AUGMENTED REALITY AS A TOOL FOR PRACTICAL SKILLS DEVELOPMENT IN BUILDING AND CIVIL ENGINEERING PROGRAMMES

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ABSTRACT

Augmented Reality (AR) enhances learning by offering immersive, interactive experiences, bridging the gap between theoretical instruction and hands-on practice. In TVET institutions, particularly in Building and Civil Engineering diploma programs, AR addresses challenges such as outdated teaching methods, limited access to modern tools, and insufficient development of practical skills. This study investigates AR's impact on trainees' practical skills acquisition in concrete mixing within Nairobi County's TVET institutions. While previous research highlights AR's potential to improve engagement, motivation, and spatial reasoning, there is limited research on its practical implementation in resource-constrained settings. This study proposes a data-driven framework for AR integration, assessment, and instructor training. The sample comprised 62 trainers and 354 trainees from 10 selected TVET institutions, using simple random sampling. The Solomon Four-Group Experimental Design minimized pre-test sensitization effects. Data were collected using structured and semi-structured questionnaires, interview schedules, and classroom observation checklists. Quantitative data were analyzed using SPSS, employing descriptive and inferential statistics, while qualitative data were analyzed thematically. The findings reveal that AR significantly improves practical skills in concrete mixing by enabling trainees to visualize processes, simulate tasks, and gain confidence before real-life applications. This study provides evidence-based insights for policymakers, curriculum developers, and educators on effectively integrating AR in TVET programs. It recommends blended instructional approaches, trainer support, and infrastructure development to optimize AR's impact on skill-based learning and improve technical education quality in Kenya.

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

1.0 INTRODUCTION

Emerging technologies, particularly Augmented Reality (AR), are transforming education, especially in technical and vocational training. AR allows learners to engage with interactive simulations that replicate real-world tasks. In construction and civil engineering, AR enables trainees to practice procedures like concrete mixing in virtual environments, providing immediate feedback, reducing material waste, minimizing risks, and increasing learner confidence and competence (Azuma, Yanco, & Furuta, 2022; Tihomirova & Atanasova, 2022). Countries such as the U.S., Germany, and South Korea have successfully integrated AR into vocational programs, significantly enhancing practical skills and workforce readiness (Zhang, Wu, & Liu, 2023; Tahir & Abdullah, 2023).

In sub-Saharan Africa, AR is being introduced to address educational resource gaps. South Africa has pioneered AR/VR applications in schools, like Richard Varha Technical High School, which uses holographic and AI-driven tools for hands-on training in engineering and design (Donally, 2022; Scavarelli, Arya, & Teather, 2021). However, broader adoption across the region is hindered by challenges such as poor internet infrastructure, a lack of trained educators, and high implementation costs (Chandrasekar, 2022).

Kenya is increasingly embracing technology in education. Initiatives like the Nation Media Group's digital push and innovations from startups like Black Rhino VR (BRVR), which launched Africa's first online AR design studio, are leading the way. However, traditional teaching methods still dominate in Kenyan TVET institutions, especially in Building and Civil Engineering (Migiro, 2022). Practical tasks like concrete mixing remain taught without the interactive, safe environments that AR can offer.

This study aims to assess AR's impact on practical skill acquisition in concrete mixing within Nairobi County's TVET institutions, offering insights to inform curriculum reform, instructional practices, and policy decisions to integrate AR in vocational education (Yazdi, 2024).

Statement of Problem

In many TVET institutions offering Building and Civil Engineering programs, traditional teaching methods such as lectures and rote learning are still widely used to teach practical tasks like concrete mixing. These teacher-led approaches often limit hands-on experience and fail to mirror real-world work conditions, making it difficult for trainees to grasp procedures, develop precision, and apply theory in practice

2.0 METHODS

This study assessed the impact of Augmented Reality (AR) on trainees' practical skills acquisition in concrete mixing using the Solomon Four-Group Experimental Design. A multi-stage sampling approach was employed, starting with purposive sampling to select ten TVET institutions in Nairobi County offering Building and Civil Engineering diploma programs. From these institutions, 354 trainees and 62 trainers were selected through simple random sampling. The sample size was calculated using Yamane's formula (1967), and proportionate stratified sampling ensured balanced representation across institutions.

The trainees were divided into four groups: Group 1 (88 trainees) received AR-based instruction in batching, mixing, workability testing, and curing; Group 2 (88 trainees) was the control group, receiving traditional instruction. Group 3 (89 trainees) was exposed to AR-based instruction, but without the theoretical lead-in or structured observation, while Group 4 (89 trainees) was a control group that engaged in practical tasks using conventional methods.

The study aimed to compare the effects of AR simulations with traditional instruction on trainees' abilities to perform practical tasks. Data were collected using structured questionnaires, skill assessments before and after the AR intervention, and observation checklists to evaluate competencies such as batching accuracy, mixing uniformity, time management, and safety compliance. Semi-structured interviews with trainers provided qualitative insights into the perceived value of AR.

Quantitative data were analyzed with descriptive statistics and chi-square tests to identify significant differences in skill acquisition between the control and experimental groups. Qualitative data were analyzed thematically to identify patterns in learner engagement and instructional effectiveness. This comprehensive mixed-methods approach allowed for an in-depth exploration of how AR enhances procedural accuracy and practical skills development in concrete mixing within TVET institutions.

3.0 RESULTS

Quantitative Analysis

The practical session assessed trainees' competencies in batching, mixing, and workability testing of concrete, comparing the impact of traditional instruction on control groups and AR-based instruction on experimental groups, with the latter using interactive simulations to enhance accuracy and consistency in tasks like material measurement, mixing, and test execution.

Table 2 *Trainees' Achievement in Practical Skills.*

Group	N	Mean	Standard Deviation
E1	88	80.23	8.48
C1	88	71.82	8.75
E2	89	76.40	8.27
C2	89	66.38	8.69

The study evaluated the impact of Augmented Reality (AR) on practical skill achievement in Building and Civil Engineering TVET programs, finding that trainees in the AR-based instruction groups (E1 and E2) scored higher (80.23 and 76.40) than those in the control groups (C1 and C2) with traditional methods (71.82 and 66.38). The narrow standard deviations (8.27 to 8.75) across all groups indicated consistent performance, suggesting AR improves skills without causing disparities in outcomes. These results highlight AR's effectiveness in enhancing learners' understanding and application of technical procedures, supporting its integration into TVET programs for better practical skill development.

Table 3 *ANOVA results for Trainees' practical skills acquisition in concrete mixing*

Source	Sum of Squares (SS)	Degrees of Freedom (df)	Mean Square (MS)	F-Value	P-Value
Between Groups	9,710.64	3	3,236.88	44.64	0.000
Within Groups	25,526.56	352	72.52	-	-
Total	35,237.20	355	-	-	-

The ANOVA results revealed a statistically significant difference in practical skills achievement among the four groups (E1, C1, E2, and C2) with a large F-value of 44.64 ($p < 0.001$), indicating that the differences in performance were due to the AR intervention rather than random chance. While variability existed within groups, the differences between groups were substantial, supporting the effectiveness of AR in enhancing practical skill acquisition. Further post hoc tests, like the Bonferroni test, are needed to identify specific pairwise differences between the groups.

Bonferroni Post Hoc Test Results

The Bonferroni post hoc test, applied after ANOVA in this study, identified specific group differences in trainees' practical skill performance while controlling for Type I errors, providing robust evidence of AR's effectiveness in enhancing TVET training outcomes (Bakar, Ghafar, & Abdullah, 2024).

Table 4 *The Bonferroni post hoc test results for Trainees' practical skills acquisition in concrete mixing*

Group 1	Group 2	t-Statistic	p-Value	Adjusted p-Value	Significant Difference
C1	C2	4.15	0.0001	0.0003	**Yes**
C1	E1	-6.48	0.0000	0.0000	**Yes**
C1	E2	-3.58	0.0004	0.0026	**Yes**
C2	E1	-10.73	0.0000	0.0000	**Yes**
C2	E2	-7.88	0.0000	0.0000	**Yes**
E1	E2	3.04	0.0028	0.0165	**Yes**

The Bonferroni post hoc test confirmed significant differences in practical skill performance, showing that both experimental groups (E1 and E2) outperformed the control groups (C1 and C2), with E1 and E2 scoring significantly higher than C2, reinforcing the positive impact of Augmented Reality (AR) on practical skill acquisition in TVET programs (AlGerafi et al., 2024; Nikimaleki & Rahimi, 2022).

Correlation Analysis

The correlation analysis using Pearson's coefficient reveals a positive and significant relationship between Augmented Reality (AR) use and trainees' practical skills acquisition in concrete mixing within Building and Civil Engineering programs in Nairobi County TVET institutions.

Table 5 *Correlation Analysis for Trainees' practical skills acquisition in concrete mixing*

		Achievement In Practical Skills	AR-Based Instruction
Achievement In Practical Skills	Pearson Correlation	1	
	Sig. (2-tailed)		
	N	173	
AR-Based Instruction	Pearson Correlation	.535*	1
	Sig. (2-tailed)	.000	
	N	173	173

A Pearson correlation analysis was conducted to assess the relationship between Augmented Reality (AR)-based instruction and trainees' practical skills in concrete mixing. The results revealed a moderately strong positive correlation ($r = .535$, $p < 0.01$) based on a sample of 173 trainees, indicating a statistically significant and meaningful relationship between AR use and skill acquisition. As AR-based instructional engagement increased, trainees demonstrated enhanced proficiency in tasks such as batching, mixing consistency, workability assessment, and safety adherence. These findings suggest that AR has a positive impact on the development of practical skills in Building and Civil Engineering diploma programs, highlighting its effectiveness as a pedagogical tool in vocational education (Liu, Yang, Huang, & Wang, 2024).

Regression Analysis

A regression analysis was conducted to assess the impact of AR-based instruction on achievement in practical skills. The results, presented in Table 6, show the following:

Table 6 *Model Summary*

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.535	.286	.282	0.457

A regression analysis was conducted to evaluate the impact of AR-based instruction on trainees' practical skills achievement. The results indicated a moderate positive correlation ($R = 0.535$), suggesting that as AR-based instruction increases, trainees' achievement in practical skills improves. The R-square value of 0.286 shows that approximately 28.6% of the variance in practical skills achievement is explained by AR-based instruction, indicating a moderate effect. The Adjusted R-square value of 0.282 confirms a good model fit after accounting for predictors, and the standard error of 0.457 indicates a reasonable fit between the model and observed data. These findings suggest that AR-based instruction moderately improves practical skills achievement in Building and Civil Engineering diploma programs in TVET institutions in Nairobi County (Amores-Valencia et al., 2022).

Table 7 *ANOVA test for predicting achievement in practical skills based on AR-based instruction*

Model	Sum of Squares	Df	Mean Square	F	Sig.
Regression	11.899	1	11.899	56.93	<.001
Residual	35.754	171	0.209		
Total	47.653	172			

An ANOVA test was conducted to assess the significance of AR-based instruction in predicting achievement in practical skills. The results showed that the regression sum of squares ($SS_{regression} = 11.899$) explained the variance in practical skills achievement, while the residual sum of squares ($SS_{residual} = 35.754$) represented unexplained variance. The F-value ($F(1, 171) = 56.93$) was highly significant with a p-value < 0.001, indicating that AR-based instruction significantly predicts practical skills achievement. Therefore, the null hypothesis was rejected, confirming that AR-based instruction contributes significantly to predicting achievement in practical skills in Building and Civil Engineering diploma programs within TVET institutions in Nairobi County (Amores-Valencia et al., 2022).

Table 8 *Coefficients*

Predictor	**B**	**Std. Error**	**Beta**	**t**	**Sig.**
(Constant)	0.628	0.328		1.91	.058

Predictor	**B**	**Std. Error**	**Beta**	**t**	**Sig.**
AR-Based Instruction	0.695	0.092	.535	7.55	<.001

A regression analysis was conducted to assess the effect of AR-based instruction on achievement in practical skills. The unstandardized coefficient (B = 0.695) indicates that for every one-unit increase in AR-based instruction, practical skills increase by 0.695 units. The standardized coefficient (β = 0.535) shows a moderate positive relationship between AR-based instruction and practical skills achievement. The t-value (t = 7.55) with a p-value of <.001 confirms that AR-based instruction is a statistically significant predictor of practical skills achievement. The constant (B = 0.628) represents the baseline achievement in practical skills when AR-based instruction is zero, though it is not statistically significant. These results highlight the positive impact of AR-based instruction on improving practical skills in Building and Civil Engineering diploma programs within TVET institutions in Nairobi County (Amores-Valencia et al., 2022).

The regression equation is: $Y_3 = 0.628 + 0.695(AR) + \epsilon$.

Descriptive Statistics

Practical skill acquisition is a critical component of technical education, requiring hands-on experience, spatial visualization, and real-world application of theoretical knowledge (Yang, Zhang, Hu, Yang, Chen, Shan, & Li, 2024). AR-based instructional methods are expected to enhance practical learning by providing immersive, interactive simulations that bridge the gap between theoretical concepts and real-world applications.

Hypothesis Testing

To assess this relationship, the following hypotheses were tested:

i. Null Hypothesis (H_0): Augmented Reality does not significantly impact trainees' achievement in acquiring practical skills.
ii. Alternative Hypothesis (H_1): Augmented Reality significantly enhances trainees' achievement in acquiring practical skills.

A combination of descriptive statistics, correlation analysis, and regression analysis was conducted to determine the extent to which AR-based instructional strategies influence trainees' practical skill acquisition.

Trainees' perceptions of AR's role in practical skills acquisition were measured using a Likert scale (where 5 = Strongly Agree, 4 = Agree, 3 = Not Sure, 2 = Disagree, and 1 = Strongly Disagree). The responses provided insights into the perceived effectiveness of AR in supporting hands-on learning, spatial reasoning, and application of engineering concepts.

Table 9 *Augmented Reality on Practical Skills Acquisition*

Statement	Mean	SD	Interpretation
AR helps me learn practical skills for engineering tasks.	3.37	1.44	Not Sure
AR helps me use what I learn in real-life situations.	3.9	1.07	Agree
I feel more confident doing practical tasks after using AR.	3.9	1.13	Agree
AR makes it easier to practice engineering skills.	4.2	1.01	Strongly Agree
AR improves my accuracy and speed in practical work	3.2	1.39	Not Sure

The results suggest that trainees generally agree that AR enhances their acquisition of practical skills, with the highest ratings given to statements indicating that AR makes practicing engineering skills easier (M = 4.2) and helps apply learned skills in real-life situations (M = 3.9). Trainees also reported increased confidence in performing practical tasks after using AR (M = 3.9). However, the effectiveness of AR was less clear for statements regarding its impact on learning practical skills for engineering tasks (M = 3.37) and improving accuracy and speed in practical work (M = 3.2). These findings align with previous studies, such as those by (Tan et al., 2022; Hajirasouli & Banihashemi, 2022), emphasizing AR's role in enhancing technical skills and spatial awareness.

Qualitative Analysis

A qualitative analysis explored trainees' and trainers' perspectives on Augmented Reality (AR)-based learning in Building and Civil Engineering diploma programs, revealing that AR significantly enhanced trainees' understanding of complex tasks and improved their confidence and efficiency in performing practical tasks. Trainees appreciated the interactive, immersive simulations, which allowed them to rehearse procedures and plan tasks more effectively, supporting self-directed learning. However, some expressed concerns about becoming overly reliant on AR, emphasizing that real-world practice remains essential. Technical challenges, such as difficulties in navigating AR applications, were also noted, particularly for those with limited digital literacy. Despite these challenges, the findings highlighted the value of integrating AR with traditional hands-on training to balance theoretical understanding with physical skill development, reinforcing prior research on AR's potential in technical education (Liu et al., 2024; Jeong, 2022; Yazdi, 2024; Olbina & Glick, 2023).

Trainers Interview

To gain deeper insights into the integration of Augmented Reality (AR) in Building and Civil Engineering diploma programs within TVET institutions in Nairobi County, interviews were conducted with trainers specializing in various technical subjects.

Most trainers agreed that AR significantly enhanced practical skills in concrete mixing. Respondent 32 observed, "*AR simulations allow trainees to practice batching and mixing procedures virtually before handling physical materials, improving their confidence and accuracy.*" Respondent 49 echoed this, stating, "*By using AR, trainees gain a clearer understanding of correct procedures and reduce errors during hands-on practice."*

Respondent 21 highlighted a key advantage: "*AR reduces material wastage by allowing trainees to perfect their techniques in a virtual environment before working with actual materials."* This aligns with recent studies by Yazdi, (2024), which found that AR enhances efficiency in hands-on training by minimizing trial and error.

A small number of trainers raised concerns. Respondent 7 argued that "*while AR is useful, nothing replaces the feel of real materials*." Respondent 28 also mentioned, "*Some trainees become too reliant on AR simulations and hesitate when performing tasks without virtual assistance."* Despite this, most trainers agreed that AR complements traditional hands-on learning rather than replacing it (Olbina, & Glick, 2023).

4.7 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 programs within TVET institutions. These observations evaluated how AR-based instruction influenced trainee behaviour, participation, and overall learning outcomes.

Table 10 *Observation Checklist and Results*

S No.	Observation Statement	YES (n)	NO (n)	YES (%)	NO (%)
1	AR improves trainees' ability to learn and practice technical skills.	50	4	93%	7%
2	Trainees feel more confident in performing practical tasks after using AR.	45	9	83%	17%
3	AR helps trainees apply what they learn in practical assessments.	41	13	76%	24%

Trainers overwhelmingly supported the positive impact of Augmented Reality (AR) on developing practical skills in concrete mixing, with 93% reporting improved learning, 83% noting increased trainee confidence, and 76% observing better application of knowledge in assessments. These findings align with previous research emphasizing AR's effectiveness in bridging theoretical and hands-on learning gaps. While trainers acknowledged AR's role in providing a risk-free environment for practice, a small minority (7%) expressed concerns about potential overreliance on simulations, suggesting that AR should be used in a blended approach with physical engagement.

4.8 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 11 *Chi-Square Analysis*

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

The chi-square analysis revealed a significant relationship between AR-based instruction and trainees' practical skills in concrete mixing ($\chi^2(1) = 74.69$, $p < 0.001$, Cramér's V = 0.68), indicating that AR significantly enhances skill acquisition. AR's immersive simulations help trainees visualize procedures, manipulate virtual tools, and observe outcomes, improving their confidence and procedural understanding. These findings align with research emphasizing AR's role in reducing material waste and enhancing precision in real-world tasks. While AR enhances conceptual clarity, its most effective use is as part of a blended learning approach that combines AR with physical hands-on training.

4.0 CONCLUSIONS, AND RECOMMENDATIONS

The study concludes that Augmented Reality (AR) significantly improves practical skills acquisition in Building and Civil Engineering diploma programs by offering immersive, interactive learning that enhances understanding, confidence, and task accuracy. While trainers value AR as a complement to traditional training, they emphasize the need for a balanced approach. The findings support constructivist learning principles and highlight AR's effectiveness in enhancing technical training when integrated into a blended learning model.

Recommendations for TVET institutions include actively incorporating AR into training, particularly in fields like concrete mixing, to reinforce theoretical concepts and build practical competencies. Educators should receive professional development on AR integration, while policymakers should invest in AR infrastructure and content development. Educational authorities should ensure AR content aligns with industry standards, and a robust monitoring system should assess its impact to ensure continuous improvement and relevance.

Recommendations for Further Studies

Future research should use longitudinal designs to examine the long-term impact of AR-based instruction on skill retention and transfer to real-world engineering tasks. Experimental studies are also needed to compare AR-enhanced training with traditional methods, focusing on outcomes like accuracy, efficiency, and confidence. Additionally, research should identify specific engineering tasks such as formwork or equipment handling that benefit most from AR, and explore how AR can be effectively integrated into blended learning models to optimize both theoretical and practical training.

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