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Analyzing Anxiety Measures in Learning Sensing Technologies within a Mixed Reality Environment

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Mixed Reality Learning Environments (MRLEs) are increasingly used in construction education to provide hands-on experiences that enhance engagement and skill development. However, their influence on learners' anxiety remains underexplored. While moderate levels can enhance engagement, excessive strain or tension may hinder performance. This study investigates how anxiety influences learning in an MRLE designed to teach sensing technologies on a virtual construction site. Twenty-two construction engineering and management students participated, completing pre- and post-knowledge tests and the State-Trait Anxiety Inventory to assess anxiety levels across different MRLE scenes. Data were analyzed using descriptive statistics, Friedman, and Wilcoxon signed-rank tests. Results showed that participants initially exhibited low anxiety levels and positive anxiety states before interacting with the MRLE. Although anxiety states like tension, dizziness, strain, and nervousness increased during MRLE, the MRLE experience did not lead to overwhelming negative anxiety responses. Also, MRLE participation improved knowledge of sensing technologies. The study highlights the importance of integrating affective design considerations in MRLE development to balance cognitive and anxiety-related demands and optimize learning outcomes in construction education.

Keywords: Mixed Reality Learning Environment, Anxiety measures, Sensing Technologies, Construction education.

Introduction

The integration of Mixed Reality Learning Environments (MRLEs) in construction education represents a significant advancement in pedagogical strategies (Tomori et al., 2025a), offering immersive, hands-on learning experiences that enhance student engagement and skill development (Almufarreh, 2023). Additionally, as the construction industry continues to integrate advanced sensing technologies due to their proven benefit in enhancing the safety, productivity, and efficiency of construction workflow, there is a growing need for educational tools that effectively teach students how to implement and utilize these systems (Tomori et al., 2025a). Industry reports indicate a critical skills gap that illustrates academia's lag in equipping graduates with the necessary technical know-how to deploy these technologies effectively (Ogunrinde et al., 2022). In construction education, MRLEs combine physical and virtual environments to allow students to interact with simulated construction sites, virtual equipment, simulated sensors, and tasks in immersive yet safe learning contexts, bridging the gap between theoretical knowledge and real-world applications. However, while these environments offer numerous advantages, there is potential for anxiety during these immersive experiences (Antoniou et al., 2020). Anxiety is a well-documented factor in educational success (Coombes et al., 2009; Picard et al., 2001), influencing motivation, cognitive processing, knowledge

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retention, and overall learning experiences (D'Mello, 2013; Um et al., 2012). Research suggests that positive anxiety enhances engagement and facilitates deeper learning (D'Mello, 2013).

Anxiety can have both positive and negative effects, acting as a motivational driver at moderate levels but impairing cognitive performance when excessive (Antoniou et al., 2020; D'Mello, 2013). High anxiety levels may hinder information retention and lead to cognitive overload (Coombes et al., 2009), negatively impacting learning outcomes and student performance. Conversely, well-managed anxiety measures can foster confidence and improve learning efficacy (Antoniou et al., 2020). Although anxiety states in traditional learning environments have been widely studied (Picard et al., 2001), limited research has specifically examined how MRLEs influence students' anxiety in construction engineering education. This oversight raises concerns regarding the optimization of MRLEs for effective learning, as poorly designed immersive experiences may unintentionally contribute to increased anxiety and diminished learning outcomes (Coombes et al., 2009). Thus, integrating affective analytics into the design of MRLEs is essential to balance cognitive load and anxiety measures for an effective learning experience. To address these concerns, this study investigates the impacts of learning on anxiety within an MRLE designed for implementing sensing technologies on a virtual construction site. This study employed the State-Trait Anxiety Inventory (STAI) survey to measure anxiety levels and conduct pre- and post-knowledge evaluations, to examine its influence on learning. Thereby, contributing to the development of more effective anxiety-aware educational technologies in construction engineering education. In the Background section, the reviews of sensing technologies in construction education were presented and situates MRLEs as a viable instructional approach.

Background

This section provides a focused review of sensing technologies in construction education and motivates the use of MRLEs as a pedagogical approach. The theoretical framework is also presented here to define the conceptual lens guiding the study design.

Mixed Reality-Based Environment for Learning Sensing Technologies

Key sensing technologies transforming the construction industry include laser scanners, drones, ground penetrating radars, radio frequency identification (RFID), inertia measurement units (IMU), global positioning systems (GPS), and real-time location sensors (RTLS). However, despite their benefits, widespread adoption of sensing technologies faces challenges, particularly regarding workforce readiness (Tomori et al., 2025a). A critical skill gap exists within the industry due to a lack of interest and the tendency of graduates to leave the field shortly after completing their education. This issue is exacerbated by the rapid evolution of technology, which demands an adaptable workforce equipped with both theoretical knowledge and practical expertise (Marra et al., 2012). To bridge this gap, construction education must integrate training that not only explains the principles of sensing technologies but also provides hands-on experiences to prepare students for industry demands. However, providing direct access to sensing technologies for students poses several barriers. The high cost of advanced tools like laser scanners, combined with safety concerns associated with hazardous construction environments, limits hands-on training opportunities (Tomori et al., 2025a). To address these challenges, virtual learning environments like mixed reality (MR) have gained traction as effective alternatives for experiential learning in construction education. Hence, it is important to investigate the anxiety responses that can hinder learning of sensing technologies within such a learning environment. This study examines the anxiety measures during MRLE interaction, and how these patterns impact knowledge acquisition.

Theoretical Framework: Attention Control Theory (ACT)

This study is grounded in Attention Control Theory (ACT), which posits that anxiety weakens attentional control, leading to performance deficits in tasks that rely on the central executive of working memory (Coombes et al., 2009). ACT distinguishes between two types of attention: Goal-directed attention, which focuses on task-relevant information; and Stimulus-driven attention, which is influenced by external distractions or perceived threats (Corbetta & Shulman, 2002). In the context of learning sensing technologies through a MRLE, ACT suggests that high anxiety levels may impair students' ability to focus on key learning components, process new concepts, and make effective decisions when applying sensing technologies. This occurs because anxiety shifts attention toward perceived threats (e.g., unfamiliar technology or cognitive overload), reducing available working memory for learning (Blair et al., 2007). Conversely, low anxiety improves attentional control, allowing for better engagement, retention, and technical skill development (Coombes et al., 2009). While prior research has explored anxiety in traditional learning environments, there is a significant gap in understanding how learning in MR-based environments impacts anxiety. This study seeks to address this gap by examining the impact of learning sensing technologies within an MRLE on anxiety measures. The theoretical framework supports the following research questions: **RQ1:** How does interaction with a Mixed Reality Learning Environment (MRLE) impact anxiety across different interaction conditions for learning sensing technologies? **RQ2:** Do anxiety measures influence knowledge acquisition of sensing technologies in an MRLE?

Methodology

Participant Recruitment and Demographics

This study adopted the methodology depicted in Figure 1. Twenty-two (22) students in construction-related disciplines (building construction, construction engineering and management, and civil engineering) were recruited for this study. Most participants were male (77%), while 18% were female, and 5% identified as non-binary/non-conforming. In terms of industry experience, 45% had worked as interns for less than a year, while others had experience as construction industry practitioners, with 14% having 1 to 2 years of experience, 23% having 3 to 4 years, and 18% having between 5 to 10 years of experience. Regarding familiarity with Mixed Reality (MR), 23% of participants reported having no familiarity, 32% were slightly familiar, 23% were moderately familiar, and the remaining 23% indicated being very familiar and extremely familiar.

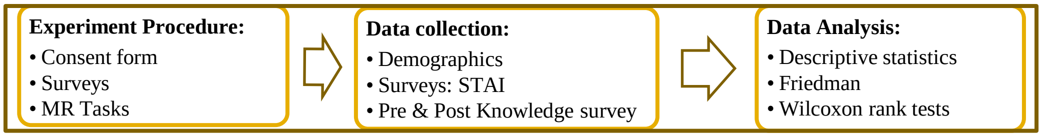

Figure 1: Methodology overview

Mixed Reality Learning Environment

The MRLE (see Figure 2) was developed to provide construction engineering students with the technical skills required to implement sensing technologies in real-world construction projects. This interactive platform enables students to engage with virtual representations of sensing technologies and explore their applications within construction workflows. The MRLE was designed using the Unity3D game engine and consists of three structured learning scenes. Within the Sensor Tutorial (Figure 2b.) and Implementation scenes (Figure 2a), students learned conceptual and procedural knowledge related to five sensing technologies. RFID instruction focused on resource tagging and inventory tracking, while laser scanning emphasized site documentation and point-cloud generation. Drone modules covered inspection workflows and flight safety, and IMU instruction addressed ergonomic monitoring and risk interpretation. GPS activities trained students in location-based tracking and site logistics. During the Explore Jobsite scene, learners interacted with a virtual construction environment to assess site risks and determine suitable sensing technologies for mitigation.

Experimental Procedure

Participation in the study was voluntary and unrelated to course grades, and participants could withdraw at any time without penalty. All data were collected anonymously, stored on password-protected systems, and used solely for research purposes in accordance with IRB approval. To ensure participant safety during MR use, scheduled breaks were provided, and participant were frequently ask for their comfort. Participants first reviewed and signed an IRB-approved consent form before completing a demographics survey and the STAI questionnaire to assess their initial anxiety states. They then received a brief introduction to the Microsoft HoloLens 2 and adjusted the device for comfort. The Microsoft HoloLens 2, a head-mounted MR device, was used to facilitate interactions in the MRLE by enabling hands-free interaction with holographic content through gaze, gesture, and voice input. The mixed reality learning experience began with the Sensor Tutorial Scene (which took an average of 20 minutes to complete), where participants received interactive training on the purpose, function, and implementation of five construction-related sensors. After the tutorial, they took a short break and completed the STAI again to assess anxiety levels during the experience. Next, in the Explore Jobsite Scene (~8.5 minutes to complete), participants interacted with a virtual construction site to identify risks related to cost, quality, schedule, and safety. They then analyzed which of the five sensors could mitigate these risks, applying their knowledge in a simulated real-world setting. Finally, in the Sensor Implementation Scene (~30 minutes), participants implemented the selected sensors in construction tasks, reinforcing their understanding of sensing technologies in practice. After completing this stage, they filled out the STAI one last time.

2a. A student interacting with a drone for Site inspection using Tangible controller

2b. An example of an activity GPS for Truckload

Figure 2. Sensor Implementation and Explore Jobsite scenes from the MRLE
The figure illustrates the information provided to learners through the HoloLens 2 during the drone operation task, including the virtual drone (1), holographic flight control user interface (2), test flight and settings controls (3), designated landing and take-off zone marker (4), crane height reference (200 ft) (5), and virtual construction jobsite game objects such as trucks, heavy equipment, cranes, etc (6).

Data Collection and Data Analysis

To assess students' anxiety states during interaction with the MRLE, the study employed self-reported measures, called the STAI survey, which is a validated instrument used to measure situational anxiety levels. It was administered to the participants before, during, and after their interaction with the MRLE to assess their baseline anxiety levels. The STAI survey contains 20 statements capturing both negatively worded statements reflecting distress-related anxiety (e.g., feeling tense, nervous, or worried) and positively worded statements reflecting calm and confident affect (e.g., feeling relaxed, secure, or satisfied), and responses were categorized into four levels: Very much so (4), Moderately so (3), Somewhat so (2), and Not at all (1). The Pre- and Post-Knowledge Assessment Scale was developed to evaluate students' conceptual understanding of sensing technologies before and after engaging with the MRLE. The collected data were analyzed using both descriptive and inferential statistical methods to evaluate changes in anxiety levels and knowledge acquisition. Descriptive statistics were computed using mean, mode, and standard deviation to summarize participants' responses. The Shapiro-Wilk test was used to assess data normality before the Friedman test, a non-parametric alternative to repeated-measures ANOVA, was employed to evaluate differences in anxiety levels across three conditions (Before, During, and After interaction with the MRLE). The results were reported using p-values. Similarly, post-hoc Wilcoxon signed-rank tests were conducted to identify significant differences between condition pairs, Before vs. During, Before vs. After, and During vs. After. The Wilcoxon signed-rank test results were reported using p-values.

Results

RQ1: How does interaction with a Mixed Reality Learning Environment (MRLE) impact anxiety across different interaction conditions for learning sensing technologies?

Anxiety Measures Across MR Interaction Phases (*Before, During, and After MR Interaction)*

Before interacting with the MRLE, participants generally exhibited high levels of positive measures (mean values > 3.5) and low agreement for negative anxiety (means 1.0–1.5). For negative anxiety measures (e.g., tense, strained, uncomfortable), higher mean scores indicate greater anxiety, whereas decreases in these items reflect reduced anxiety (improvement), and vice versa for positive anxiety measures. The mode for most items was 4, with Shapiro-Wilk results (p < .001) indicating non-normality (see Table 1 and Figure 3, and Figure 4). Most participants reported feeling calm (77%), secure (91%), at ease (68%), self-confident (73%), relaxed (77%), steady (64%), and pleasant (73%), while very few felt tense (9%), strained (23%), nervous (5%), upset (5%), frightened (5%), or jittery (0%). These findings indicate that participants began the MRLE session with low and stable anxiety states.

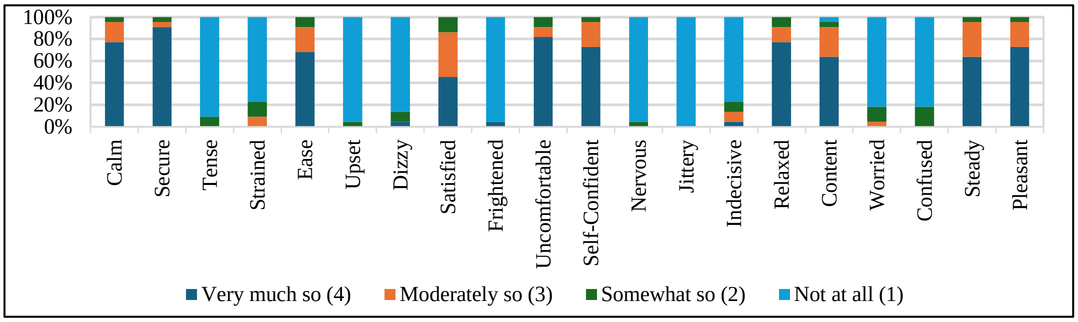

Figure 3. Anxiety and Emotional States Before MRLE Interactions

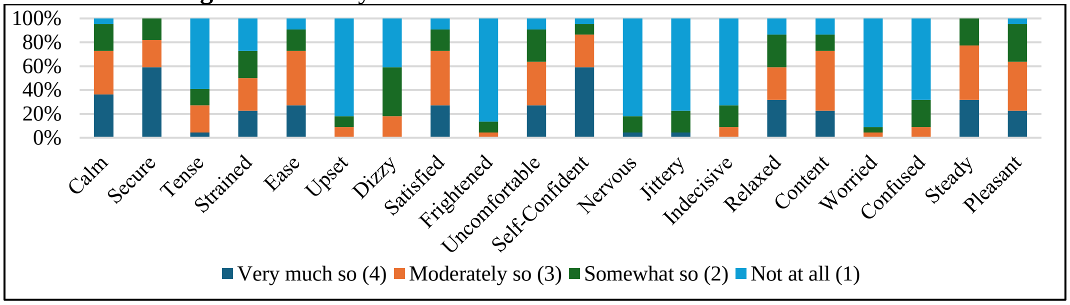

Figure 4. Anxiety and Emotional States During MRLE Interactions

During the MR interaction, participants maintained generally positive anxiety measures, feeling secure (M = 3.50, Mode = 4) and self-confidence (M = 3.32, Mode = 4), though some tension (M = 1.82) and nervousness (M = 1.36) were noted. Positive states like calmness, steadiness, satisfaction, and pleasantness were endorsed by over 70% of participants, suggesting that the MRLE supported engagement. Negative anxiety measures were low as revealed in reported ratings for anxiety sates like frightened (86% not at all), nervous (73% not at all), jittery (73% not at all), worried (82% not at all), upset (77% not at all), confused (68% not at all), and indecisive (64% not at all). However, 9% of the participants reported high tension, 23% strain, and 27% discomfort, indicating minor stress for some users.

After MR interaction, participants continued to report positive anxiety measures, including feeling secure (M = 3.41, SD = 0.80), self-confidence (M = 3.41, SD = 0.85), calm (M = 3.05, SD = 0.90), and steady (M = 3.09, SD = 0.75). Negative anxiety measures remained low, nervousness (M = 1.27), confusion (M = 1.41), and worry (M = 1.14), with most participants not feeling worried (91%), frightened (86%), or nervous (82%) (see Table 1 and Figure 5). A few reported mild dizziness (41%) and strain (23%), suggesting slight physical or cognitive fatigue. Overall, the findings reveal that while the MRLE engagement improved learning and maintained mostly positive anxiety measures, some participants experienced minor strain and discomfort, indicating the need for ergonomic and cognitive load refinement in future MRLE designs.

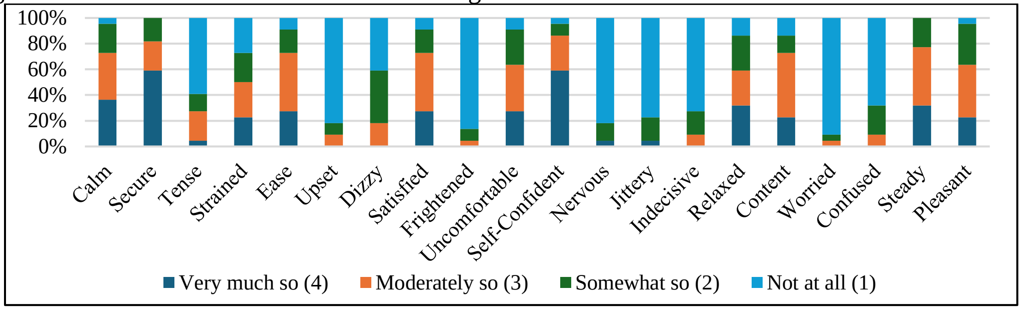

Figure 5. Anxiety Measures After MRLE Interaction

Table 1. Descriptive Statistics (Before, During and After MRLE interaction condition)

	Before MR Interaction Condition				**During MR Interaction Condition**				**After MR Interaction Condition**			
Statement	**Mean**	**Mode**	**Std**	**S. wilk**	**Mean**	**Mode**	**Std Dev**	**S. wilk**	**Mean**	**Mode**	**Std dev**	**S. Wilk**
calm	3.73	4	0.55	<.001	3.05	3	0.84	0.003	3.05	4	0.90	0.003
secure	3.86	4	0.47	<.001	3.50	4	0.60	<.001	3.41	4	0.80	<.001
tense	1.09	1	0.29	<.001	1.82	1	1.05	<.001	1.73	1	0.99	<.001
strained	1.32	1	0.65	<.001	2.32	2	1.13	0.003	2.45	3	1.14	0.005
ease	3.59	4	0.67	<.001	2.59	3	0.96	0.017	2.91	3	0.92	0.004
upset	1.05	1	0.21	<.001	1.45	1	0.96	<.001	1.27	1	0.63	<.001
dizzy	1.23	1	0.69	<.001	1.82	2	0.85	<.001	1.77	2	0.75	<.001
satisfied	3.32	4	0.72	<.001	3.05	3	0.90	<.001	2.91	3	0.92	0.004
frightened	1.14	1	0.64	<.001	1.23	1	0.69	<.001	1.18	1	0.50	<.001
uncomfortable	3.73	4	0.63	<.001	2.73	2	0.99	0.007	2.82	3	0.96	0.01
self-confident	3.68	4	0.57	<.001	3.32	4	0.84	<.001	3.41	4	0.85	<.001
nervous	1.05	1	0.21	<.001	1.36	1	0.66	<.001	1.27	1	0.70	<.001
jittery	1.00	1	0.00	<.001	1.32	1	0.57	<.001	1.32	1	0.72	<.001
indecisive	1.41	1	0.85	<.001	1.36	1	0.49	0.013	1.36	1	0.66	0.006
relaxed	3.68	4	0.65	<.001	2.73	3	0.94	0.002	2.77	4	1.07	0.002
content	3.50	4	0.80	<.001	2.91	4	1.07	<.001	2.82	3	0.96	<.001
worried	1.23	1	0.53	<.001	1.36	1	0.85	<.001	1.14	1	0.47	<.001
confused	1.18	1	0.40	<.001	1.50	1	0.86	0.002	1.41	1	0.67	<.001
steady	3.59	4	0.59	<.001	3.09	4	0.92	0.005	3.09	3	0.75	0.008
pleasant	3.68	4	0.57	<.001	2.95	3	0.84	0.003	2.82	3	0.85	0.003

Changes in Anxiety Levels Across MRLE Interaction Phases and Pairwise Comparisons

The study further assesses the changes in anxiety levels across interactions in the MRLE (Table 2). A Friedman test was conducted to analyze differences in anxiety levels across these conditions. The test revealed significant changes reported below. Participants experienced a notable increase in anxiety-related measures such as feeling tense (+0.73, p = 0.004), strained (+1.00, p < 0.001), and dizzy (+0.59, p = 0.004) increased during MR interaction, while positive anxiety measures such as feeling calm (-0.68, p < 0.001), at ease (-1.00, p < 0.001), and relaxed (-0.95, p < 0.001) significantly declined. However, post-interaction results came with a slight improvement in ease (+0.32) and relaxation (+0.04) compared to the during-interaction phase, though not returning to pre-interaction levels. Interestingly, while discomfort decreased substantially from before to during interaction (-1.00, p < 0.001), it remained relatively stable afterward (+0.09). Some anxiety measures decreased slightly after interaction. Tense (-0.09), dizzy (-0.05), and upset (-0.18) all showed minor reductions, but only ease (+0.32, p < 0.001) indicated a significant positive shift. Feelings of security (-0.45, p = 0.003) and pleasantness (-0.86, p < 0.001) declined after MR exposure, though confidence levels remained relatively unchanged. Nervousness, worry, and confusion remained low across all phases, with no significant fluctuations (p > 0.05). However, strained and dizzy responses indicate potential discomfort associated with MRLE immersion. These findings suggest that MR interaction induced temporary anxiety, which slightly subsided post-interaction but did not fully return to baseline, highlighting the need for improved user experience to mitigate stress responses.

Post-hoc Wilcoxon signed-rank tests identified significant pairwise differences in anxiety measures (Table 2). Anxiety increased from before to during the MR interaction, suggesting initial unease when engaging with the virtual environment, but decreased afterward as participants adapted. Specifically, feelings of tension (Z = –2.676, p = 0.007) and strain (Z = –2.714, p = 0.007) rose significantly during MR use, while ease (Z = –3.573, p < 0.001), calmness (Z = –3.066, p = 0.002), and relaxation (Z = –3.535, p < 0.001) declined. Negative states such as dizziness (Z = –2.356, p = 0.018) and nervousness (Z = –2.070, p = 0.038) also increased, though upset, frightened, and worried responses showed no significant change (p > 0.05). Discomfort rose temporarily (Z = –3.508, p < 0.001) but stabilized post-interaction (Z = –0.577, p = 0.564). After MR activities, anxiety declined significantly, with reduced strain (Z = –3.122, p = 0.002) and tension (Z = –2.724, p = 0.006), while positive anxiety measures such as pleasantness (Z = –3.416, p < 0.001) and relaxation (Z = –3.115, p = 0.002) improved, reflecting emotional recovery and adaptation.

Table 2: Summary of Anxiety Changes Across MR Interaction Phases

	Changes in Anxiety Levels			**Friedman test**		**Post-hoc Wilcoxon signed-rank**		
Statement	**Before vs. During Δ**	**Before vs. After Δ**	**During vs. After Δ**	**Sig (Before, During, and After)**	**Sig**	**Before vs. During (p-value)**	**Before vs. After Δ(p-value)**	**During vs. After Δ(p-value)**
calm	-0.68	-0.68	0	**<0.001**	**Yes**	**0.002**	**0.005**	1
secure	-0.36	-0.45	-0.09	**0.003**	**Yes**	**0.005**	**0.015**	0.41
tense	+0.73	+0.64	-0.09	**0.004**	**Yes**	**0.007**	**0.006**	0.71
strained	+1.00	+1.13	+0.13	**<0.001**	**Yes**	**0.007**	**0.002**	0.57
ease	-1.00	-0.68	+0.32	**<0.001**	**Yes**	**<.001**	**0.012**	0.12
upset	+0.40	+0.22	-0.18	0.17	No	0.07	0.13	0.40
dizzy	+0.59	+0.54	-0.05	**0.004**	**Yes**	**0.018**	**0.028**	0.78
satisfied	-0.27	-0.41	-0.14	0.30	No	0.20	0.26	0.06
frightened	+0.09	+0.04	-0.05	0.37	No	0.58	0.32	0.71
uncomfortable	-1.00	-0.91	+0.09	**<0.001**	**Yes**	**<.001**	0.56	0.001
self-confident	-0.36	-0.27	+0.09	0.21	No	0.09	0.41	0.16
nervous	+0.31	+0.22	-0.09	0.07	No	**0.038**	0.48	0.10
jittery	+0.32	+0.32	0	**0.04**	**Yes**	**0.02**	**1**	0.03
indecisive	-0.05	-0.05	0	0.891	No	0.73	**1**	0.75
relaxed	-0.95	-0.91	+0.04	**<0.001**	**Yes**	**<.001**	0.79	0.002
content	-0.59	-0.68	-0.09	**<0.001**	**Yes**	**0.006**	0.48	0.004
worried	+0.13	-0.09	-0.22	0.47	No	0.52	0.10	0.59
confused	+0.32	+0.23	-0.09	0.37	No	0.12	0.53	0.3
steady	-0.50	-0.50	0	0.005	No	**0.016**	1	0.008
pleasant	-0.73	-0.86	-0.13	**<0.001**	**Yes**	**<.001**	0.32	<.001

RQ2: Does anxiety influence knowledge acquisition of sensing technologies in an MRLE?

Participants' knowledge levels before and after engaging with the MRLE were assessed using a 5-point Likert scale. The results (Figure 6) indicate a significant increase in knowledge across all five technologies, Laser Scanner, Drones, RFID, IMU, and GPS. Before the MRLE interaction, a substantial proportion of participants reported having only little to moderate knowledge of various sensing technologies, while the number of participants with a great deal and extensive knowledge was relatively low.

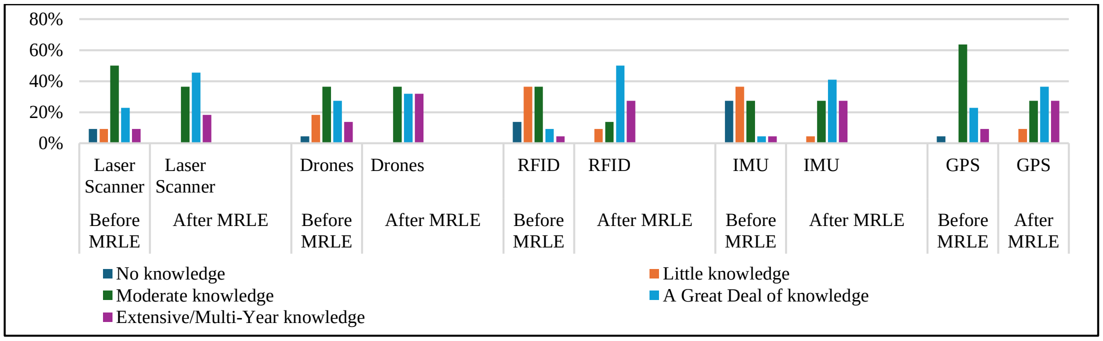

Figure 6. Level of Knowledge Before and After Interacting with MRLE

However, post-interaction results show a marked shift toward higher levels of expertise across all technologies, suggesting that MRLE effectively facilitated learning. For Laser Scanners, the percentage of participants with "extensive knowledge increased from 41% to 64%. RFID showed one of the most significant improvements, with a great deal and extensive knowledge rising from 14% to 77%, and "No Knowledge" responses reducing. Knowledge increased from 32% before MRLE to 63% after MRLE, while those with no or little knowledge dropped from 18% to 0%. A similar trend was observed for Drones, where “extensive or multi year knowledge” increased from 14% to 32%, indicating that MRLE was particularly effective in teaching this technology. IMU knowledge also showed a strong positive shift, with those reporting a great deal and extensive knowledge increasing from 10% to 68%. Also, for IMU, 27% of participants had no prior knowledge, which reduced to 0% post-intervention. For GPS, knowledge gains were notable, with extensive knowledge increasing from 32% to 63%, despite starting with relatively higher baseline knowledge. These findings suggest that despite the initial anxiety, challenges associated with MR interaction, participants were able to significantly improve their knowledge. The observed anxiety fluctuations did not hinder learning, indicating that MRLE provides an engaging and effective learning platform.

Impact of Anxiety Changes on Knowledge Gain (RQ2).

The study examined whether changes in anxiety correlated with learning outcomes by computing post–pre change scores for anxiety and knowledge and running Spearman’s rho correlations. Most anxiety dimensions showed weak or no associations with knowledge gain, but notable patterns emerged (Table 3). Increases in negative indicators (nervousness, jitteriness, and confusion) were linked to lower knowledge gains in RFID, IMU, GPS, and Laser Scanner modules, suggesting heightened anxiety may hinder MR learning. Conversely, positive states like self-confidence and satisfaction correlated with higher gains in Laser Scanner and GPS. For GPS, greater satisfaction and less confusion predicted better learning. For Drones, increased discomfort related to lower gains. Other measures (calm, tense, content, pleasant, etc) showed no significant effects, indicating not all anxiety changes influence learning.

Table 3. Significant Correlations Between Changes in Anxiety Measures and Knowledge Gain (Spearman’s ρ)

Anxiety Change (Δ)	Technology	ρ	p-value	Anxiety Change (Δ)	Technology	ρ	p-value
Δ self-confident	Laser Scanner	0.427	0.048	**Δ nervous**	IMU	−0.521	0.013
Δ confused	Laser Scanner	−0.431	0.045	**Δ jittery**	IMU	−0.604	0.003
Δ jittery	Laser Scanner	−0.429	0.046	**Δ satisfied**	GPS	0.469	0.028
Δ nervous	RFID	−0.443	0.039	**Δ confused**	GPS	−0.455	0.033
Δ jittery	RFID	−0.530	0.011	**Δ uncomfortable**	Drones	−0.574	0.005

Discussion and Practical Implications for MR-Based Learning

The first research question aimed to investigate the impact of MRLE on students' anxiety states when learning sensing technologies. The findings indicate that participants generally exhibited low anxiety levels before interacting with the MRLE, with an initial sense of calmness, confidence, and security before exposure. Most participants reported feeling relaxed and self-assured, while negative anxiety, such as nervousness, tension, jitteriness, and confusion, was not significantly felt before engaging with MR. This suggests that most participants entered the MRLE study with a comfortable and stable state, free from heightened anxiety or stress. However, the MR interaction itself led to a moderate increase in anxiety levels, as evidenced by significant increases in feelings of tension, strain, and dizziness, coupled with declines in calmness, ease, and relaxation. These results align with previous research suggesting that immersive technologies can introduce initial cognitive challenges (D'Mello, 2013). Despite these temporary discomforts, the absence of extreme negative anxiety, such as worry, frightening, jittery, or nervousness, suggests that MRLE does not inherently induce overwhelming anxiety but instead introduces a manageable level of anxiety states. However, the post-interaction phase indicated partial emotional recovery, with a significant reduction in negative anxiety measures. Most participants reported an increase in feelings of security, confidence, and satisfaction with a reduction in tension and strain and slight improvements in relaxation, pleasantness, and ease. This suggests that participants were able to adapt to the MR environment over time, mitigating their initial discomfort. This pattern mirrors prior findings that learners tend to acclimate to immersive environments over time as interaction familiarity increases (Radianti et al., 2020). The Friedman test and post-hoc Wilcoxon signed-rank tests confirmed significant differences in anxiety levels across the three phases. The findings suggest that while initial MR exposure may induce mild discomfort, participants generally adapt over time and regain emotional stability.

The second research question examined the impact of anxiety on knowledge acquisition of sensing technologies in an MRLE. The findings demonstrate that the MRLE had a positive impact on participants' knowledge acquisition. Across all five sensing technologies (Laser Scanner, Drones, RFID, IMU, and GPS), the findings reveal that participants experienced substantial knowledge gains after interacting with the MRLE. The reduction in "No Knowledge" and "Little Knowledge" responses, coupled with the increase in "A Great Deal of Knowledge" and "Extensive Knowledge" categories, suggests that MRLE effectively facilitates learning. Notably, the most significant improvements were observed in RFID and IMU knowledge, where participants had the lowest baseline understanding. Spearman correlation analysis revealed that increases in negative anxiety measures (e.g., nervousness, jitteriness, confusion, and discomfort) were significantly associated with reduced knowledge gains across several sensing technologies, particularly RFID, IMU, and drones. In contrast, positive affective states, such as self-confidence and satisfaction, were positively associated with knowledge gains in Laser Scanner and GPS modules.

This underscores the potential of MRLE as an effective educational tool, capable of improving technical proficiency in the construction engineering field. These findings reinforce prior research that immersive learning environments can enhance conceptual understanding and procedural knowledge (Radianti et al., 2020). Despite temporary increases in anxiety during the interaction, knowledge acquisition was not negatively impacted, suggesting that anxiety measures fluctuations do not act as a barrier to learning. From a practical perspective, these findings highlight the importance of designing MRLEs that balance immersion with user comfort. Design strategies such as gradual onboarding, adaptive interaction pacing, and visual stability controls may help mitigate discomfort and dizziness. Incorporating brief breaks, user-adjustable settings, and clear feedback mechanisms can further support emotional regulation and learning effectiveness. Overall, the results support the integration of MRLEs into construction engineering curricula while emphasizing the need for anxiety-aware and ergonomically informed design to maximize educational benefits.

Conclusion, Limitations, and Future Research

This study examined the impact of MRLE on anxiety measures and knowledge acquisition among construction engineering students. The finding revealed that while the participants had positive anxiety states before interacting with the MRLE, the aftermath of their interaction temporarily increased their anxiety. Importantly, these anxiety increases remained moderate and did not escalate into overwhelming distress, and participants demonstrated partial emotional recovery following continued interaction with the system. In terms of knowledge acquisition, the findings suggest participants gained significant knowledge of the various sensing technologies. This was more evident in technologies where baseline knowledge was low, such as RFID and IMU. These results suggest that manageable levels of anxiety did not hinder learning and may coexist with, or even accompany, effective engagement and skill development in immersive environments. The temporary increase in anxiety suggests the need for optimized user experience strategies. Potential improvements include better interface design to minimize anxiety and adaptive features to accommodate varying levels of familiarity with MR technology. Addressing the reported dizziness, discomfort, and strain will be critical in ensuring a more comfortable and engaging learning environment. While the study provides meaningful insights, certain limitations must be acknowledged. Firstly, the study primarily relied on self-reported measures. Although these measures provided useful insights, incorporating physiological measures (e.g., heart rate, EEG, or galvanic skin response) could offer a more comprehensive understanding of anxiety variations. Additionally, longitudinal studies should examine the long-term effects of MRLE on learning retention and adaptation to anxiety-inducing stimuli.

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