but also broader considerations such as environmental responsibility, social equity, and ethical leadership. The need for graduates to think systemically and innovatively is particularly pressing in regions where socio-economic disparities persist, requiring education systems to integrate sustainable and inclusive development into their curricula.

At the same time, rapid technological advancements are reshaping industries at an exponential pace, placing immense pressure on educators to prepare graduates for an evolving workforce (Kruger et.al., 2022). Emerging technologies such as artificial intelligence, automation, and smart manufacturing demand new skill sets, necessitating continuous curriculum adaptation. However, in the Global South, this challenge is compounded by resource limitations, massification of education, and barriers to access. The high cost of advanced equipment and restricted opportunities for industrial site exposure make it difficult for institutions to provide students with the hands-on experience needed to bridge the gap between theory and practice. These constraints create disparities in the ability of graduates to compete in global job markets, despite their academic potential.

Amid these challenges, the principles of Industry 5.0 are gaining traction, blending Industry 4.0 technologies with human-centric considerations (Leng et al., 2022). This paradigm shift is evident in the latest competency frameworks from the International Engineering Alliance (IEA), which highlight the importance of inclusivity and sustainability in engineering education. By recognizing the significance of human factors alongside technological advancements, these frameworks reinforce the need for a more balanced and ethical approach to innovation. As educational institutions adapt to these evolving expectations, they must find ways to integrate sustainability, technological literacy, and socio-economic awareness into their teaching strategies, ensuring that graduates are equipped to drive meaningful progress in their respective fields.

Against this background, the broader objective of this research study is how to enable equitable access (for diverse cohorts) to industrial experiential learning opportunities (Kolb, 1984) through cost-effective, contextually-responsive, technology-supported strategies?

The growing student population in South African classrooms, coupled with logistical challenges, has made traditional site visits increasingly difficult to implement. Engineering and technical education, which rely heavily on hands-on learning and real-world exposure, are particularly affected by these constraints. Industrial site visits are essential for bridging the gap between theoretical knowledge and practical application, but factors such as cost, safety concerns, and limited industry access make them less feasible. As a result, educators are exploring alternative methods to ensure students still gain valuable industry insights, with virtual reality (VR) emerging as a promising solution to address these challenges (Steed et al, 2025).

VR technology offers an innovative way to create immersive, interactive learning experiences that allow students to explore industrial environments without physically being present. This approach not only overcomes logistical barriers but also promotes inclusivity by ensuring that all students, regardless of location or mobility constraints, have access to experiential learning. By simulating real-world scenarios, VR enables students to engage with complex systems, practice problem-solving skills, and develop industry-relevant competencies in a controlled, repeatable environment. As South African universities and technical institutions strive to provide quality education amidst growing class sizes and resource limitations, VR presents an opportunity to democratize access to experiential learning.

le many of the earlier challenges associated with the cost and technological limitations of VR in education are increasingly being addressed (Ardiny & Khanmirza, 2018), new opportunities now emerge around understanding the pedagogical and dyadic potential of VR (Graeske & Sjöberg, 2021). A major enabler of this educationally responsive shift is the significant reduction in the cost of VR hardware. Once prohibitively expensive, headsets and supporting systems have become more affordable as a result of rapid advancements in manufacturing and growing market competition. This trend has made it feasible for institutions, including those in resource-constrained environments, to adopt VR-based learning. At the same time, issues such as low simulation realism, physical discomfort, and hardware limitations are being actively resolved. Improvements in graphics, ergonomic design, and sensor fidelity have enhanced immersion while reducing simulator sickness and user frustration. As these technical barriers diminish, attention turns toward VR's potential to enhance student engagement and better prepare learners for digitally transformed industries.

Importantly, this evolution underscores the role of affective learning in VR-based education and how immersive experiences can actively enhance student mood, creating emotionally supportive environments optimal for learning. Instruments like the Positive and Negative Affect Schedule (PANAS) offer a structured means to assess this dimension (Crawford & Henry, 2004). Studies have shown that VR environments—particularly those designed to induce calm or simulate nature—can significantly boost positive affect (Pallavicini et al., 2020). These findings suggest that beyond increasing engagement, VR can be used intentionally to create affective conditions conducive to learning, helping students feel more relaxed, focused, and emotionally prepared for challenging educational tasks. This paper focuses on the affective dimension of student support in two different cohort contexts (3rd and 4th years). The question is: ***What is the emotional impact (affective) of a virtual industrial experience designed to enhance student engagement (affective) and interest in Industry 4.0 concepts (cognitive)***?

The integration of virtual reality (VR) in education is not a new concept, with numerous studies exploring its potential applications. Tootell et al. (2024) advocate for the use of VR training as a valuable tool for Continuous Professional Development among medical practitioners, highlighting its ability to enhance skill acquisition and retention. Similarly, the EVRIM framework emphasizes the ethical employment of VR in education (Geriş, 2024). This framework consists of five stages: Discovery, Design, Development, Deployment, and Impact. The Impact stage evaluates critical aspects such as Educational Assessment, focusing on transparency, fairness, and privacy (Cao, 2023; Yu & Xu, 2022). Additionally, User Satisfaction is assessed in terms of objectivity and privacy (Alizadeh & Cowie, 2022; Sadek et al., 2023), while Continuous Improvement considers transparency and a user-centered approach (Chen, Fu, Liu, & Wang, 2024; Walker, 2022). In the field of engineering education, Chandramouli and Williams (2024) propose VR as a cost-effective solution for providing students with exposure to smart factory equipment and environments. While their study effectively demonstrates VR-based experiences, it does not assess their impact on learning outcomes. Collectively, these studies reinforce the potential of VR in education, spanning from professional training to ethical and practical considerations in its implementation.

3 Theoretical framing in context

Given the focus on holistic engineering student development, the research site for this paper is a research-intensive university in South Africa, in which the engineering faculty has adopted a formal ‘head-heart-hand' development approach to engineering education. This approach combines the theories of learning objectives (Bloom, 1956), curriculum framing (Barnett, 2000), and student support (Tait, 2000) into an overarching Cognitive-Affective-Systemic (CAS) model. The CAS model enables educators to unpack and analyse the different educational dimensions of student learning. (Gilmore et al., 2016; Kruger, 2021; Lewis et al., 2025)

This study was conducted within the industrial engineering department of a research-intensive university, which has a substantial student body of approximately 500 enrolled in the degree program across various academic years. Focusing specifically on the third and fourth-year cohorts, which each comprise around 150 students, the large class sizes present a significant challenge, particularly in facilitating industry visits that are crucial for practical learning in the field. Furthermore, student engagement has been notably low and has resulted in decreased class attendance, impacting the overall learning environment and necessitating innovative approaches to re-engage students and enhance their educational experience. The study forms part of an ongoing, faculty-wide, developmental programme renewal process with a continuous improvement ethic.

Production Management & Ergonomics modules cover key concepts like facility layouts and the effective placement of equipment for manual assemblies in factories – Initial observations revealed that lack of exposure to real-world environments influences student grasp (cognitive) and application of these key concepts. The focus on calculating inventory, production line capacity and material resource planning (MRP), for example, can be richly enhanced if the student actually sees and even physically engages with artefacts in a real-world environment. Ideally, the experiential learning cycle entails concrete experience, reflective observation, abstract conceptualisation and active experimentation. This kind of experiential learning (Kolb, 1984) reinforces psychomotor skill development within the context of a larger system. These are aspects entailed in the Systemic domain of the CAS model.

As a result of resource constraints, large class sizes and low student engagement, the students in these modules were effectively speaking only working at the abstract conceptual level when trying to implement (calculate and decide) their understanding in a system. The collaborating researchers decided to develop a VR experience in order to address the challenge by allowing students to experience the real-world/ factory environments in class. Figure 1 showcases the VR experience that build to model the physical learning factory at the university.

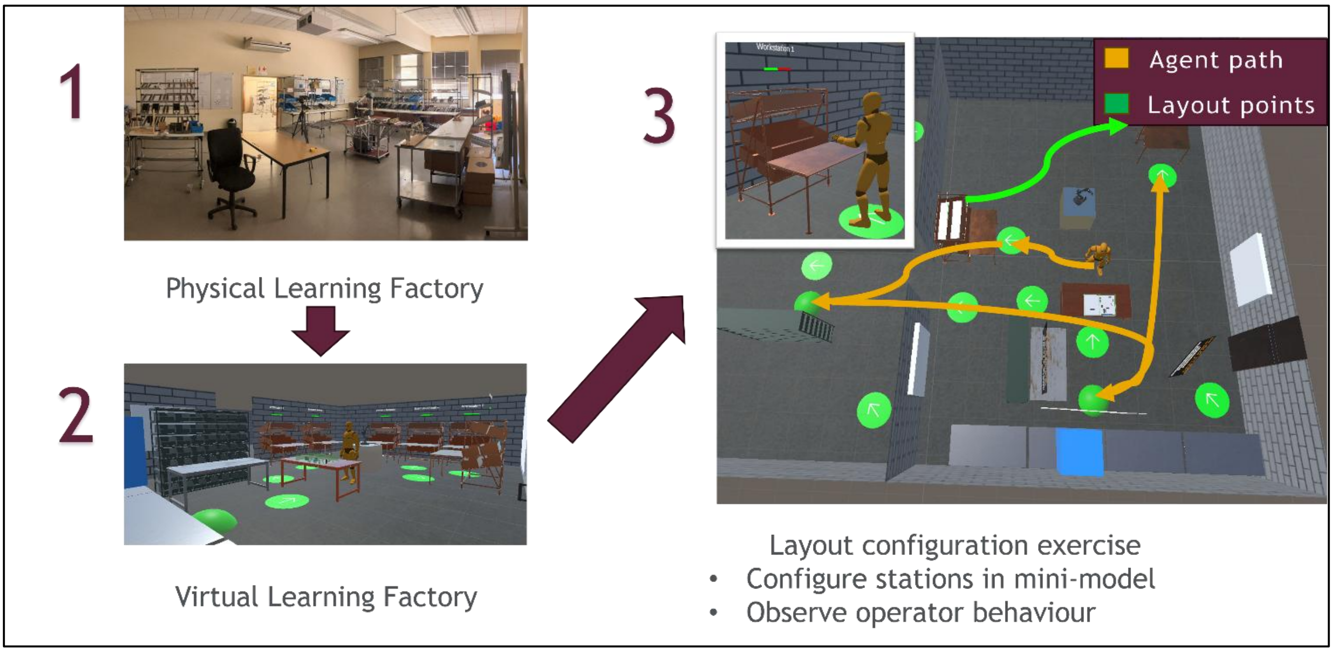

Figure 1: Progression from a physical learning factory (1) to a virtual representation (2), enabling a layout configuration exercise (3) in which users arrange stations and observe simulated operator behaviour along agent paths.

4 Research methodology and intervention design

To enhance experiential learning in a resource-constrained, large-class environment, this study implemented a Virtual Reality (VR) upgrade to a previously manual assembly exercise traditionally used in the classroom (figure 1). The original practical involved observing a single group assemble a skateboard in an unoptimized layout, followed by a demonstration of the improved layout's reduced lead time. This format limited student interaction and engagement. In contrast, the redesigned VR activity allowed students to actively reconfigure assembly station layouts within a virtual factory environment. They could manipulate workstation positions, observe simulated operator paths, and accelerate time to visualize the effects of their layout decisions more rapidly. This interactive and immersive approach aligned closely with Kolb’s experiential learning cycle by enabling concrete experience, active experimentation, and reflective observation within the classroom setting.

The VR activity was made available voluntarily during class time. Students could choose between experiencing the VR scenario privately or projecting their interaction onto a shared screen for peer observation, allowing for varied engagement levels suited to different comfort zones. Following the activity, students completed an online feedback survey that included the Positive and Negative Affect Schedule (PANAS) and additional questions focused on their interest in digital technologies and manufacturing. This self-reporting data provided insight into students' emotional responses and interest levels. Data collection and interpretation were framed within the CAS model to account for the emotional (affective), reflective (cognitive), and practical (systemic) dimensions of learning. Comparative analysis between third- and fourth-year student responses indicated that senior students reported higher positive affect and lower negative affect, consistent with expectations of increased academic maturity and technological familiarity. Moreover, interest-related items showed that the activity contributed to greater curiosity about digital manufacturing technologies, even though enthusiasm for the manufacturing domain itself remained unchanged. These findings informed a continuous improvement cycle for refining VR content and instructional design.

5 Findings

A voluntary VR learning activity engaged 15 third-year (Group A) and 25 fourth-year students (Group B) from a cohort of over 100, with noticeably higher participation among the fourth-year group. This difference may be attributed to factors such as greater academic maturity and/or increased technological familiarity. These results suggest that senior students are more receptive to integrating emerging technologies into their learning processes.

Emotional responses, assessed using the PANAS survey (figure 2), revealed a generally positive experience across both groups, with positive affect (PA) scores averaging above 3.5 and negative affect (NA) scores below 2. While some discomfort persisted, particularly among third-year students, fourth-year participants reported greater emotional ease—indicating that repeated exposure to VR may enhance comfort and engagement. The most positively rated emotions were “enthusiastic,” “proud,” and “inspired,” all of which align with Bandura’s (1977) framework of self-efficacy development.

From a systemic and psychomotor perspective, both groups demonstrated strong interest in Industry 4.0 technologies, though fourth-year students reported higher levels of technological adaptability and comfort. While interest in digital technologies and active engagement were generally high for both cohorts, enthusiasm for manufacturing itself remained relatively static. This suggests that although VR boosts engagement with advanced technologies, additional refinement may be needed to increase interest in specific domains such as manufacturing.

The data also revealed a polarization in responses: some students embraced the VR experience enthusiastically, while others experienced discomfort or disengagement. This highlights the importance of a nuanced and student-centred approach to VR content design. Overall, the findings affirm the potential of VR to enhance engagement in engineering education—especially among senior students—while emphasizing the need for ongoing content refinement. A continuous improvement framework will be essential to ensure that VR remains both effective and scalable in future iterations of the curriculum.

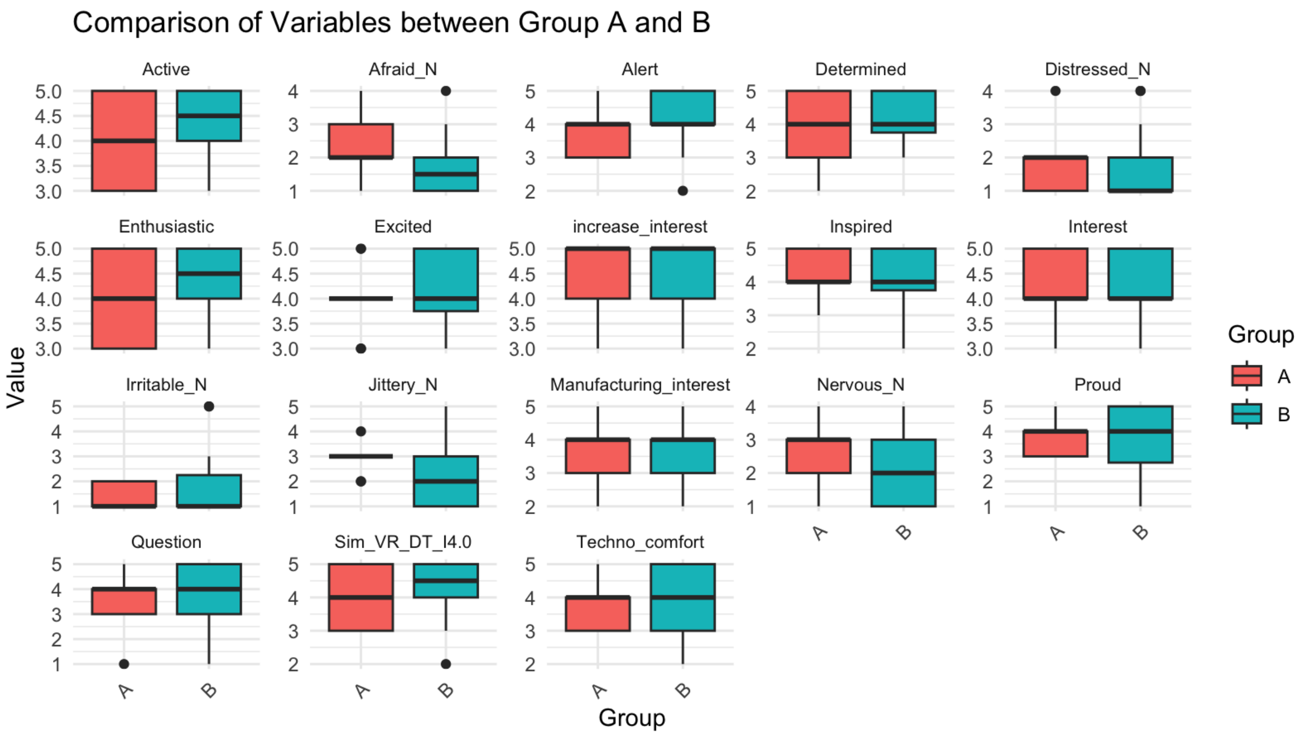

Figure 2: Boxplot comparison between group A (3rd years) and group B (4th years)

The boxplot comparison between Group A and Group B (figure 2) reveals notable differences in engagement, emotional responses, and interest in technology. Group B generally shows higher enthusiasm, excitement, and a greater sense of pride, suggesting a more positive emotional experience. They also demonstrate a slightly stronger interest in emerging technologies such as Simulation, VR, Digital Twins, and Industry 4.0, along with higher techno-comfort levels. Additionally, Group B appears more engaged, with higher median values for increased interest and questioning behaviour. In contrast, Group A exhibits slightly more variation in negative emotional responses, such as fear and distress. However, both groups share similar distributions in determination, inspiration, and comfort with technology. Overall, the results indicate that Group B may have found the experience more engaging and stimulating, while Group A displayed more variation in emotional responses.

Viewing comfort with the technology as a positive PANAS result, we see—as expected—that the fourth-year class is more comfortable with technology. This suggests that the technology may be more appropriate for that cohort and stands a higher chance of engaging students. For example, Group B self-reported significantly higher positive emotions such as techno-comfort, pride, and enthusiasm compared to Group A. Group B also reported lower levels of negative emotions (jitteriness, nervousness, distress, and fear) than Group A. Interestingly, both groups reported a significant increase in general interest, which was notably higher than the limited increase observed in interest in manufacturing. This suggests that while the technology itself may be engaging, it did not necessarily increase domain-specific interest and should therefore be examined more closely.

6 Conclusion and recommendations

6.1 Summary

This study demonstrates the potential of Virtual Reality (VR) to enhance engagement, emotional response, and interest in Industry 4.0 technologies within large-class engineering education. By integrating experiential learning principles and evaluating emotional feedback through the Cognitive-Affective-Systemic framework, the VR-based activity provided students with a more interactive and scalable alternative to traditional industrial exposure. Findings indicate that senior students show greater receptiveness and emotional ease, suggesting maturity and familiarity play key roles in technology adoption. Moving forward, the continuous improvement model and ecosystem-based development framework offer a sustainable path for refining and expanding VR integration in engineering curricula.

6.2 Future Work: Expanding the Ecosystem Design-Based Research Framework

A key avenue for future work involves further developing the collaborative framework underpinning this study through an Ecosystem Design-Based Research (DBR) (figure 3) strategy focused on continuous improvement. This approach is visualized as a layered ecosystem—akin to a pyramid—where each academic level contributes uniquely to the iterative development of VR-enhanced learning experiences.

At the strategic apex of the pyramid, academic staff act as principal investigators, introducing key learning objectives and theoretical foundations that guide the overall educational vision. At the tactical level, master's students take on the role of VR system developers, building and iterating on the technical infrastructure in alignment with these objectives. Honours students operate at the operational level, designing and customizing specific VR learning activities within the established system, supported by both lecturers and master's students.

At the base of the pyramid, third- and fourth-year undergraduate students engage directly with the VR content, serving as active participants and feedback providers. Their user experience data—emotional, cognitive, and systemic—is used to inform ongoing improvements in both content and pedagogy. This ecosystem structure promotes vertical integration of skills and knowledge across academic levels, enabling a sustainable model for continuous improvement and innovation in engineering education.

By structuring development and evaluation responsibilities across academic tiers, this framework not only offers the possibility of scalability and relevance, but may also create meaningful opportunities for mentorship, collaboration, and iterative refinement of both technology and teaching practice.

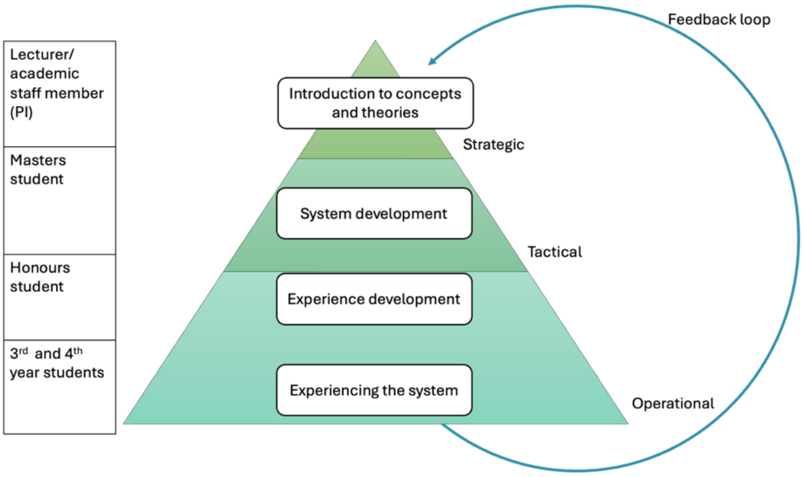

Figure 3: Ecosystem Design-Based Research Framework. A layered, collaborative model for continuous improvement in VR-enhanced learning. Each academic level—from staff to undergraduates—contributes

uniquely to system development, implementation, and feedback, enabling scalable, sustainable educational innovation

6.3 Future Interventions

Future research will investigate the impact of offering multiple, distinct educational experiences within the same 3D virtual factory environment. Currently, this virtual space supports various applications—such as a tablet-based interface for teaching industrial robot programming (van Dyk et al, 2025) via a Human-Machine Interface (HMI), and a VR-based facility layout exercise where students reconfigure workstations and observe simulated operator paths [Steed et al, 2025]. Figure 4 depicts these current applications. While this reuse is designed to enhance engagement and promote cognitive transfer through familiarity, the educational value and potential trade-offs of repeated exposure to the same virtual context across different learning activities remain underexplored. Understanding how familiarity affects learning, motivation, and performance will be central to refining the design of scalable VR-based curricula.

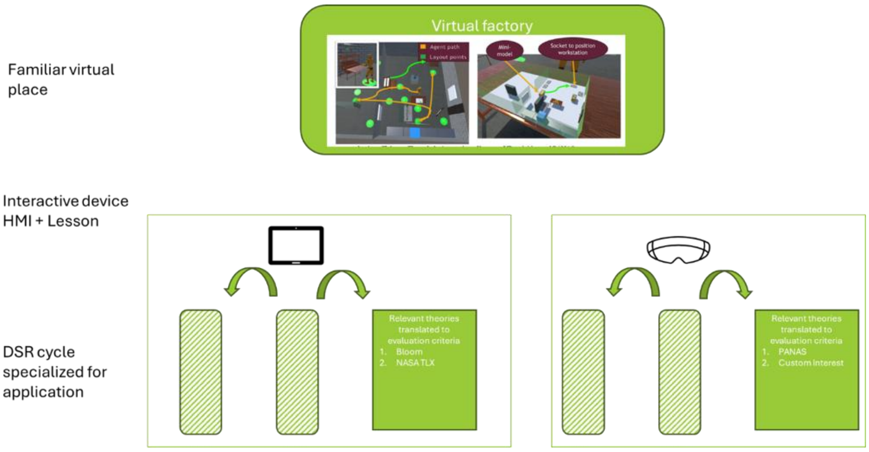

Figure 4 The virtual factory is reused across tablet- (Van Dyk et al., 2025) and VR-based lessons to support robot programming and layout design exercises. Familiarity from repeated use is intended but remains underexplored.

6.4 Limitations

As part of the faculty-wide continuous improvement strategy aimed at enhancing engagement in large classroom settings, future studies will address the following limitations:

- Expanded sample and statistical rigor: Future research will broaden the scope of qualitative approaches and increase the sample size to enable more meaningful statistical analysis and demonstrate significance. More granular data will also be collected to strengthen insights.
- Enhanced participant profiling: Higher-fidelity demographic data—including age, gender, and social background—will be gathered for focus group participants. These variables may influence results, especially given the small sample sizes used in earlier phases.
- Industry-Academia alignment: Incorporating feedback from industry stakeholders can further inform these studies. This will not only provide industry with insight into the current state of classroom technologies but also help bridge the gap between academic instruction and industry needs.

Acknowledgments

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7 References

Alizadeh, M., & Cowie, N. (2022). Self-directed learning using VR. Pacific Journal of Technology Enhanced Learning, 4(1), 10-11. doi:10.24135/pjtel.v4i1.130

Bandura, A. (1977). Self-efficacy: toward a unifying theory of behavioral change. *Psychological review*, *84*(2), 191.

Barnett, R. (2000). Supercomplexity and the curriculum. Studies in higher education, 25(3), 255-265.

Bloom, B. S. (1956). Taxonomy of. Educational Objectives.

Cao, L. (2023). A meta-analysis of the impact of AR and VR technologies on mathematics learning. Journal of Education, Humanities and Social Sciences, 23, 637-649. doi:10.54097/ehss.v23i.13133

Chandramouli, M., & Williams, A. (2024). Affordable virtual and augmented reality training modules for workforce development and smart manufacturing. Journal of Manufacturing Engineering, 19(4), 101-107.

Chen, J., Fu, Z., Liu, H., & Wang, J. (2024). Effectiveness of Virtual Reality on Learning Engagement: A Meta-Analysis. International Journal of Web-Based Learning and Teaching Technologies (IJWLTT), 19(1), 1-14. doi:10.4018/IJWLTT.334849

Dorfling, C., Wolff, K., & Akdogan, G. , Expanding the semantic range to enable meaningful real-world application in chemical engineering, South African Journal of Higher Education, vol. 33, no. 1, pp. 42-58, 2019.

GeriÅŸ, A. (2024). The EVRIM Framework: Guiding Ethical and Inclusive Virtual Reality Integration in Education. Manisa Celal Bayar Ãœniversitesi EÄŸitim FakÃ¼ltesi Dergisi, 12(2), 567-583.

Gilmore, J., Wolff, K., & Bladergroen, M. (2017, June). The night before the test: Electrical engineering students use of online resources to prepare for assessment. In Proceedings of the Biennial Conference of the South African Society for Engineering Education (p. 82).

Gilmore, R. O., Adolph, K. E., Millman, D. S., & Gordon, A. (2016). Transforming education research through open video data sharing. Advances in engineering education, 5(2), http-advances.

Graeske, C., & Sjöberg, S. A. (2021). VR-Technology in Teaching: Opportunities and Challenges. *International Education Studies*, *14*(8), 76. https://doi.org/10.5539/ies.v14n8p76

H. Ardiny and E. Khanmirza, "The Role of AR and VR Technologies in Education Developments: Opportunities and Challenges," *2018 6th RSI International Conference on Robotics and Mechatronics (IcRoM)*, Tehran, Iran, 2018, pp. 482-487, doi: 10.1109/ICRoM.2018.8657615.

IEA, Graduate Attributes and Professional Competencies, International Engineering Alliance, 2021.

Kolb, D. A. (1984). Experiential learning. New Jersey, Eaglewood Cliffs, 5, 1-12.

Kruger, K., Wolff, K., & Cairncross, K. (2022). Real, virtual, or simulated: Approaches to emergency remote learning in engineering. Computer Applications in Engineering Education, 30(1), 93-105.

Leng, J., Sha, W., Wang, B., Zheng, P., Zhuang, C., Liu, Q., ... & Wang, L. (2022). Industry 5.0: Prospect and retrospect. Journal of Manufacturing Systems, 65, 279-295.

Lewis, C., Wolff, K., & Bekker, B. (2025). Making the implicit explicit: operationalising occurrences of cognitive development in a postgraduate engineering Community of Practice. European Journal of Engineering Education, 1-16.

N. a. o. engineering, NAE Grand Challenges for Engineering, 2024. [Online]. Available: https://www.engineeringchallenges.org/challenges/discovery.aspx.

Sadek, O., Baldwin, F., Gray, R., Khayyat, N., & Fotis, T. (2023). Impact of virtual and augmented reality on quality of medical education during the COVID-19 pandemic: a systematic review. Journal of Graduate Medical Education, 15(3), 328-338. doi:10.4300/JGME-D-22-00594.1

Steed, C. A., Wolff, K., & Mangaroo-Pillay, M. (2025). A Framework for Virtual Reality Adoption in Engineering Education: Measuring Emotional Engagement and Long-term Effects. 15th Conference on Learning Factories 2025. Conference on Learning Factories.

Tait, A. (2000). Planning student support for open and distance learning. Open learning: The Journal of open, distance and e-learning, 15(3), 287-299.

Tootell, A., Jackson, M., Jiminez, Y., & Rainford, L. (2024). Advancing radiography education: Bridging theory and practice. Radiography, 30, 156-157.

United Nations. (2025). The 17 goals. United Nations. [Online]. Available: https://sdgs.un.org/goals

Van Dyk, M., Mangaroo-Pillay, M., & Steed, C. A. (2025). Scaling Industrial Robotics Education: A Serious Game Approach for Resource-Limited Regions. 15th Conference on Learning Factories 2025. Conference on Learning Factories.

Walker, R. (2022). Using virtual reality to support first-year online initial teacher education students. ASCILITE Publications, e22113-e22113. doi:10.14742/apubs.2022.113

Yu, Z., & Xu, W. (2022). A meta analysis and systematic review of the effect of virtual reality technology on users' learning outcomes. Computer applications in engineering education, 30(5), 1470-1484. doi:10.1002/cae.22532

Crawford, J. R., & Henry, J. D. (2004). The Positive and Negative Affect Schedule (PANAS): Construct validity, measurement properties and normative data in a large non-clinical sample. *British Journal of Clinical Psychology*, *43*(3), 245–265. https://doi.org/10.1348/0144665031752934

Di Pompeo, I., D’Aurizio, G., Burattini, C., Bisegna, F., & Curcio, G. (2023). Positive mood induction to promote well-being and health: A systematic review from real settings to virtual reality. *Journal of Environmental Psychology*, *91*, 102095. https://doi.org/10.1016/j.jenvp.2023.102095

Pallavicini, F., & Pepe, A. (2020). Virtual Reality Games and the Role of Body Involvement in Enhancing Positive Emotions and Decreasing Anxiety: Within-Subjects Pilot Study. *JMIR Serious Games*, *8*(2), e15635. https://doi.org/10.2196/15635

8 Review

Reviewer	Comment	Actions	Response
Reviewer 3	Good research paper on an innovative learning process for students using VR.	N/A	
Reviewer 3	Literature review is well done and solid.	N/A	
Reviewer 3	The effect of COVID is contradictory – less engagement vs. more technological maturity.	Clarify the narrative around COVID's impact, ensuring consistency and nuance in how these two aspects are discussed.	I've removed reference to Covid. While it may be relevant, (1) we did not provide sufficient evidence (2) nor did we compare pre and post covid groups. My suggestion is that we remove the minor mentions of it.
Reviewer 3	Methodology is theoretically relevant, but small study groups (15 in Year 3, 25 in Year 4) make findings fragile.	Acknowledge the limitation; propose expansion of sample size in future work section.	Added section 6.4.
Reviewer 3	No profile data for focus group participants (age, gender, social background) – may affect results given small sample size.	Add a note on the lack of demographic data as a limitation and suggest its inclusion in future studies.	Added section 6.4.
Reviewer 3	Data in Figure 2 are not very self-explanatory for some indicators.	Improve the clarity of Figure 2; add detailed captions or explanations in the text.	Added a paragraph at the end of the section.
Reviewer 3	Overly positive tone on VR; lacks mention of drawbacks or weak points.	Include a paragraph discussing limitations or challenges associated with VR in education.	See comment.
Reviewer 3	Industry feedback is missing – would help assess the approach more fully.	Suggest the inclusion of industry feedback in future work or acknowledge its absence as a current limitation.	Added section 6.4.
Reviewer 4	Issue of active learning for large student groups is very relevant, especially in unequal contexts.	N/A	
Reviewer 4	VR strategy is viable; well-written document.	N/A	
Reviewer 4	Lacks clarity on importance of students' emotional response to the strategy.	Expand discussion to explicitly include emotional responses and their potential impact.	Refer to earlier addition for figure 2.
Reviewer 4	Problem definition should more clearly state the significance of emotional responses for effective implementation.	Revise the problem statement to emphasize emotional aspects of learning with VR and their implications.	