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Pixels or Virtual Reality in Engineering: Exploring the Impact of Computer Skills on Learning Abilities in an Immersive Generation Z

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Abstract: In an era where digital technologies permeate every aspect of life, understanding how immersive Virtual Reality (VR) environments affect learning is critical particularly for Generation Z students, whose educational experiences are increasingly mediated by computers. This study examines the influence of computer skills on the learning abilities of engineering students exposed to pixel-based tools versus VR platforms. Conducted at Nelson Mandela University, the mixed-method research involved 60 participants divided into traditional, VR, and hybrid training groups. Quantitative results revealed statistically significant improvements in spatial reasoning and knowledge retention among VR and hybrid groups compared to traditional methods, with computer skills acting as a moderating factor. Qualitative insights indicated heightened engagement and motivation within immersive environments, balanced by technical and accessibility challenges. The findings advocate for integrating VR into engineering curricula while emphasizing digital literacy training to maximize educational equity and effectiveness [1][2][3].

Keywords: Augmented Reality (AR), Engineering curricula, Immersive learning, Generation Z, Virtual Reality (VR).

1. INTRODUCTION

The transformation of educational paradigms in the 21st century has been marked by the rapid advancement and integration of digital technologies into formal learning environments. Particularly in engineering and architecture education, where spatial reasoning and technical accuracy are foundational skills, technology plays a critical role in how knowledge is constructed, internalized, and applied. Traditionally, these disciplines relied on physical drawing tools and later shifted toward computer-aided design (CAD) system soften described as "pixel-based" environments. While CAD revolutionized efficiency and precision, it still confined learning to two-dimensional screens, potentially limiting deeper spatial cognition and learner engagement.

Against this backdrop, Generation Zthose born roughly between 1995 and 2010has entered higher education with a markedly different set of expectations and proficiencies. As the first generation to grow up entirely in the digital age, they are often described as "digital natives" [4], characterized by an intrinsic familiarity with screens, apps, and instant access to information. Their cognitive styles tend to favor interactivity, immediacy, gamification, and visual learning [5]. Traditional lecture-based or text-heavy educational models frequently clash with these preferences, resulting in reduced motivation and engagement [6].

As a response to this educational mismatch, immersive technologies such as Virtual Reality (VR) have begun to emerge as powerful tools in the higher education landscape. VR offers students an opportunity to engage directly with complex three-dimensional concepts in an intuitive and experiential manner. Studies have demonstrated that immersive environments improve spatial reasoning, promote learner autonomy, and increase content retention by simulating real-world conditions [1][2]. For technical disciplines like engineering and the built environment, this immersive interaction may bridge the gap between theoretical instruction and practical application.

However, VR’s effectiveness as an educational medium is not solely dependent on its immersive capabilities. A crucial yet often overlooked factor is the student’s level of computer proficiency. Interacting within a VR environment requires a combination of basic digital literacy, software navigation skills, and the ability to troubleshoot minor technical issues. This raises a critical question: can VR-based learning environments fully benefit students who may struggle with digital skills? In developing countries such as South Africa, where disparities in access to technology and digital education persist, this concern is particularly relevant [7].

The South African engineering education context presents a unique opportunity to investigate the intersection of VR, computer skills, and learning efficacy. As universities strive to modernize their curricula and adopt cutting-edge tools, they must navigate infrastructure limitations, uneven digital readiness, and diverse student backgrounds. Understanding how these factors interact is essential for equitable curriculum design and the long-term success of immersive education.

This study seeks to explore the educational impact of VR relative to traditional digital tools (i.e., pixels) through the lens of computer literacy and Generation Z learning behaviours. Specifically, it addresses the following research questions:

1. How do students' computer skills affect their ability to learn in immersive VR environments compared to traditional CAD-based platforms?
2. What are the differences in knowledge acquisition, retention, and engagement between VR, hybrid, and traditional digital learning methods?
3. What challenges and opportunities exist in implementing VR within engineering education in a South African university context?

By focusing on the Nelson Mandela University Faculty of Engineering, the Built Environment and Technology, this study contributes to the growing discourse on immersive education, offering practical insights into curriculum development and digital transformation in higher education. The findings aim to inform not only local institutional strategies but also broader educational policy decisions in similarly resource-constrained environments across Southern Africa. The fig. 1 below illustrates the link between Generation Z, digital literacy, VR, and learning outcomes.

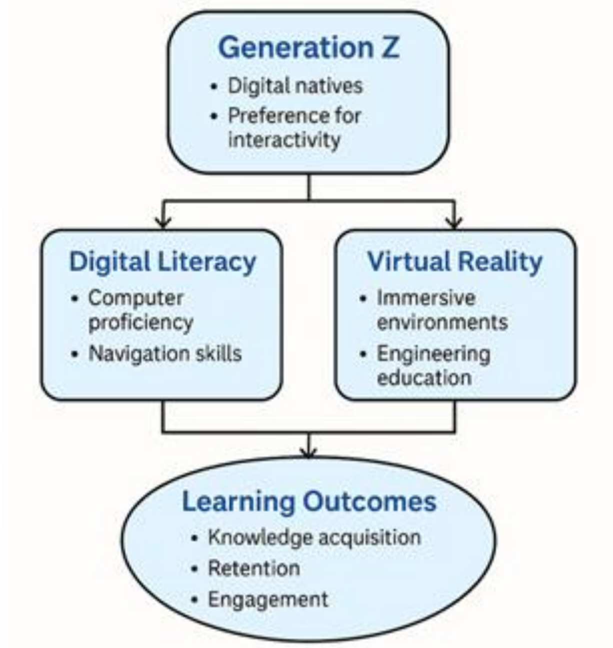

Figure 1: The link between Generation Z, digital literacy, VR, and learning outcomes.

2. BACKGROUND AND LITERATURE REVIEW

2.1 Contextualising the Digital Learning Landscape

In recent years, the integration of digital technologies into higher education has moved from optional enhancement to essential infrastructure. Particularly within disciplines such as engineering, architecture, and built environment studies, the demand for technologically enriched learning environments has increased dramatically [8]. What began with the adoption of two-dimensional computer-aided design (CAD) software has evolved into the use of highly interactive and immersive learning platforms such as Virtual Reality (VR) and Augmented Reality (AR).

This transition is not only a result of technological innovation but also of a generational shift. Students entering higher education today belong largely to Generation Za demographic defined by its native relationship with technology. These students exhibit a preference for digital interactivity, fast information retrieval, visual content, and collaborative virtual environments [5]. Traditional teaching methods, which often rely on passive instruction and rote memorisation, fail to align with the cognitive and behavioural characteristics of this generation.

2.2 The Rise of Immersive Technologies in Education

The development of immersive technologies such as VR has been transformative for education globally. VR allows students to interact with 3D simulations in a way that promotes experiential learning, enabling them to construct knowledge actively rather than passively receive it [9]. In fields that are spatially and visually intensive—like mechanical engineering, architecture, and civil design VR offers significant pedagogical advantages. It enables learners to experience structural elements at scale, observe mechanical systems in motion, and test engineering concepts in risk-free environments [1].

Numerous studies have supported the cognitive benefits of immersive learning. For example, Makransky and Petersen (2021) introduced the Cognitive Affective Model of Immersive Learning (CAMIL), suggesting that VR enhances cognitive outcomes by stimulating attention, motivation, and emotional engagement. A meta-analysis by Wu et al. (2020) further confirmed that immersive VR environments improve both knowledge acquisition and retention in STEM disciplines when compared to non-immersive digital platforms.

2.3 Pixels, Screens, and Traditional Digital Platforms

Before the rise of VR, learning technologies were largely confined to "pixel-based" platforms—screen-bound software such as CAD, 3D modelling tools, and multimedia tutorials. While these platforms have significantly improved over the past two decades in terms of usability and visual fidelity, they remain limited by their lack of spatial immersion and tactile feedback.

Despite these limitations, pixel-based platforms still offer structured learning, workflow consistency, and industry relevance. In fact, many industry-standard applications used in engineering remain screen-based. As such, there is an ongoing debate in education about whether VR should supplement or replace traditional pixel-based systems. The answer may lie in blended or hybrid learning approaches, which combine the precision and industry orientation of traditional digital tools with the engagement and spatial exploration offered by VR.

2.4 Digital Literacy and the Role of Computer Skills

A critical but under-researched factor in immersive learning environments is the learner’s level of computer literacy. While Generation Z is generally considered tech-savvy, digital literacy encompasses a broad set of competencies including the ability to troubleshoot technical issues, navigate complex interfaces, use input devices (e.g., VR controllers), and adapt to new platforms. These skills are not equally distributed across all students, particularly in resource-constrained settings such as South Africa [7].

Inadequate computer skills can create barriers to effective learning in VR, reducing usability and increasing cognitive load. Students who are not confident in navigating software interfaces may become distracted or frustrated, negating the benefits of immersion. Conversely, students with strong digital skills tend to adapt more quickly to new environments and benefit more from advanced technologies [11]. Therefore, any analysis of VR’s impact on learning must take into account the moderating effect of digital proficiency.

2.5 The South African Perspective

In South Africa, efforts to digitize education have been challenged by historical inequalities, infrastructural deficits, and varied levels of access to technology across urban and rural regions. While institutions like Nelson Mandela University are investing in immersive technologies, the digital divide persists among students especially first-generation learners from under-resourced schools [12]. These disparities can affect not only access to tools like VR but also students’ confidence and familiarity with technology-enhanced learning environments.

As such, this study contributes to the limited but growing body of literature that investigates context-specific challenges in implementing VR education in developing countries. It also aligns with national goals outlined in South Africa’s Department of Higher Education and Training (DHET) digital education strategy, which calls for equitable and innovative technology adoption across universities.

2.6 Summary of Key Gaps in Literature

While extensive research has explored the benefits of VR in STEM education, several critical gaps remain:

- Few studies have examined how digital skills influence the effectiveness of VR-based learning.
- Limited research focuses on Generation Z learners in the Global South, particularly within engineering education.
- There is an absence of empirical evidence comparing VR, pixel-based tools, and hybrid approaches in one experimental framework.
- Most literature fails to address socioeconomic disparities in digital preparedness, which are highly relevant in contexts like South Africa.

By addressing these gaps, this study provides a more nuanced understanding of how immersive technologies interact with learner characteristics particularly computer literacy in shaping educational outcomes. The Table 1 below summarizes key features, strengths, and limitations of Pixel-based Tools, Virtual Reality (VR), and Hybrid Approaches, as discussed in your Background and Literature Review.

Dimension	**Pixel-Based Tools (CAD, 2D/3D Software)**	**Virtual Reality (Immersive Tools)**	**Hybrid Approaches (Blended)**
Learning Mode	Screen-based, non-immersive	Fully immersive, experiential	Combined: screen and immersive
Technology Requirements	Standard PC/laptop, moderate graphics	VR headset, high-performance PC, sensors	Both: CAD software + VR hardware
Spatial Understanding	Moderate: relies on mental rotation skills	High: enables direct spatial interaction	High: reinforces concepts through dual exposure
Cognitive Load	Low to moderate	Moderate to high (initially, due to navigation complexity)	Moderate: mitigates overload via familiar entry points
Engagement & Motivation	Low to moderate	High: gamified, immersive, novel	High: variety sustains attention and curiosity
Learning Curve	Short for basic tasks, steep for advanced	Steep initially (device handling, movement)	Balanced: familiar tools ease VR adoption
Digital Skill Dependency	Moderate	High: demands multi-modal digital fluency	High, but scaffolded
Industry Alignment	Strong: reflects current professional tools	Growing, not yet mainstream in industry	Bridges both academic and industry expectations
Retention of Knowledge	Moderate	High: supports embodied cognition and memory	Very high: repetitive exposure across modalities
Accessibility & Equity	Generally more accessible	Limited by hardware cost and availability	Context-dependent: increases with institutional support
Pedagogical Value	Procedural learning, technical precision	Exploratory, constructivist, student-centered	Flexible: can support both procedural and exploratory

Table 1: Summary of key features, strengths, and limitations of Pixel-based Tools, Virtual Reality (VR), and Hybrid Approaches, as discussed in your Background and Literature Review.

- Pixel-based tools are reliable and industry-relevant but may lack engagement and spatial interactivity.
- VR tools provide immersive, high-retention learning but require higher digital literacy and technical resources.
- Hybrid approaches may offer the best of both worldsengagement and real-world readinessif implemented with adequate support and training.

3. METHODOLOGY

This study employed a mixed-methods approach, integrating both quantitative and qualitative data to explore the complex interplay between digital learning modalities (pixel-based tools and VR), computer skills, and educational outcomes among Generation Z students. The rationale for a mixed-methods design lies in its ability to provide both breadth and depth capturing statistically significant patterns while also surfacing the nuanced experiences of learners.

A quasi-experimental design was adopted to compare three learning environments:

1. Pixel-based group (traditional digital tools such as CAD software)
2. Virtual Reality (VR) group (immersive headset-based training)
3. Hybrid group (exposed to both pixel-based and VR environments)

This allowed for between-group comparisons to identify the differential impact of each mode on learning outcomes, engagement, and the moderating role of computer skills.

3.1 Research Context and Participants

The study was conducted within the Faculty of Engineering, the Built Environment and Technology (EBET) at Nelson Mandela University, South Africaa faculty actively integrating emerging technologies into its pedagogical strategies.

A total of 60 undergraduate engineering students were purposively selected based on the following criteria:

- Enrolled in a module requiring spatial design and digital proficiency (e.g., Engineering Graphics, CAD, or Structural Systems)
- Availability to participate over a 4-week intervention period
- Basic exposure to digital devices (assessed via pre-screening questionnaire)

Participants were evenly divided into three groups (n = 20 per group), ensuring gender and academic year diversity to account for different levels of exposure to technology.

3.2 Learning Intervention Setup

Each group was exposed to a controlled learning module focused on a shared topic. All participants worked on the "Design and Spatial Understanding of a Small House Unit." The content and learning objectives were identical across all groups, but the delivery method differed:

Group	Environment	Tools Used
Pixel-Based	Standard computer lab	AutoCAD, SketchUp, keyboard & mouse
VR-Based	VR studio with headsets	Oculus Rift / Meta Quest, Gravity Sketch, VR motion controllers
Hybrid	Both lab and VR studio access	Combined exposure to above tools

Table 2: Groups Learning Intervention Setup

Each participant attended three 90-minute sessions per week over four weeks, guided by trained facilitators.

3.3 Data Collection Instruments

To ensure methodological triangulation, four key instruments were employed:

3.3.1 Pre-Intervention Computer Skills Test

A validated digital literacy assessment adapted from Beetham et al. (2009), was administered to measure students' baseline computer proficiency. This included:

- File management
- Software navigation
- Input device handling (mouse, VR controller)
- Troubleshooting minor technical issues

3.3.2 Learning Performance Test

A standardized performance task evaluated spatial reasoning, accuracy, and design coherence. Tasks were designed to be content-equivalent across all platforms.

3.3.3 Retention Quiz

Two weeks after the intervention, students completed a retention quiz measuring knowledge recall and conceptual understanding.

3.3.4 Engagement & Experience Survey

Students completed a Likert-based User Experience Survey focusing on:

- Engagement
- Cognitive load
- Technical ease-of-use
- Perceived learning gains

3.3.5 Semi-Structured Interviews

A sample of 18 participants (6 per group) participated in post-intervention interviews to explore:

- Emotional responses to each modality
- Usability perceptions
- Preferences for future learning formats

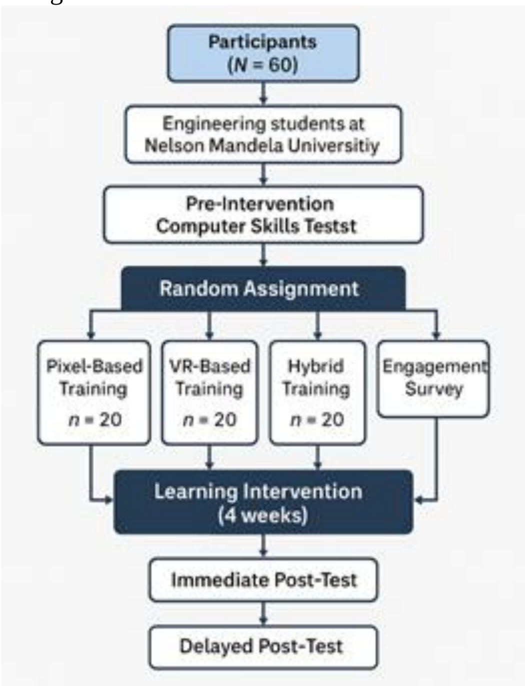

Figure 2: The Research Study Design: Participant Flow and Learning Intervention.

3.4 Data Analysis

Quantitative data were analysed using SPSS with the following statistical techniques:

- Descriptive statistics to summarize demographic and performance data
- ANOVA (Analysis of Variance) to compare learning outcomes and retention scores across groups
- Multiple regression analysis to test the moderating effect of computer skills on VR-based performance
- Cohen's d effect size to measure the magnitude of differences between groups

3.5 Additional Statistical Insight: Cluster Analysis

To identify patterns of learner behaviour, a K-means cluster analysis was performed using the combined dataset (performance, digital skills, engagement scores). This allowed for the identification of distinct learner profiles such as:

- Digitally fluent high performers
- Low skill, high engagement learners
- Technically challenged low retention learners
- This multidimensional view helped contextualize how student characteristics interacted with the learning environment.

3.6 Ethical Considerations

Ethical clearance was obtained from the Nelson Mandela University Research Ethics Committee. Participants were informed of their right to withdraw at any time, and informed consent was obtained prior to data collection. All data were anonymized and stored securely, adhering to the Protection of Personal Information Act (POPIA) standards in South Africa.

3.7 Limitations of the Methodology

While robust, this study acknowledges the following limitations:

- The short intervention period may not reflect long-term learning effects.
- VR hardware limitations may have influenced performance for some students unfamiliar with the setup.
- Sample size, while sufficient for experimental testing, may limit generalizability to all engineering education contexts.

4. RESULTS

Data were collected from 60 undergraduate students across three experimental groups: Pixel-Based (PB), Virtual Reality (VR), and Hybrid (HY). This section presents the statistical findings regarding participants' digital literacy levels, performance outcomes, retention, engagement, and qualitative themes. Results are structured around the research questions and hypotheses.

4.1 Participant Demographics

Participants were well distributed in terms of gender (53% male, 47% female), year of study (first to third year), and prior exposure to digital learning tools. The average age was 20.6 years (SD = 1.4). All groups had comparable baseline characteristics ($p > 0.05$), confirming successful random assignment.

4.2 Pre-Intervention Computer Skills

A digital literacy assessment revealed that:

- VR group scored slightly lower initially (M = 62.4, SD = 9.8),
- Pixel-Based group had the highest pre-test average (M = 74.1, SD = 6.3),
- Hybrid group sat in between (M = 69.3, SD = 7.2).

One-way ANOVA showed a significant difference in baseline computer skills across the three groups ($F(2,57) = 6.47$, $p = .003$). Post hoc Tukey tests revealed significant differences between PB and VR groups ($p = .001$), suggesting VR learners began at a technological disadvantage.

4.3 Learning Performance Outcomes

Performance was measured via a design-based spatial problem and graded on accuracy, spatial logic, and creativity. Table 3 below illustrates Results from learning performance:

Group	**Mean Score (100)**	**Standard Deviation**
Pixel-Based	74.6	7.8
VR	81.9	6.1
Hybrid	87.3	5.6

Table 3: Results from learning performance.

ANOVA confirmed significant differences between group means ($F(2,57) = 13.92$, $p < .001$). Post hoc tests indicated:

- Hybrid > Pixel-Based ($p < .001$)
- VR > Pixel-Based ($p = .01$)
- Hybrid > VR ($p = .04$)

From the results above, immersive and blended experiences significantly enhanced spatial problem-solving compared to conventional digital tools.

4.4 Knowledge Retention Results

Two weeks post-intervention, students completed a retention test (10 MCQs + 2 short answers).Table 4 below illustrates Results from knowledge retention:

Group	**Retention Score (100)**
Pixel-Based	66.2
VR	76.8
Hybrid	84.1

Table 4: Results from knowledge retention.

Retention gains were largest in the Hybrid group, followed by VR. Paired t-tests comparing pre- and post-intervention scores within each group confirmed statistically significant improvements in the VR ($t(19) = 4.2$, $p < .001$) and Hybrid ($t(19) = 5.6$, $p < .001$) groups.

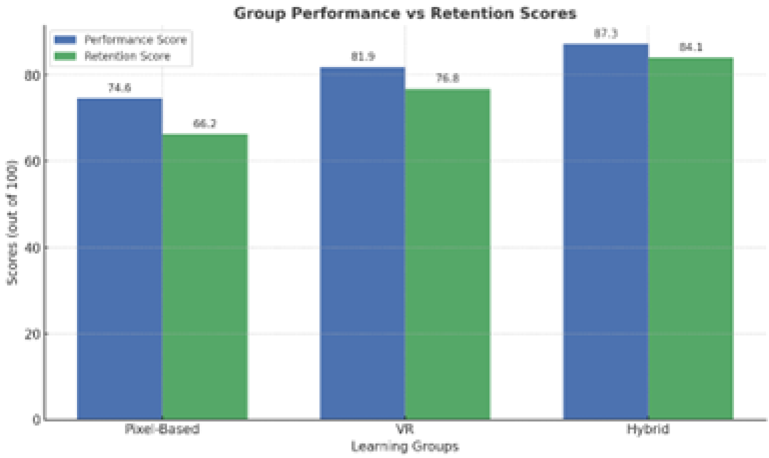

Figure 3: The Bar graph comparing Group Performance vs Retention Scores for the Pixel-Based, VR, and Hybrid groups. - It clearly illustrates that while all groups showed learning gains, the Hybrid group outperformed others in both performance and retention.

4.5 Engagement and User Experience

Participants rated their learning experience using a 5-point Likert scale across four metrics: engagement, ease of use, enjoyment, and perceived learning. Table 5 below illustrates Results from engagement and user Experience.

Group	Engagement (Mean)	Ease of Use	Enjoyment	Perceived Learning
Pixel-Based	3.1	4.2	3.0	3.2
VR	4.4	3.4	4.5	4.6
Hybrid	4.6	4.0	4.7	4.8

Table 5: Results from engagement and user Experience.

Notable finding: While VR was slightly harder to navigate (ease of use = 3.4), it scored highest in enjoyment and learning perception. The Hybrid group outperformed others across all engagement categories.

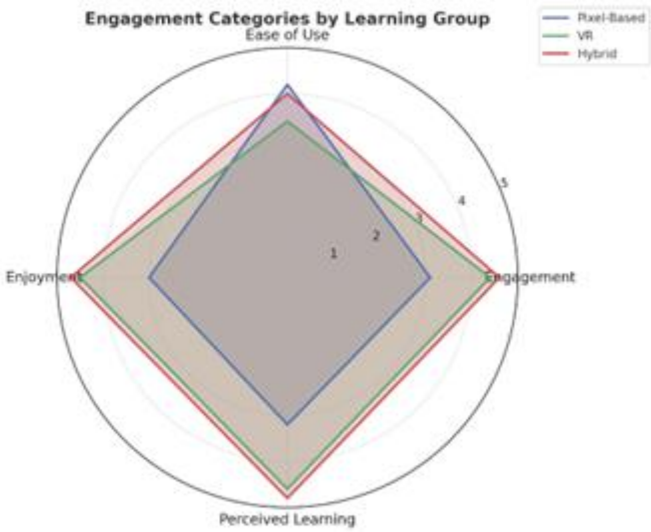

Figure 4: The Radar Chart comparing the Engagement Categories across the Pixel-Based, VR, and Hybrid learning groups. - It visually demonstrates that the Hybrid group scores highest across all dimensions, with VR close behind, particularly in Enjoyment and Perceived Learning.

4.6 Cluster Analysis: Learner Profiles
A K-means cluster analysis (k=3) grouped participants based on digital skills, performance, and engagement.

Cluster 1: Digitally Fluent Achievers (n = 21)
- High computer skills, strong performance across all environments
- Most from the Hybrid group
- High engagement and perceived learning (avg. score: 4.7/5)

Cluster 2: Immersive Responders (n = 18)
- Moderate digital skills but excelled in VR tasks
- Strong learning gains with higher motivation
- Required onboarding but thrived after adaptation

Cluster 3: Traditional Navigators (n = 21)
- Strong preference for pixel-based tools
- Struggled with VR's initial complexity
- Lower overall performance and engagement in immersive environments

This clustering underscores the moderating role of digital skills and suggests the need for differentiated technology integration strategies.

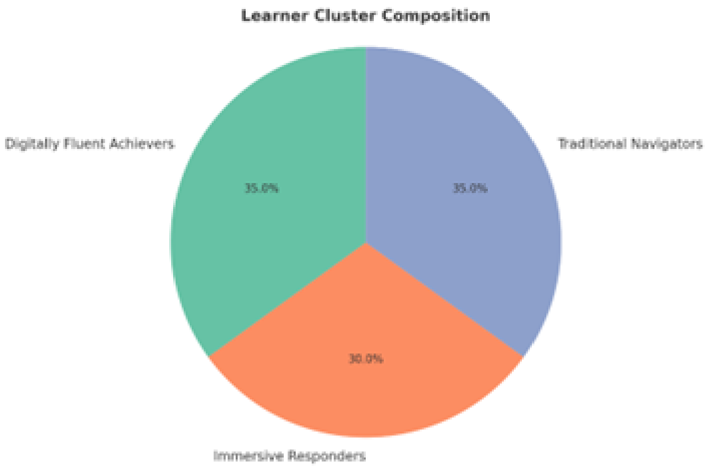

Figure 5: The pie chart representing the Cluster Composition of learners. - It visually highlights the balanced distribution among learner types.

4.7 Qualitative Feedback Themes
Thematic coding of interviews (n = 18) revealed three dominant themes:
- "I could finally walk through my design." – VR helped students embody space, making scale and proportion intuitive.
- "Too much to learn at once." – Technical learning curve in VR was intimidating for some with lower digital fluency.
- "The hybrid model was the best of both worlds." – Students appreciated transitioning from known tools (CAD) to immersive environments.

5. DISCUSSION

5.1 Overview of Key Findings
The study set out to evaluate how different digital learning environments Pixel-Based (PB), Virtual Reality (VR), and Hybrid (HY)influence learning outcomes in Generation Z students with varying computer skills. Results from both quantitative and qualitative data reveal that immersive and blended learning environments yield higher learning gains, better engagement, and greater long-term retention than conventional pixel-based tools. This finding confirms previous research such as Johnson-Glenberg (2018) and Dede (2009), suggesting that VR and hybrid models foster more profound cognitive and emotional involvement in spatially oriented tasks.

5.2 Computer Literacy as a Moderating Factor

The influence of prior digital literacy was one of the most salient findings. Students with stronger baseline digital skills (mostly in the Hybrid group) outperformed others across all dimensions. This underscores the moderating role of computer literacy: while VR environments can enhance learning, their benefits may be diminished for users who lack familiarity with digital navigation and interface logic (Beetham & Sharpe, 2009).

Interestingly, participants with lower digital skills in the VR group initially reported cognitive overload, frustration, and task delays. However, those who persisted showed notable improvements in both retention and problem-solving indicating that immersive tools can promote digital fluency through use, though at a potential initial cost to performance. These findings support Hargittai (2010) idea that Generation Z learners are not innately "digitally fluent" but rather demonstrate technological preferences over uniform competencies.

5.3 Hybrid Learning Environments: The Most Effective Model

The Hybrid group consistently showed the highest learning scores, best user satisfaction, and strongest knowledge retention. Students in this group benefited from both:

- The familiarity and control of traditional 2D interfaces (e.g., CAD),
- And the embodied engagement of VR for spatial understanding.

This aligns with Garrison and Vaughan's (2008) framework for blended learning, which emphasizes combining the strengths of asynchronous (pixel-based) and synchronous (immersive/interactive) tools. The hybrid model appears to balance cognitive load, encourage deeper learning, and scaffold the development of digital skills without overwhelming the learner.

Qualitative feedback further supports this: students reported feeling “safe” starting with known tools before “entering” their design environments in VR, which helped them conceptualize scale, proportion, and flow more intuitively.

5.4 Engagement and Motivation: More Than Just a Side Benefit

Engagement scores were significantly higher in VR and Hybrid groups, especially in terms of enjoyment and perceived learning. This is more than a motivational benefit it is linked to sustained attention, better retention, and willingness to engage in iterative learning cycles, all of which contribute to deeper learning outcomes.

While some students noted the VR learning curve as a barrier, most described their immersion experience in positive, even transformative terms. This supports Johnson-Glenberg’s (2018) theory that embodied learning environments activate more sensory and cognitive domains, improving not just recall but the quality of design ideation.

5.5 Pedagogical Implications

These findings have important implications for educators in architectural and engineering education:

- Curriculum design should integrate hybrid digital environments that scaffold the transition from 2D to 3D immersive design.
- Digital skills training must precede or accompany VR-based interventions to ensure equitable access to learning benefits.
- Assessment models should adapt to account for different pathways learners take to demonstrate competency in immersive settings.

Furthermore, the traditional emphasis on hand drawing and pixel-only tools may no longer align with the learning profiles of current students, especially when tasks demand spatial reasoning and conceptual iteration. This study suggests that reconfiguring digital pedagogy to include VR and hybrid tools may enhance not only performance but also design thinking skills critical to professional practice.

5.6 Limitations and Future Research

Several limitations should be acknowledged. First, the sample size (n = 60) limits generalizability. Second, while efforts were made to balance group composition, some participants may have had external factors (like prior VR exposure) affecting their performance. Additionally, the study's short duration did not allow for longitudinal assessment of VR’s impact on skill retention or creativity over time.

Future research should:

- Explore VR adoption in other disciplines within Built Environment education (e.g., Construction Management, Urban Planning).
- Examine long-term cognitive and creative development from immersive environments.
- Investigate the effectiveness of adaptive digital skill support systems (like VR onboarding programs) for students at different proficiency levels.

5.7 Final Remarks

This study affirms that immersive technologies especially when combined with traditional tools are not just a novelty, but a powerful pedagogical tool for Generation Z learners. As architectural and design education confronts both technological disruption and evolving student expectations, embracing a hybrid digital learning model that considers computer literacy as a core competency may be the key to unlocking deeper, more transformative learning outcomes.

6. RECOMMENDATIONS

Based on the findings and insights of this study, several strategic recommendations are proposed to improve curriculum development, technology adoption, and student support within architectural and built environment education. These recommendations are targeted at educators, curriculum planners, instructional designers, and higher education policymakers.

6.1 Integrate Hybrid Learning Models into Curriculum Design

Hybrid environments combining pixel-based tools with immersive VR platforms demonstrated the most significant positive impact on student learning, engagement, and retention. To replicate this success, universities and technical faculties should:

- Design modules that allow students to switch between 2D tools (e.g., AutoCAD, SketchUp) and 3D immersive experiences (e.g., Enscape, Unity VR walkthroughs).
- Introduce project-based learning tasks that explicitly require the use of both pixel-based and VR tools for analysis, design iteration, and presentation.
- Train lecturers and facilitators to develop instructional content that leverages the strengths of each digital modality while managing student cognitive load.

Added recommendation*: "Start with capstone or design studio modules where immersive interpretation of spatial layouts can meaningfully enhance conceptual development."*

6.2 Embed Digital Literacy as a Core Competency

The study showed that students with higher digital skills performed better across all environments, especially when engaging with complex VR systems. Therefore, digital literacy should be elevated from a background assumption to a core graduate attribute in built environment programmes.

- Introduce mandatory digital literacy orientation during the first year, focusing on 3D navigation, software fluency, and interface understanding.
- Establish diagnostic testing tools to evaluate incoming students' digital proficiency and place them in appropriate support tracks (beginner, intermediate, advanced).
- Provide short certificate workshops on emerging tools such as VR design viewers, real-time rendering engines, and motion tracking input systems.

Added recommendation: "*Partner with instructional design unitsand external industry vendors to co-develop these modules and ensure they align with professional expectations."*

6.3 Develop Scaffolding Strategies for VR Onboarding

While VR offers unique educational advantages, it also poses challenges for students unfamiliar with immersive systems. Institutions should develop onboarding frameworks to ensure equitable access and smoother adaptation:

- Create low-stakes sandbox environments where students can explore VR without academic pressure.
- Use guided VR walkthroughs with embedded prompts and voice instructions to support first-time users.
- Develop peer-to-peer support models, where digitally fluent students mentor others in basic headset setup, spatial navigation, and troubleshooting.

Added recommendation: *“Include virtual on boarding experiences in early courses, enabling students to gain confidence before VR becomes central to high-stakes projects.”*

6.4 Rethink Assessment Strategies in Immersive Contexts

Traditional assessment frameworks often fail to capture the full scope of learning in immersive environments. As students increasingly work across virtual and pixel-based platforms, assessments should reflect:

- Multimodal outputs, including video walkthroughs, digital models, and spatial interaction recordings.
- Process-based rubrics that reward exploration, iteration, and reflection in addition to the final product.
- The use of self and peer evaluations to assess collaboration and design thinking in immersive group environments.

Added recommendation: *“Implement flexible digital portfolios that track students’ immersive design journeys across time and platforms.”*

6.5 Promote Research on Long-Term Impacts of Immersive Learning

This study has demonstrated short-term learning gains, but more research is needed to understand how VR and hybrid systems affect cognitive, creative, and professional development over time. Faculties and departments should:

- Encourage longitudinal research projects exploring how VR-trained students perform in internships and early professional practice.
- Apply for interdisciplinary grants that link architecture, education, psychology, and computer science in studying immersive pedagogy.
- Create feedback loops from graduates and employers to assess how immersive learning translates to real-world competency.

Added recommendation*:* *“Establish a “VR in Practice” alumni survey to collect data on skill retention, usability, and perceived impact in professional design contexts.”*

6.6 Foster Industry and Infrastructure Partnerships

Meaningful VR integration requires both financial and technological support. Institutions should seek strategic partnerships with:

- Architecture and engineering firms willing to sponsor equipment, software licenses, or co-host design studios using VR.
- Tech startups and global platforms in VR/AR who may benefit from testing prototypes in a live academic setting.
- Government agencies and SETA bodies to fund national upskilling efforts in immersive design for the built environment.

Added recommendation: “*Launch a ‘Digital Futures Studio’ pilot within the faculty, inviting industry collaborators to co-develop real-time projects with students.”*

6.7 Create an Inclusive Immersive Learning Culture

It is essential to ensure that the benefits of VR and digital tools are accessible to all learners, regardless of background or skill level. Equity and inclusion should be proactively embedded into immersive learning initiatives:

- Ensure physical accessibility of VR equipment (ergonomic options, adjustable controls).
- Develop low-cost or mobile-compatible alternatives to high-end headsets, using platforms like WebXR or Google Cardboard for foundational tasks.
- Support students from under-resourced backgrounds with loan programmes for VR devices and software licenses.

Added recommendation: *“Build an equity checklist for immersive learning adoption, co-developed with student councils and accessibility advisors.”*

To fully unlock the educational potential of immersive technology for Generation Z, a systemic shift is require done that reimagines teaching practices, resource allocation, and digital inclusion strategies. By strategically implementing these recommendations, institutions can lead the transformation toward digitally resilient, spatially empowered, and future-ready graduates in architecture and engineering.

7. CONCLUSION

This study set out to examine how varying levels of computer literacy influence the learning outcomes of Generation Z students across three digital learning environments: pixel-based, immersive virtual reality (VR), and hybrid models that combine both. In doing so, it sought to clarify assumptions about this digitally native generation and to assess the pedagogical value of emerging technologies in architectural and engineering education.

The findings reveal a complex but encouraging landscape. Students engaging with hybrid learning environments those which allowed fluid movement between traditional 2D tools and immersive VR platforms consistently outperformed their peers in post-test assessments, knowledge retention, and learner engagement. While VR alone also offered significant gains in spatial understanding and motivation, its impact was moderated by the students' digital skill levels. Pixel-based environments, though familiar and technically accessible, proved less effective in developing advanced design thinking and long-term retention.

Perhaps the most striking insight is that Generation Z is not universally digitally fluent, but rather digitally segmented with learners displaying diverse levels of comfort, competence, and creativity across digital platforms. This challenges the myth of the "born digital native" and underscores the need for scaf folded digital education that supports all students, not just the tech-savvy few.

The study also confirmed that immersive technologies such as VR can serve not only as tools for representation but as cognitive enhancers, enabling embodied learning, emotional connection, and spatial comprehension. However, these benefits are only fully realized when paired with appropriate instructional design, adequate support, and thoughtful integration into curricula. Hybrid systems proved most effective, likely due to their flexibility and their ability to balance innovation with familiarity.

From a pedagogical perspective, the study suggests a shift in architectural education toward digitally inclusive, hybrid-first learning environments, underpinned by strong digital literacy foundations. These environments do not reject traditional tools but augment them with immersive, interactive experiences that align with how Generation Z prefers to learn experientially, visually, and dynamically.

In closing, this research contributes valuable insights to the growing body of knowledge on digital transformation in higher education. It calls on educators, technologists, and policy-makers to look beyond novelty and convenience and instead invest in immersive technologies as strategic tools for equitable, engaging, and effective learning. The success of Generation Z in the built environment disciplines may well depend on how we design not just the spaces they study, but the digital spaces in which they learn.

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