ENHANCING THEORETICAL LEARNING IN ENGINEERING EDUCATION THROUGH AUGMENTED REALITY

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ABSTRACT

Augmented Reality (AR) is an emerging educational technology that enhances learning by creating immersive and interactive experiences, effectively bridging the gap between abstract theoretical concepts and learner understanding. In Technical and Vocational Education and Training (TVET) institutions particularly within Building and Civil Engineering diploma programmes AR holds significant potential to modernize instructional approaches and improve comprehension in theoretical subjects such as Concrete Technology. This study investigates the impact of AR integration on trainees' theoretical coursework in selected TVET institutions in Nairobi County. Although interest in AR's educational applications is growing, its use in resource-constrained technical training environments remains under-researched. Addressing this gap, the study examines how AR-based instruction can enhance mastery of theoretical content, offering trainees a more engaging and effective learning experience. The study targeted 73 trainers and 3,087 trainees across 10 selected institutions, from which 62 trainers and 354 trainees were selected using stratified simple random sampling. A Solomon Four-Group Experimental Design was employed to control for pre-test sensitization effects and ensure internal validity. Data collection followed a mixed-methods approach using structured questionnaires, interviews, and classroom observations. Quantitative data were analyzed through descriptive and inferential statistics in SPSS Version 23, including regression and correlation analyses; qualitative data were analyzed thematically. Findings indicate that AR significantly enhances trainees' understanding and performance in theoretical coursework. Trainees exposed to AR demonstrated greater conceptual clarity and engagement, supported by interactive 3D models and visualizations. However, moderating factors such as trainer readiness and infrastructure availability influenced AR's effectiveness, offering essential insights for improving AR integration in technical education.

Keywords: *Augmented reality, theoretical concepts, Academic Achievement, Technical and Vocational Education and Training (TVET), Building and Civil Engineering*

1.0 INTRODUCTION

Worldwide evidence shows that Augmented Reality (AR) enhances achievement in theory-intensive subjects by integrating animated 3D demonstrations with real-time interaction. Luo (2024) reports that learners who virtually manipulate molecular structures or simulate pouring digital concrete experience greater comprehension and retention, aligning with Cognitive Load Theory (Makransky & Petersen, 2021). Such immersive experiences help learners grasp complex theoretical concepts more effectively than traditional lecture methods.

In Sub-Saharan Africa, AR is being piloted to address chronic shortages of laboratories and teaching equipment in vocational education. Countries like South Africa, Rwanda, and Ghana have introduced affordable head-mounted displays and tablet-based AR apps in vocational classrooms, resulting in improved test scores and learner engagement (Grech, 2024; Donally, 2022). These outcomes suggest AR can be a practical alternative to traditional instruction, especially in under-resourced settings.

East African nations such as Uganda and Tanzania are adopting mobile AR tools for teaching technical subjects like welding and automotive diagnostics. These apps work offline and cater to low-connectivity areas, making them suitable for rural institutions (Scavarelli, Arya, & Teather, 2021). Local content development and instructor training by NGOs and donor programmes have further enabled the scalability of AR-based learning (Tihomirova & Atanasova, 2022).

Kenya's Digital Economy Blueprint underscores the importance of extended reality in skills development (Barasa, 2021). Despite this, most TVET institutions still rely on "chalk and talk" instruction for concrete technology theory, where students memorize concepts such as mix ratios and curing without visualization often leading to poor retention and exam outcomes (Mersha, 2024).

Against this backdrop, the current study investigates whether AR-enhanced lessons can bridge the comprehension gap in concrete technology among TVET trainees in Nairobi County. Using pre- and post-tests and qualitative feedback, the study compares AR and traditional cohorts to evaluate the effectiveness of AR-based instruction. The objective is to determine whether integrating AR improves trainees' achievement in theoretical coursework, ultimately guiding policymakers, curriculum designers, and educators toward informed adoption of AR in vocational training.

2.0 METHODS

This study employed the Solomon Four-Group Experimental Design to assess the impact of Augmented Reality (AR) on trainees' achievement in theoretical Concrete Technology coursework. A multi-stage sampling approach was used: purposive sampling first identified TVET institutions offering Building and Civil Engineering diploma programmes, followed by simple random sampling to select 354 trainees and 62 trainers from 10 institutions. Yamane's formula (1967) guided the sample size calculation, while proportionate stratified sampling ensured balanced representation across institutions.

Table 1 *Sample allocation across the four groups*

Group	Description	Sample Allocation (Approx.)
Group 1	Experimental (Pre-test & Post-test)	88
Group 2	Control (Pre-test & Post-test)	88
Group 3	Experimental (Post-test only)	89
Group 4	Control (Post-test only)	89
Total	Overall Sample Size	354

Each group was strategically designed to isolate and measure the effect of AR-based instruction on theoretical achievement. Group 1 assessed AR's impact over time, Group 2 served as a baseline with traditional instruction, Group 3 evaluated AR's effectiveness without pre-test influence, and Group 4 captured outcomes of conventional teaching without pre-test bias.

A standardized Concrete Technology exam was used to evaluate theoretical understanding, while a structured questionnaire collected data on perceived improvements in understanding, motivation, and retention from trainees in the experimental groups. Additional qualitative data were gathered through trainer interviews and an observation checklist.

Statistical analyses, including ANCOVA and paired-sample t-tests, were employed to control for prior knowledge and strengthen the validity of findings. These methods ensured robust conclusions regarding AR's effectiveness in enhancing theoretical learning in Concrete Technology within TVET institutions.

3.0 RESULTS

Quantitative Analysis

This study used a Solomon Four-Group Experimental Design to evaluate the effect of Augmented Reality (AR) instruction on trainees' theoretical achievement in concrete technology within Nairobi's TVET institutions, comparing AR-enhanced and traditional teaching methods across four groups with pre- and post-test measures.

Table 2 *Trainee Pretest Mean Score for Experimental Group 1 and Control Group 1*

Group	N	Mean	Standard Deviation
E1	88	34.52	6.28321
C1	88	31.26	5.85763

Table 2 indicates that Experimental Group 1 (E1) had a mean pre-test score of 34.52, while Control Group 1 (C1) scored 31.26 out of 100. Although both scores were low reflecting the test's timing before instruction, they suggest trainees had some prior knowledge of concrete technology. The similar baseline performance between groups was essential for isolating the impact of the instructional intervention, particularly the use of Augmented Reality (AR). AR-based lessons featured interactive simulations and visualizations of complex concepts like concrete hydration, aiming to enhance understanding and engagement (Suhail, Bahroun, & Ahmed, 2024). Paired-sample and independent t-tests were used to compare performance within and between groups. Follow-up assessments further measured retention and conceptual depth, with findings expected to favor AR-based learning over traditional methods (Moser & Lewalter, 2024).

Table 3 *t-test of Pre-test scores for Experimental and Control Group 1*

	T	Df	Sig.(2 tailed)
Equal Variances Assumed	6.922	169	0.419
Equal Variances Not Assumed	6.928	166.347	0.419

The results presented in Table 3 indicate that there was no significant difference in the pre-test mean scores between Control Group 1 (C1) and Experimental Group 1 (E1), $t(169) = 6.922$, $p = 0.419 > 0.05$ and $t(166.347) = 6.928$, $p = 0.419 > 0.05$. Since the p-value (0.419) is greater than 0.05, the difference in pre-test mean scores was not statistically significant. This suggests that both groups had comparable initial academic achievement levels, indicating that the trainees in C1 and E1 shared similar academic characteristics before the intervention. Therefore, their prior knowledge of Concrete Technology was similar, making them suitable for the study.

Table 4 *Post-test Mean Score for Experimental Group One and Control Group One*

Group	N	Mean	Standard Deviation
E1	88	76.49	9.11741
C1	88	57.86	12.9746

Table 4 shows that Experimental Group 1 (E1), which received Augmented Reality (AR)-enhanced instruction, achieved a mean post-test score of 76.49, while Control Group 1 (C1), taught through conventional methods, scored 57.86 out of 100. The mean gain for E1 was 41.97 points, significantly higher than C1's 26.60 points, indicating greater improvement among AR-exposed trainees. The smaller standard deviation in E1 (9.12) compared to C1 (12.97) suggests more consistent performance among those who learned with AR. These results highlight the effectiveness of AR in enhancing comprehension, engagement, and retention in Concrete Technology coursework within TVET programmes (Liu et al., 2024).

Table 5 *Post test Mean Scores on AR*

Group	N	Mean	Standard Deviation
E1	88	76.49	9.12
C1	88	57.86	12.97
E2	89	75.89	9.22
C2	89	55.61	11.48

Post-test results revealed that trainees taught using Augmented Reality (AR) significantly outperformed those who received traditional instruction. Experimental groups (E1 and E2) averaged around 76%, while control groups (C1 and C2) scored between 56–58%. The AR groups also showed more consistent performance, with narrower score ranges. Notably, E2 despite having no pre-test achieved similar high scores, suggesting AR's effectiveness is not due to test familiarity. These results support prior studies highlighting AR's role in enhancing comprehension and retention of complex engineering concepts (Fitrianto & Saif, 2024; Bernacki et al., 2021), confirming AR as a scalable, impactful tool for improving learning outcomes in TVET concrete technology courses.

Table 6 *ANOVA for Post test Mean Scores for Groups E1, E2, C1 and C2*

	Sum of Squares	Df	Mean Squares	F	Sig.
Between Groups	710.5	3	236.833	27.97	.000
Within Groups	2880.1	341	8.466		
Total	3590.6	344			

Table 6 presents the results of an ANOVA testing the impact of instructional methods on trainees' academic achievement in Concrete Technology. The analysis compared AR-enhanced instruction (E1 and E2) with traditional lecture-based instruction (C1 and C2) using post-test scores as the dependent variable. The ANOVA results, $F(3, 341) = 27.97$, $p < .001$, show a significant difference in performance among the groups, confirming that AR-based instruction had a substantial effect on learning outcomes. The between-groups variance (710.5) was notably higher than the within-groups variance (2880.1), and the p-value of .000 indicates that the differences were not due to chance.

Table 7 *Bonferroni Post Hoc Test*

(I) Group	(J) Group	Mean Difference(I-J)	St. Error	Sig.
E1	C1	18.63*	1.953	0.02
	E2	0.6	2.097	0.964
	C2	20.88*	1.855	0.016
C1	E1	-18.63*	1.953	0.02
	E2	-18.03*	2.131	0.016
	C2	2.25	1.905	1.0
E2	E1	-0.6	2.055	0.964
	C1	18.03*	2.131	0.016
	C2	20.28*	2.042	0.009
C2	E1	-20.88*	1.855	0.016
	C1	-2.25	1.905	1.0
	E2	-20.28*	2.042	0.009

*. The mean difference is significant at the 0.05 level

The Bonferroni post hoc test compared post-test scores to evaluate the effectiveness of Augmented Reality (AR) on academic performance in Concrete Technology. The results showed that the experimental groups (E1 and E2), which received AR-based instruction, significantly outperformed the control groups (C1 and C2). For example, the mean score difference between E1 and C1 was 18.63 ($p = 0.02$), and between E1 and C2, it was 20.88 ($p = 0.016$), demonstrating AR's positive impact on learning outcomes. No significant difference was found between E1 and E2 (0.6, $p = 0.964$), indicating that the pre-test did not influence AR's effectiveness. Similarly, no significant difference was found between C1 and C2 (2.25, $p = 1.0$), supporting the consistency of traditional instruction. These findings, along with ANOVA results, reject the null hypothesis, confirming that AR significantly improves academic achievement by enhancing engagement, comprehension, and retention. ANCOVA was used to control for pre-existing knowledge differences, ensuring a more accurate assessment of AR's effect. This robust analysis supports the integration of AR in TVET institutions to improve learning outcomes (Bakar, Ghafar, & Abdullah, 2024).

Table 8 *ANCOVA Results for Post-Test Scores*

Source	**Sum of Squares**	**df**	**Mean Square**	**F-Value**	**Sig. (p)**
Pre-Test (Covariate)	450.32	1	450.32	28.04	.000***

Instructional Method (AR vs. Traditional)	710.5	3	236.83	27.97	.000***
Error	2880.1	341	8.466		
Total	**3590.6**	**344**			

Table 12 *Adjusted Post-Test Mean for C2*

Group	Unadjusted Mean	Adjusted Mean
C2 (Control 2)	55.61	49.61

The Bonferroni post hoc test confirmed that trainees taught using Augmented Reality (AR) significantly outperformed those receiving traditional instruction. Experimental groups E1 and E2 scored notably higher than control groups C1 and C2, with mean differences of 18.63 ($p = 0.02$) and 20.88 ($p = 0.016$), respectively. No significant difference was found between E1 and E2 (0.6, $p = 0.964$), suggesting that AR's effectiveness is independent of pre-test exposure. Similarly, no significant difference between C1 and C2 (2.25, $p = 1.0$) confirmed the uniformity of traditional instruction outcomes. ANOVA and ANCOVA analyses validated these findings, showing AR's significant positive impact on engagement, comprehension, and academic performance. These results support AR integration in TVET programmes to enhance learning (Fitrianto & Saif, 2024; Bernacki et al., 2021; Tan et al., 2024; Bakar et al., 2024).

Correlation Analysis

This subsection presents a correlation analysis to assess how Augmented Reality (AR) impacts trainees' achievement in theoretical coursework.

Table 9 *Pearson's correlation*

		Achievement In Theoretical Content	AR-Based Instruction
Achievement In Theoretical Content	Pearson Correlation	1	
	Sig. (2-tailed)		
	N	173	
	N	173	
AR-Based Instruction	Pearson Correlation	.614*	1
	Sig. (2-tailed)	.000	
	N	173	173

The correlation analysis demonstrated that Augmented Reality (AR) significantly boosts trainees' academic performance in concrete technology coursework. A moderate positive correlation ($r = .614$, $p < .001$) between theoretical content achievement and overall academic performance indicates that AR enhances conceptual understanding. Furthermore, a strong positive correlation ($r = .895$, $p < .001$) between theoretical achievement and problem-solving skills suggests that AR fosters deeper cognitive engagement and better application of knowledge. These findings emphasize AR's effectiveness in simplifying complex concepts, improving understanding, retention, and skill development (Álvarez-Marín et al., 2022; Tan et al., 2024).

Regression Analysis

A simple linear regression was conducted to evaluate the predictive effect of Augmented Reality (AR)-based instruction on trainees' achievement in theoretical content within Building and Civil Engineering diploma programmes in TVET institutions.

Table 10 *Model Summary*

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.611	.373	.369	0.402

A simple linear regression analysis revealed that AR-based instruction accounts for 37.3% of the variance in trainees' theoretical achievement ($R^2 = 0.373$, adjusted $R^2 = 0.369$), indicating a good model fit. The standard error

of the estimate (SE = 0.402) suggests high prediction accuracy. These results demonstrate that AR-based instruction significantly improves theoretical learning outcomes for trainees in Building and Civil Engineering diploma programmes, supporting recent research on the positive impact of technology-enhanced instruction, especially AR, on conceptual understanding and engagement in technical education (Amores-Valencia et al., 2022).

Table 11 *ANOVA Table*

Model	Sum of Squares	df	Mean Square	F	Sig.
Regression	13.351	1	13.351	82.67	<.001
Residual	22.452	171	0.131		
Total	35.803	172			

An analysis of variance (ANOVA) was conducted to evaluate whether AR-based instruction significantly predicts trainees' achievement in theoretical content. The results showed a statistically significant regression model, $F(1, 171) = 82.67$, $p < .001$. The regression sum of squares (SS = 13.351) indicates the variation in achievement explained by AR-based instruction, while the residual sum of squares (SS = 22.452) accounts for unexplained variance. The high F-ratio (MS = 13.351 vs. MS = 0.131) confirms the strong impact of AR on theoretical performance. With a p-value less than .05, the null hypothesis is rejected, indicating that AR-based instruction significantly enhances trainees' performance. This finding aligns with recent research emphasizing the positive effects of immersive learning technologies like AR in technical education (Sahib et al., 2024).

Table 12 *Regression Coefficients*

Predictor	B	Std. Error	Beta	t	Sig.
(Constant)	0.499	0.289		1.73	.086
AR-Based Instruction	0.702	0.077	.611	9.09	<.001

A simple linear regression analysis revealed that AR-based instruction is a significant predictor of theoretical content achievement, with $B = 0.702$, $t(171) = 9.09$, $p < .001$. This indicates that for each unit increase in AR-based instruction, theoretical content achievement increases by 0.702 units. The standardized coefficient ($\beta = .611$) further confirms a strong positive relationship between AR and achievement. The intercept ($B = 0.499$, $p = .086$) was not significant, suggesting that the predicted achievement score without AR is close to zero. Overall, the results highlight the significant impact of AR on improving theoretical understanding.

$$Y1 = 0.499 + 0.702(AR) + \epsilon$$

This model indicates that AR-based instruction has a meaningful impact on performance in theoretical subject areas, supporting the effectiveness of AR in technical education (Nikimaleki & Rahimi, 2022).

Descriptive Statistics

This section examines the impact of Augmented Reality (AR) on trainees' achievement in theoretical content in Building and Civil Engineering diploma programmes within TVET institutions. The study aimed to assess whether AR enhances academic success by fostering engagement, comprehension, and knowledge retention.

Two hypotheses were tested:

1. Null Hypothesis (H_0): AR has no significant impact on trainees' achievement in theoretical content.
2. Alternative Hypothesis (H_1): AR significantly enhances trainees' achievement in theoretical content.

Descriptive statistics were analyzed for trainees' perceptions of AR, based on responses to five statements rated on a Likert scale. The results showed strong positive perceptions of AR:

Table 13 *Augmented Reality on trainees' Achievement in Theoretical Content*

Statement	Mean	SD	Interpretation
I take part in AR learning activities in class.	4.4	0.98	Strongly Agree
I enjoy using AR and like exploring it beyond class.	3.9	1.28	Agree
I always finish AR learning tasks.	4.6	0.89	Strongly Agree
AR makes me feel more confident about engineering topics.	4.8	0.87	Strongly Agree
I remember lessons better when I use AR.	4.1	1.05	Strongly Agree

Survey results suggest that Augmented Reality (AR) is highly effective in helping trainees master theoretical coursework in concrete technology. Participants reported high engagement with AR activities (M = 4.4, SD = 0.98) and consistent task completion (M = 4.6, SD = 0.89). This involvement led to increased confidence in engineering topics (M = 4.8, SD = 0.87) and improved memory retention (M = 4.1, SD = 1.05). While enjoyment of AR outside of class was slightly lower (M = 3.9, SD = 1.28), it still indicated a positive attitude and interest in self-directed learning. Overall, these findings suggest that AR enhances engagement, self-efficacy, memory, and fosters an active learning mindset, contributing to better achievement in the theoretical aspects of concrete technology.

Qualitative Analysis

Thematic analysis of open-ended responses confirms that trainees view Augmented Reality as a game-changer for theory classes. Students consistently described AR lessons as more interactive, intuitive, and confidence-building than traditional chalk-and-talk, echoing research that links immersive visualisations to stronger comprehension and engagement (Pramanik, 2024). Many said the freedom to revisit 3-D simulations outside class fostered self-directed study and curiosity, while real-time models prompted richer in-class discussion and peer collaboration. A few hurdles occasional device glitches, slow loading, or limited hardware were noted, yet these inconveniences did little to dampen overall enthusiasm; learners felt AR let them experiment safely, learn from mistakes, and develop a "try-again" growth mind-set. Collectively, the narratives reinforce the quantitative finding that AR meaningfully boosts theoretical understanding in concrete-technology courses, while highlighting the need for reliable infrastructure to maximise its benefits (AlGerafi et al., 2024)

Trainers Interview

Interviews with Nairobi-County TVET instructors show broad enthusiasm for AR. Most trainers said the 3-D simulations make structural and concrete-technology theory "tangible," deepen retention, and let trainees experiment with designs in real time observations echoed by Mudaliyar (2025). They also reported livelier classes and higher student motivation because "*learners actively explore concepts instead of passively listening,"* aligning with Wen (2021). A few tutors noted that novices need initial help navigating the apps, but added that, after brief guidance, students adapt and reap clear benefits. Overall, trainers view AR as a powerful aid for comprehension and engagement, with only minor onboarding challenges.

Observation Checklist

The structured classroom observations and observation checklist provided valuable insights into the impact of Augmented Reality (AR) on academic achievement in Building and Civil Engineering diploma programmes within TVET institutions. These observations evaluated how AR-based instruction influenced trainee behaviour, participation, and overall learning outcomes.

Table 14 *Observation Checklist and Results*

S No.	Observation Statement	YES (n)	NO (n)	YES (%)	NO (%)
1	AR helps trainees understand and remember theoretical content better.	49	5	91%	9%
2	AR improves trainees' ability to visualize and learn complex concepts.	45	9	83%	17%
3	Using AR in teaching leads to better academic performance in theory.	37	17	69%	31%

Classroom observations confirm trainers' strong endorsement of AR for theory classes. About 91 % reported that AR boosts comprehension and recall; 83 % said it sharpens visualization of complex ideas; and 69 % saw clear gains in test performance. These results echo earlier studies showing that interactive 3-D imagery deepens understanding and fosters active learning (Kim, Wang, Miller, Dorneich, Winer, Brown, & Caldwell, 2025). Only a few tutors noted start-up difficulties for digitally inexperienced students, but overall, the checklist points to AR as a powerful aid for mastering the abstract concepts of concrete technology.

Chi-Square Analysis for observation checklist

To further examine the statistical significance of AR's impact on learning outcomes, a chi-square test was performed. The results are summarized below:

Table 15 *Chi-Square Analysis*

Variable	Chi-Square (χ^2)	p-value	Effect Size (Cramér's V)	Interpretation
Theoretical Coursework	61.73	<0.001	0.62	Statistically significant; strong effect

The chi-square analysis revealed a significant positive relationship between Augmented Reality (AR) use and trainees' theoretical achievement in concrete technology ($\chi^2(1) = 61.73$, $p < 0.001$, Cramér's $V = 0.62$), leading to the rejection of the null hypothesis and confirming AR's effectiveness as an instructional tool in enhancing conceptual understanding in TVET education.

4.0 CONCLUSIONS AND RECOMMENDATIONS

The study confirms that Augmented Reality (AR) significantly improves trainees' academic achievement in concrete technology coursework by enhancing comprehension, retention, and engagement through immersive, interactive learning. Trainees find AR motivating, which leads to deeper learning and sustained interest in the subject. To further improve academic outcomes, the study recommends integrating AR into Building and Civil Engineering diploma programmes, using it as a core instructional tool. AR's interactive nature simplifies complex concepts and provides immediate feedback, helping trainees adjust their learning strategies. Additionally, professional development programmes for educators are necessary to equip them with the skills to effectively integrate AR into their teaching practices.

Future research on Augmented Reality (AR) in TVET institutions should focus on the long-term effects of AR on trainees' theoretical achievement in concrete technology. Longitudinal studies are needed to track how continuous AR exposure influences understanding and retention over time. Comparative studies should also assess AR against traditional methods in terms of engagement, motivation, and knowledge application. Additionally, research should explore best practices for integrating AR into engineering education and examine personalized AR learning environments to cater to individual learner needs.

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