IMPACTS OF AUGMENTED REALITY ON THE ACADEMIC ACHIEVEMENT OF BUILDING AND CIVIL ENGINEERING TRAINEES IN TVET INSTITUTIONS IN NAIROBI, KENYA

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A Thesis Submitted in Partial Fulfilment of the Requirements for the Degree of Doctor of Philosophy in Technology Education of Murang'a University of Technology

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DECLARATION

Student Declaration

I hereby declare that this Thesis is my original work and that to the best of my knowledge has not been presented for a degree award in this or any other University. I understand what plagiarism is and I am aware of the University's policy in this regard. I understand that any false claim in respect of this work shall result in disciplinary action in accordance with the university Anti-Plagiarism Policy.

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Supervisors' Approval

The undersigned certify that they have read and hereby recommended for acceptance of Murang'a University of Technology a Thesis entitled "**Impacts of Augmented Reality on The Academic Achievement of Building and Civil Engineering Trainees in TVET Institutions in Nairobi, Kenya**

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DEDICATION

This research is dedicated with deep gratitude to my beloved wife, Abigael Chepkwemoi Ndiema, whose unwavering support, encouragement, and patience have been my anchor throughout this academic journey. Her understanding and sacrifices, particularly in managing the family during my long hours of study and research, have been invaluable.

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ABSTRACT

Augmented Reality (AR) is an innovative educational technology that enhances learning by merging digital content with real-world environments, offering immersive and interactive experiences. In Technical and Vocational Education and Training (TVET) institutions particularly in Building and Civil Engineering diploma programmes AR has the potential to address persistent challenges such as outdated instructional methods, limited access to advanced learning tools, and underdeveloped practical competencies. While global research supports AR's capacity to improve trainee engagement, motivation, and conceptual understanding, limited empirical evidence exists on its application and effectiveness in resource-constrained TVET settings. Moreover, few studies have assessed the moderating role of trainees' prior knowledge on AR's instructional impact. This study sought to fill these gaps by evaluating the influence of AR on academic achievement in Building and Civil Engineering diploma programmes across selected TVET institutions in Nairobi County. The study aimed to assess how AR enhances trainee engagement, supports instructional strategies, improves retention of complex content, fosters self-directed learning, and contributes to overall academic achievement. Additionally, the study examined the moderating effect of trainees' prior knowledge on learning outcomes in AR-supported environments. The target population comprised 3,087 trainees from ten purposively selected public and private TVET institutions within Nairobi County. From this population, 354 trainees were selected using simple random sampling to ensure fairness and representativeness, while 10 trainers were purposively sampled based on their expertise in teaching Construction Technology and their involvement in delivering the intervention. To rigorously evaluate the AR intervention, the study employed a Solomon Four-Group Design, a quasi-experimental approach that helps control for pretest sensitization and experimental bias. A mixed-methods approach was used for data collection, incorporating pre-tests, post-tests, structured questionnaires, summative exam results, and semi-structured interviews. Quantitative data were analyzed using both descriptive statistics (frequencies, means, percentages, and standard deviations) and inferential tests (correlation and multiple regression) via SPSS. Qualitative data from interviews and open-ended survey responses were analyzed thematically to capture trainers' and trainees' experiences with AR-based instruction. Findings revealed that AR significantly improved trainees' academic performance by enhancing theoretical understanding, increasing content retention, and boosting problem-solving abilities. AR also positively influenced instructional strategies and led to improved performance in summative assessments. Trainees exposed to AR demonstrated better acquisition of practical skills and more confidence in engaging with technical content compared to those taught through traditional methods. However, the effectiveness of AR integration was influenced by factors such as trainers' digital preparedness, the availability of supportive infrastructure, and trainees' prior exposure to technology. These insights highlight the need for institutional readiness, digital equity, and continuous professional development for educators. This study contributes practical evidence for policymakers, curriculum designers, and educators seeking to integrate AR in technical training. It supports the adoption of AR-enhanced pedagogies aligned with the evolving demands of 21st-century vocational education, ensuring that trainees are better equipped for modern construction and engineering industries.

TABLE OF CONTENTS

DECLARATION ..... **ii**
DEDICATION ..... **iii**
ACKNOWLEDGEMENT ..... **iv**
ABSTRACT ..... **v**
LIST OF TABLES ..... **x**
LIST OF FIGURES ..... **xii**
LIST OF EQUATIONS ..... **xiii**
ACRONYMS AND ABBREVIATIONS ..... **xiv**
OPERATIONAL DEFINITION OF TERMS ..... **xv**
CHAPTER ONE: INTRODUCTION **1**
1.1 Chapter Overview 1
1.2 Background 1
1.3 Statement of the Problem 7
1.4 Objectives of the Study 8
1.4.1 General Objective 8
1.4.2 Specific Objectives 8
1.4.3 Hypothesis 9
1.5 Significance of the Study 10
1.6 Scope of the Study 11
1.7 Limitations of the Study 12
1.8 Assumptions of the Study 13
1.9 Contribution of the Thesis 14
1.10 Organization of the Thesis 15
CHAPTER TWO: LITERATURE REVIEW **17**
2.1 Introduction 17
2.2 Theoretical Literature 17
2.2.1 Constructivist Learning Theory 17
2.2.2 Cognitive Load Theory (CLT) 18
2.3 Conceptual Framework 20
2.4 Empirical Literature 22
2.4.1. Augmented Reality and Trainees Engagement 22
2.4.2. Augmented Reality and Instructional Strategies 24
2.4.3. Augmented Reality and Trainees' Retention of Complex Technical Content…… 26
2.4.4. Augmented Reality and Development of Trainees Self-Directed Learning 28

2.4.5 The Moderating Effect of Trainees' Prior Knowledge on the Relationship Between Augmented Reality and Academic Achievement. 30
2.4.6. The Overall Impact of Augmented Reality on Academic Achievement..32
2.5 Research gaps 34
2.6 Chapter summary 38
CHAPTER THREE: RESEARCH METHODOLOGY 39
3.1 Introduction 39
3.2 Research Design 39
3.3 Experimental Implementation Process 41
3.3.1 Trainer Training and Orientation 41
3.3.2 Concrete Technology Topics Covered 42
3.3.3 Use of Lesson Plans and Course Outlines Aligned to Objectives 42
3.4 Location of Study 43
3.5 Target Population 44
3.6 Sample and Sampling techniques 45
3.6.1 Purposive sampling 45
3.6.2 Simple Random sampling 46
3.6.3 Proportionate Stratified Sampling 48
3.7 Data Collection Instruments 51
3.7.1 Questionnaire 51
3.7.2 Interview 52
3.7.3 Pre-Test and Post-Test 52
3.7.4 Summative Examination Results 54
3.7.5 Procedure for Data Collection 55
3.8 Summary of Measurement of Research Objectives 57
3.8.1 Impact of Augmented Reality and trainee engagement 57
3.8.2 Impact of Augmented Reality and instructional strategies 58
3.8.3 Impact of Augmented Reality and enhancing retention of complex technical content 59
3.8.4 Impact of Augmented Reality and self-directed learning 59
3.8.5 To assess the moderating effect of trainees' prior knowledge on the relationship between AR and academic achievement 60
3.8.6 To evaluate the overall impact of Augmented Reality and academic achievement 61
3.9 Validity and Reliability 61
3.9.1 Validity of Research Instruments 63
3.9.2 Reliability of Research Instruments 66
3.10 Data Analysis 68
3.11 Ethical Issues 71

3.12 Chapter Summary 72
CHAPTER FOUR: RESULTS AND DISCUSSION 74
4.1 Introduction 74
4.2 General and Demographic information 74
4.2.1 Response Rate 74
4.2.2 Demographic Characteristics of Trainee Respondents 76
4.2.3 Demographic Characteristics of Trainers who Participated 82
4.3 Preliminary Statistical Analysis 84
4.3.1 Descriptive Statistics for Main Study Variables 85
4.3.2 Correlation Analysis 88
4.3.3 Diagnostic Tests 91
4.4 Impact of Augmented Reality and trainee engagement 97
4.4.1 Descriptive analysis on Trainee engagement 98
4.4.2 Qualitative Analysis on Trainee Engagement 100
4.4.3 Trainers' Interview on Trainee Engagement 101
4.5 Impact of augmented reality and instructional strategies 103
4.5.1 Descriptive analysis on instructional strategies 103
4.5.2 Qualitative Analysis on Influences Instructional Strategies 106
4.5.3 Trainers' Interview on Instructional Strategies 108
4.6 Impact of augmented reality and retention of complex technical content. 110
4.6.1 Descriptive analysis on trainees' retention of complex 110
4.6.2 Pre-Test and Post-Test on trainees' retention of complex 113
4.6.3 Qualitative Analysis on trainees' retention of complex 123
4.6.4 Trainers' Interview on trainees' retention of complex 124
4.7 Impact of augmented reality and self-directed learning among trainees. 126
4.7.1 Descriptive analysis on self-directed learning among trainees 127
4.7.2 Qualitative Analysis on self-directed learning among trainees 129
4.7.3 Trainers' Interview on self-directed learning among trainees 131
4.8 Multiple Regression 132
4.9 Impact of trainees' prior knowledge on the relationship between Augmented Reality and academic achievement. 138
4.9.1 Descriptive analysis on prior knowledge 139
4.9.2 Hierarchical Regression 141
4.9.3 Qualitative Analysis on prior knowledge 149
4.9.4 Trainers' Interview on prior knowledge 150
4.10 Impact of Augmented Reality on the academic achievement 152
4.10.1 Descriptive analysis on the academic achievement 153
4.10.2 Summative Examination Performance Analysis 155
4.10.3 Qualitative Analysis on the academic achievement 158

4.10.4 Trainers' Interview on the academic achievement 160
4.11 Hypothesis Testing Results 161
4.12 Chapter Summary 163
CHAPTER FIVE: SUMMARY, CONCLUSION AND RECOMMENDATIONS 164
5.1 Summary of Results 164
5.1.1 Impact of augmented reality and trainee engagement 164
5.1.2 Impact of augmented reality and instructional strategies. 165
5.1.3 Impact of augmented reality and retention of complex technical content. 165
5.1.4 Impact of augmented reality and self-directed learning among trainees. 166
5.1.5 Impact of trainees' prior knowledge on the relationship between Augmented Reality and academic achievement 167
5.1.6 Overall impact of Augmented Reality and academic achievement of trainees 168
5.2 Conclusion 168
5.2.1 Impact of augmented reality and trainee engagement 168
5.2.2 Impact of augmented reality and instructional strategies. 169
5.2.3 Impact of augmented reality and retention of complex technical content. 170
5.2.4 Impact of augmented reality and self-directed learning among trainees. 170
5.2.5 Impact of trainees' prior knowledge on the relationship between Augmented Reality and academic achievement 171
5.2.6 Overall impact of Augmented Reality and academic achievement of trainees 171
5.3 Recommendations for TVET Institutions, Policymakers, and Educators 172
5.4 Recommendations for Further Studies 173
REFERENCES 175
APPENDICIES 189

LIST OF TABLES

Table 2.1: Summary of Empirical Literature and Research Gaps 37
Table 3.1: Distribution of the target population.....44
Table 3.2: Distribution of target population per institution and strata sample size ...48
Table 3.3: Distribution of trainee's target population per institution and strata sample size for respondents 49
Table 3.4: Sample distribution for the four groups.....50
Table 3.5: Participants distribution across ten TVET institutions 50
Table 3.6: Reliability Test Results.....67
Table 4.1: Trainees Questionnaire Response Rate.....75
Table 4.2: Demographic Characteristics of trainees Respondents.....77
Table 4.3: Background information for trainers who participated.....82
Table 4.4: Descriptive Statistics for Main Study Variables.....86
Table 4.5: Correlation Matrix Table 89
Table 4.6: Tests for Normality.....92
Table 4.7: Autocorrelation Test 94
Table 4.8: Multicollinearity Test 96
Table 4.9: Augmented Reality and Trainee Engagement Among Trainees 99
Table 4.10: Augmented Reality as an Instructional Strategy.....105
Table 4.11: Augmented Reality Improving Trainee Understanding and Retention of Complex Concepts 112
Table 4.12: Trainee Pretest Mean Score for Experimental Group 1 and Control Group 1 114
Table 4.13: t-test of Pre-test scores for Experimental and Control Group 1 116
Table 4.14: Post test Mean Scores on AR.....116
Table 4.15: ANOVA for Post test Mean Scores for Groups E1, E2, C1 and C2.....119
Table 4.16: Bonferroni Post Hoc Test 120
Table 4.17: ANCOVA Results for Post-Test Scores 121
Table 4.18: Adjusted Post-Test Mean for C2 122
Table 4.19: Augmented Reality and Self-Directed Learning 128
Table 4.20: Model Summary of Multiple regression analysis.....134
Table 4.21: AVOVA table 135
Table 4.22: Coefficients Table.....136
Table 4.23: Descriptive Statistics on Trainee Prior Knowledge.....140
Table 4.24: Model Summary for the Moderating Variable 143
Table 4.25: ANOVA table for the Moderating Variable 145
Table 4.26: Coefficients Table for the Moderating Variable.....147

Table 4.27: Descriptive analysis for overall impact of Augmented Reality on the academic achievement 154
Table 4.28: Mean and Standard Deviation for E1, C1, E2, C2 summative examination 156
Table 4.29: ANOVA table for the summative results 157
Table 4.30: Bonferroni Post Hoc Test for Trainees' Summative Examination Performance 157
Table 4.31: Hypothesis Testing Results 162

LIST OF FIGURES

Figure 2.1: Conceptual Framework of Augmented Reality Integration in TVET Training 22
Figure 4.1: Trainees' Age Distribution 78
Figure 4.2: Trainees' Gender Distribution 79
Figure 4.3: Trainees' Previous Qualifications 80
Figure 4.4: Trainees' Programme Enrolment 81
Figure 4.5: Boxplot of trainee pretest score for Experimental and Control Group .114
Figure 4.6: post-test mean scores of the four groups 117

LIST OF EQUATIONS

Equation 3.1: Yamane's formula 47
Equation 3.2: Proportionate Stratified Sampling Formula 49
Equation 3.3: Regression model equation.....70
Equation 4.1: Mean formula 85
Equation 4.2: Standard Deviation formula 85
Equation 4.3: Multiple regression model equation 133
Equation 4.4: Hierarchical regression equation 142

ACRONYMS AND ABBREVIATIONS

3D	Three Dimensional
AEC	Architectural Engineering and Construction
AI	Artificial Intelligence (if mentioned in comparison or literature)
ANOVA	Analysis of Variance
AR	Augmented Reality
CBET	Competency-Based Education and Training
Df	Degrees of Freedom
F	F-Statistic (used in ANOVA/MANOVA)
H0	Null Hypothesis
ICT	Information and Communication Technology
KICD	Kenya Institute of Curriculum Development
MoE	Ministry of Education
MoEST	Ministry of Education, Science and Technology (Kenya)
RQ	Research Question
SDL	Self-Directed Learning
SPSS	Statistical Package for Social Sciences
STEM	Science, Technology, Engineering, and Mathematics
TSC	Teachers Service Commission
TVET	Technical and Vocational Education and Training
UNESCO	United Nations Educational, Scientific and Cultural Organization
VET	Vocational Education and Training
VR	Virtual Reality

OPERATIONAL DEFINITION OF TERMS

Academic Achievement: refers to is the quantifiable measure of a trainee's performance as evidenced by scores on standardized assessments, examinations, or cumulative grade point averages (Elvis, 2021). In this study, academic achievement is specifically measured by the post-test scores obtained on a standardized Concrete Technology examination, with a maximum score of 100 marks. Additionally, academic achievement is further evaluated by calculating the mean gain between pre-test and post-test scores, providing a clear metric for improvement in knowledge and skills resulting from the instructional intervention.

Achievement in Practical Skills: The degree to which trainees acquire and demonstrate hands-on competencies in construction techniques, engineering design, and material applications, as evaluated through AR-based simulations, and practical assessments in Building and Civil Engineering courses (Hajirasouli, and Banihashemi, 2022).

Achievement in Theoretical Content: The level of understanding and retention of core engineering concepts, principles, and theories by trainees in Building and Civil Engineering diploma programmes, as measured through written tests, quizzes, and classroom assessments after exposure to Augmented Reality (AR)-assisted instruction (Nisbett, and Budynas, 2024).

Augmented Reality: refers to an interactive technology that overlays digital information onto the real-world environment to enhance learning Siricharoen, (2023). In this study, AR is used as a teaching tool in Building and Civil Engineering Diploma courses within TVET institutions to improve trainee engagement, understanding, and retention of complex concepts.

Competency-Based Education and Training (CBET): CBET is an instructional approach that emphasizes outcomes-based learning, where progression is determined by a trainee’s demonstrated mastery of specific competencies.

This framework guided the instructional design and assessment tools used in the study.

Control Group: The control group consisted of trainees who were taught using conventional instructional methods without AR integration. Their performance served as a baseline for comparison with the experimental group.

Experimental Group: The experimental group refers to the trainees who were exposed to AR-based instruction in addition to conventional teaching. Their outcomes were compared against those of the control group to determine the effectiveness of AR.

Mixed Methods Approach: This refers to the use of both quantitative (e.g., tests, rubrics) and qualitative (e.g., interviews, observations) data collection and analysis techniques. It enabled comprehensive understanding of the impact of AR-based instruction.

Practical Skills Acquisition: Practical skills acquisition represents the ability of trainees to apply learned techniques and procedures in hands-on tasks. It was measured through a Practical Skills Assessment Rubric that evaluated performance in real-world construction or engineering activities.

Problem-Solving Skills: The ability of trainees to critically analyze engineering-related challenges, apply logical reasoning, and develop appropriate solutions within Building and Civil Engineering contexts (Froehle et al., 2022). This is assessed through AR-enhanced learning activities, structured problem-solving tasks.

Solomon Four-Group Experimental Design: This is a research design used to control for testing effects and improve internal validity. In this study, it involved randomly assigning participants to four groups two experimental and two control with varying combinations of pre-tests and post-tests to accurately measure the impact of AR instruction.

Summative Examination Performance: The performance of trainees in standardized academic assessments, including theoretical examinations, applied tests, and competency-based evaluations, used to measure the effectiveness of AR in improving their overall academic achievement in Building and Civil Engineering diploma programmes (Kotsunthon, 2025).

Technical and Vocational Education and Training (TVET): TVET refers to formal training programs offered in post-secondary institutions that equip trainees with practical and technical skills relevant to specific trades and professions. In this study, it specifically pertains to diploma-level training in Building and Civil Engineering.

Theoretical Content Achievement: This refers to the trainees' understanding and mastery of classroom-taught theoretical concepts in Building and Civil Engineering. It was measured using standardized written assessments administered before and after the instructional intervention.

Trainee Prior Knowledge: The existing understanding, skills, and experiences that a trainee possesses before being introduced to Augmented Reality (AR)-based learning in Building and Civil Engineering Diploma courses within TVET institutions (AlGerafi, Zhou, Oubibi, and Wijaya, 2023). It includes foundational concepts, technical skills, and previous exposure to construction-related subjects that influence how trainees engage with and comprehend new AR-enhanced content.

Triangulation: Triangulation in this study refers to the use of multiple data sources and methods quantitative scores, interview data, and classroom observations to validate findings and improve the credibility of results.

CHAPTER ONE

INTRODUCTION

1.1 Chapter Overview

This chapter provides a foundational overview of the study, presenting the key components essential for understanding the research. It begins by offering background information that contextualizes the study within the broader academic and practical landscape, highlighting the relevance of AR in Technical and Vocational Education and Training (TVET), particularly in Building and Civil Engineering programmes. The chapter then presents the statement of the problem, identifying the specific educational gaps and challenges that the study seeks to address.

The research objectives and questions are outlined to guide the study's direction and maintain focus throughout the investigation. The chapter also discusses the significance of the study, emphasizing its potential contributions to academic knowledge, instructional practice, and policy development.

Additionally, the chapter defines the scope of the study and acknowledges its assumptions and limitations, ensuring clarity regarding its boundaries and possible constraints. By the end of the chapter, readers will have a comprehensive understanding of the research context, purpose, and direction. The chapter is structured to include the following sections: introduction, background of the study, statement of the problem, research objectives, research questions, research hypotheses, significance of the study, scope of the study, assumptions, and limitations.

1.2 Background

Global technological advancements have significantly reshaped the education sector, with AR emerging as a transformative tool. AR blends digital information with real-world environments, allowing trainees to interact with learning content in more immersive, engaging, and learner-centered ways. This interactivity not only enhances comprehension but also improves content retention. As noted by Pramanik (2024), the immersive quality of AR is instrumental in fostering sustained trainee engagement and stimulating curiosity critical drivers of academic success in technical education.

Advances in computing and information technologies have further enabled the integration of AR into instructional practice. According to AlGerafi et al. (2023), AR facilitates the delivery of complex technical content, enhances instructional strategies, and bridges the gap between theoretical understanding and practical application. These benefits are particularly relevant in Technical and Vocational Education and Training (TVET), where applied learning is essential. AR also promotes active engagement, critical thinking, and independent learning key components of effective study habits and cognitive development.

Internationally, the adoption of AR in education has gained momentum. In the United States, AR is embedded in K-12 and higher education, especially in STEM and vocational fields, through applications like Google Expeditions and Merge EDU. In Europe, countries like Germany and Finland employ AR to simulate complex industrial processes in vocational training. Similarly, Asian countries such as China, Singapore, and South Korea integrate AR in their national education strategies to improve science and skills-based learning (Yazdi, 2024). Australia has adapted AR for both urban and rural vocational settings to address disparities in educational access and quality.

Despite global advancements, AR's integration in TVET remains underexplored, particularly in Sub-Saharan Africa. Most existing studies focus on general education or university-level contexts, with limited attention to how AR can improve learning outcomes in hands-on, skills-oriented programs such as Building and Civil Engineering. Guntur et al. (2020) and Yazdi (2024) point to a critical gap in understanding the practical application of AR in vocational education, particularly in enhancing engagement, instructional delivery, content retention and self-directed learning. Affandi et al. (2024) also stress the need for research that identifies which AR approaches are most effective across various TVET contexts.

To address this gap, empirical studies are needed to evaluate AR's influence on trainee engagement, instructional strategies, retention of complex content and self-directed learning within TVET institutions. Research should also assess the moderating effect of prior knowledge on learning outcomes, as it may significantly shape how trainees interact with AR content. Longitudinal and experimental studies could offer insights

into how AR impacts academic achievement over time, as well as how it prepares trainees for real-world application in construction and engineering sectors (AlGerafi et al., 2023).

A major determinant of AR success in classrooms is teacher readiness. As Bonde (2024) emphasizes, effective AR integration requires educators to be trained not only in operating AR tools but also in embedding them within appropriate pedagogical frameworks. Teachers must be able to align AR content with learning objectives, foster interactive learning environments, and assess trainee progress. Nikimaleki and Rahimi (2022) note that educators' attitudes toward AR significantly influence its classroom implementation; resistance or unfamiliarity with digital tools can hinder adoption. Targeted capacity-building initiatives are, therefore, essential to ensuring AR's successful adoption in TVET settings.

AR technologies are generally categorized into marker-based, marker-less, and location-based formats (Rani et al., 2023). Marker-based AR relies on visual markers such as printed images or QR codes to trigger the display of 3D content via mobile cameras. Marker-less AR uses device sensors and spatial recognition to overlay digital content without predefined markers, while location-based AR employs GPS data to deliver context-aware experiences (Rotsios et al., 2022). Although often discussed alongside Virtual Reality (VR), which immerses users in a fully digital environment, AR distinguishes itself by layering digital elements onto the real world, maintaining physical context and facilitating interaction with both real and virtual components simultaneously. While VR is valuable for full-immersion simulations, AR is especially well-suited for Technical and Vocational Education and Training (TVET), where it enhances learning by linking real-life physical tasks with digital support systems, allowing for simultaneous engagement with real tools, environments, and AR-based content (Dash et al., 2024).

Unlike general or higher engineering education, where theoretical abstraction dominates, TVET programmes particularly in Building and Civil Engineering demand hands-on competencies that can be directly reinforced through AR's visual and spatial affordances. AR supports active learning by engaging trainees in realistic, skill-based simulations, fostering better content retention and conceptual mastery (Azuma et al.,

2022). While other disciplines like astronomy (Chen et al., 2022), physics (Lai & Cheong, 2022), and dentistry (Haji et al., 2021) have successfully employed AR to visualize abstract concepts, its application in TVET settings emphasizes procedural accuracy, safety training, and spatial orientation critical in fields such as construction, drafting, and materials science.

In this study, marker-based AR was primarily used. It involved mobile applications installed on tablets and smartphones that triggered instructional 3D models when scanning pre-designed markers embedded within course materials. For example, during lessons on concrete mixing or structural modelling, trainees could scan images to launch animations showing correct material ratios, equipment handling, and construction sequencing. These applications offered context-relevant interactivity that complemented classroom instruction and provided real-time visual reinforcement. AR tools in this setting promoted higher engagement, improved the delivery of complex concepts, and supported knowledge retention core elements addressed in this study's objectives (Pramanik, 2024; AlGerafi et al., 2023).

Furthermore, AR integration was reinforced through virtual laboratory activities that complemented physical tasks. These labs provided immersive scenarios in which trainees could manipulate digital models of construction equipment or structural elements without resource constraints or safety risks (Okono, 2023; Cai et al., 2021). This approach standardized training across diverse institutions with varied infrastructure, ensuring consistent instructional quality. In line with the study's objectives, these technologies supported enhanced trainee engagement, innovative instructional strategies, improved retention of complex content, self-directed learning and better academic outcomes. Ultimately, this study examined how AR, when carefully integrated into Building and Civil Engineering diploma programmes, bridges gaps between theory and practice and how this relationship is further shaped by trainees' prior knowledge.

Similar AR-based educational innovations are emerging in other African countries. In Rwanda, AR is being piloted in Technical and Vocational Education and Training (TVET) institutions to improve instruction in construction and automotive engineering. These initiatives aim to overcome the limitations of physical resources

by supplementing traditional instruction with virtual simulations (Butt, 2025). In Nigeria, educational technology hubs are exploring AR tools to enhance teaching in science and engineering, providing interactive 3D models and simulations that mimic real-world scenarios and promote experiential learning.

A key benefit of AR is its ability to replicate real-life scenarios in a safe, controlled environment, thereby improving trainees' practical skill development. For example, automotive engineering trainees can simulate engine diagnostics and repair without physical vehicles, reducing both equipment costs and risk of injury (Arici & Yilmaz, 2023; Ravichandran & Mahapatra, 2023). This approach builds trainee confidence and ensures repetitive practice before real-world application.

In Building and Civil Engineering programmes, AR is especially effective in enhancing theoretical understanding and practical skills. Through interactive 3D models, AR enables trainees to visualize structural layouts, building cross-sections, and infrastructure systems, facilitating better comprehension of abstract engineering concepts (Zhang et al., 2023). Unlike traditional lecture-based instruction, AR provides dynamic, context-rich learning environments that connect theory with application (Tahir & Abdullah, 2023). For instance, animated simulations can demonstrate the layering of construction materials or the step-by-step sequence of engineering processes, making learning more intuitive and engaging (Rahman & Liu, 2023).

Moreover, AR supports the development of critical problem-solving skills, an essential competency in engineering education. Interactive simulations allow trainees to test alternative solutions, experiment with design variables, and receive real-time feedback, thereby honing analytical thinking and decision-making (Alkhabra et al., 2023). Repetitive, risk-free practice in virtual settings also prepares trainees for the demands of real-world construction tasks, improving overall industry readiness (Tihomirova & Atanasova, 2022).

AR-based instruction also positively impacts summative examination performance. By reinforcing knowledge through multisensory interaction, trainees show higher retention and understanding in formal assessments (Sakr & Abdullah, 2024). This is particularly valuable in fields like civil engineering, where technical accuracy and

comprehension are critical. However, the success of AR-enhanced learning is not uniform; trainees with a strong foundational understanding tend to benefit more, while those with limited prior knowledge may need additional scaffolding and instructional support (Tahir & Abdullah, 2023). Recognizing the moderating role of prior knowledge is essential for developing adaptive instructional strategies that cater to diverse trainee profiles (Affandi et al., 2024).

Locally, in Kenya, there is growing momentum around integrating AR into education and workforce development. Companies such as Black Rhino VR (BRVR) and Elimutab are pioneering the use of AR in education. BRVR has launched Africa's first online AR design studio, enabling educators to create immersive content without coding skills, while Elimutab develops AR tools tailored for academic use (Mlambo et al., 2024). Other firms, including Ipop and Jays Pyrotechnics, are also employing AR to enhance user experiences, and Nobleprog Kenya is spearheading local AR training for educators and businesses, contributing to a digitally skilled workforce.

Despite the growing evidence of AR as a transformative tool in Technical and Vocational Education and Training (TVET), particularly in enhancing engagement, theoretical understanding, practical skill development, and problem-solving abilities, its integration remains limited especially within resource-constrained environments like many TVET institutions in Nairobi County. While AR has demonstrated success in various educational contexts globally, there is a lack of empirical research examining its effectiveness specifically within Building and Civil Engineering diploma programmes in Kenya which is echoed by (Barke, 2021). Furthermore, little is known about how AR influences instructional strategies, content retention, or the role of trainees' prior knowledge in shaping learning outcomes in these technical disciplines. This gap underscores the need for a focused investigation to assess the impact and applicability of AR in improving academic achievement and instructional delivery within local TVET settings.

Despite promising developments, AR adoption in TVET institutions in Nairobi County remains limited, particularly in Building and Civil Engineering programmes where hands-on skills are vital. Traditional, lecture-based methods dominate instruction, often with minimal interactivity or experiential learning opportunities.

Yet, tasks like concrete mixing require precision, repetition, and spatial awareness skills that AR is well suited to enhance. By simulating mixing processes, demonstrating correct proportions, and guiding tool use, AR can improve both understanding and practical execution (Azuma et al., 2022; Tihomirova & Atanasova, 2022). This study seeks to close this gap by empirically assessing the effectiveness of AR in concrete mixing and broader technical instruction.

Thus, the present study aims to investigate the impact of Augmented Reality on academic achievement among Building and Civil Engineering trainees in Nairobi County's TVET institutions. Specifically, the study will assess how AR affects trainee engagement, enhances instructional strategies, supports retention of complex content, self-directed learning and improves overall academic performance. It will also explore the moderating role of prior knowledge in shaping these outcomes. By addressing these objectives, the research will offer practical recommendations for curriculum design, teacher training, and policy formulation, and contribute to the broader goal of aligning TVET training with 21st-century educational and industry standards.

1.3 Statement of the Problem

Traditional teaching methods continue to dominate Building and Civil Engineering diploma programmes in Technical and Vocational Education and Training institutions within Nairobi County. These teacher-centered approaches often reliant on lectures, textbooks, and rote memorization frequently fail to stimulate active trainee engagement or support deep understanding and retention of complex technical content (Mersha, 2024). In engineering education, where the application of theory to practice is critical, such instructional methods fall short in equipping trainees with the hands-on skills and problem-solving competencies required by modern industry standards (Kumar et al., 2024). Compounding this issue are systemic challenges, including outdated curricula, limited access to modern instructional technologies, and infrastructure deficits that hinder the adoption of innovative teaching strategies (Scott & Husain, 2021).

Globally, Augmented Reality has emerged as a promising educational innovation capable of transforming how technical concepts are taught and learned. AR enables immersive and interactive learning environments, bridging the gap between abstract theory and practical application through real-time 3D simulations and visualizations.

It has been shown to improve trainee engagement, content retention, and academic performance across various disciplines (Sharmila, 2024; Azuma et al., 2022). However, despite these benefits, the adoption of AR in TVET institutions in Nairobi County remains limited. High implementation costs, lack of digital infrastructure, and insufficient trainer preparedness continue to restrict its effective use (Mbatha, 2024).

Furthermore, while existing literature has explored AR's impact on learning outcomes, few studies have systematically examined how AR influences specific academic dimensions such as trainee engagement, instructional strategies, content retention, self-directed learning and overall academic achievement in Building and Civil Engineering diploma programmes within the TVET context. Even fewer studies have considered how trainees' prior knowledge might moderate the effectiveness of AR-based instruction. Without this understanding, efforts to integrate AR into vocational education risk being ineffective, unscalable, or misaligned with trainee needs.

This study therefore seeks to address these gaps by investigating the impacts of Augmented Reality on the academic achievement of Building and Civil Engineering trainees in TVET institutions in Nairobi County. The study focuses on AR's influence on trainee engagement, instructional delivery, retention of complex technical content, self-directed learning and overall academic achievement, while also assessing the moderating role of trainees' prior knowledge. By doing so, the research aims to provide empirical insights that inform policy, curriculum development, and pedagogical practices for technology-enhanced vocational education in Kenya.

1.4 Objectives of the Study

1.4.1 General Objective

To investigate the impact of augmented reality on the academic performance of building and civil engineering trainees in TVET institutions in Nairobi, Kenya.

1.4.2 Specific Objectives

The study was guided by the following five specific objectives:

i. To assess the extent to which augmented reality induces trainee engagement among building and civil engineering trainees in TVET institutions.

ii. To examine how augmented reality influences instructional strategies used in teaching technical concepts in building and civil engineering.
iii. To analyze the role of augmented reality in enhancing trainees' retention of complex technical content.
iv. To determine the effect of augmented reality on the development of effective self-directed learning among trainees.
v. To assess the moderating effect of trainees' prior knowledge on the relationship between Augmented Reality and academic achievement.
vi. To assess the overall impact of augmented reality on the academic achievement of trainees in building and civil engineering programmes in Nairobi's TVET institutions.

1.4.3 Hypotheses

The study was guided by the following null hypotheses:

H_{01}: Augmented reality has no significant effect on trainee engagement among building and civil engineering trainees in TVET institutions.

H_{02}: Augmented reality does not significantly influence instructional strategies used in teaching technical concepts in building and civil engineering.

H_{03}: Augmented reality has no significant impact on the retention of complex technical content by building and civil engineering trainees.

H_{04}: Augmented reality has no significant effect on on the development of effective self-directed learning among trainees.

H_{05}: Trainees' prior knowledge has no significant impact on Augmented Reality as a pedagogical tool and trainee academic achievement in Building and Civil Engineering Diploma courses within TVET institutions in Kenya.

H_{06}: Augmented reality has no significant effect on the academic performance of building and civil engineering trainees in TVET institutions in Nairobi.

1.5 Significance of the Study

This study is significant in addressing the pressing need to modernize teaching and learning in Building and Civil Engineering diploma programmes within Kenya's TVET institutions. Traditional instructional strategies often lecture-based and teacher-centered have been linked to low trainee engagement, poor retention of complex content, and inadequate practical skills (Scott & Husain, 2021; Mersha, 2024). The integration of Augmented Reality into these programmes presents an opportunity to transform pedagogical approaches, enhance academic performance, and prepare trainees for technologically advanced work environments.

By focusing on how AR affects trainee engagement, instructional strategies, self-directed learning, content retention, and overall academic achievement, this research contributes to the growing body of knowledge on the role of immersive technologies in technical education. Prior studies have shown that AR can significantly enhance trainee motivation, attention, and understanding in science and engineering disciplines (Azuma et al., 2022; Lai & Cheong, 2022; Zhang et al., 2023). This study builds on those findings by contextualizing AR's application within Kenya's TVET system specifically in Building and Civil Engineering where such integration remains limited despite its potential benefits (Mbatha, 2024; Huang et al., 2021).

The research is valuable for educators and instructional designers, as it provides evidence on how AR can support more interactive, visual, and trainee-centered learning environments. By examining the influence of AR on instructional strategies, the study offers a practical guide for rethinking how technical concepts can be effectively delivered in digital formats that align with competency-based education and training (CBET) models (UNESCO-UNEVOC, 2022).

The study also informs policy-makers and curriculum developers on the strategic value of adopting AR tools in technical training. With Kenya's Vision 2030 and the Digital Economy Blueprint emphasizing ICT integration in education, these findings can guide investments in digital infrastructure, capacity building for trainers, and curriculum reforms that support inclusive and technology-driven learning environments (Kipkoech, 2023).

For TVET institutions and administrators, the study offers insights into how AR can help trainees develop effective study habits, better retain complex concepts, and bridge the gap between theoretical instruction and hands-on application. It also highlights the importance of accounting for individual differences in prior knowledge, ensuring that AR integration is equitable and responsive to diverse trainee needs (Tahir & Abdullah, 2023; Affandi et al., 2024).

Finally, industry stakeholders will benefit from a more skilled and digitally literate workforce. The study supports the argument that AR can help align TVET outcomes with modern industry demands by fostering critical thinking, precision, and job-readiness among trainees (Donally, 2022; Ravichandran & Mahapatra, 2023).

In summary, this research contributes to the advancement of technical education in Kenya by demonstrating how AR can improve trainee engagement, instructional delivery, learning outcomes, and preparedness for the evolving demands of the engineering and construction sectors.

1.6 Scope of the Study

This study focused on evaluating the impact of Augmented Reality (AR) on academic achievement among trainees enrolled in Building and Civil Engineering diploma programmes within Technical and Vocational Education and Training (TVET) institutions in Nairobi County, Kenya. The research specifically investigated how AR influences trainee engagement, enhances instructional strategies, supports the retention of complex technical content, promotes self-directed learning, and improves overall academic performance. In addition, the study examined the moderating effect of trainees' prior knowledge on the relationship between AR-based instruction and academic outcomes.

The study was conducted in Nairobi County, selected for its high concentration of TVET institutions offering diploma-level programmes in Building and Civil Engineering, and its readiness to implement technology-driven instructional innovations. The research was carried out between January and December 2024, covering the full academic year to allow adequate exposure to the intervention and evaluation of its effects over time. Data were collected from ten purposively selected public and private institutions, including national polytechnics, technical training

institutes, vocational training centers, and university-affiliated TVET campuses, thereby capturing diverse institutional contexts and varying levels of technological infrastructure.

The scope was limited to diploma-level training in Building and Civil Engineering programmes. The study did not include certificate-level courses, other engineering disciplines, or general education subjects. The focus was strictly on academic outcomes influenced by AR in the context of technical content delivery. Therefore, the findings are most applicable to institutions with similar programme structures, learner profiles, and technological readiness, and should be generalized to other contexts with caution.

1.7 Limitations of the Study

As with any academic inquiry, this study was subject to several limitations that may influence the interpretation and generalizability of its findings. The research focused solely on the use of Augmented Reality (AR) and did not consider other emerging instructional technologies such as Virtual Reality (VR), QR codes, or artificial intelligence-based learning tools. As a result, the study does not provide a comprehensive picture of the broader technological ecosystem in technical and vocational training. Geographically, the study was limited to TVET institutions within Nairobi County, Kenya. While this area was appropriate due to its high concentration of institutions offering Building and Civil Engineering training, the findings may not fully capture the experiences of trainees and trainers in other counties where infrastructure, access to technology, and institutional support may differ.

Another limitation concerned the study's timeframe, which spanned from September 2021 to February 2025. This period, though adequate for measuring short-term academic performance, may not be sufficient to capture the long-term effects of AR integration, particularly its sustained influence on study habits, content retention, and pedagogical transformation. A longer-term or longitudinal approach would provide deeper insight into the evolving impact of AR on academic development. In addition, although the sample size of 354 trainees and 10 trainers was substantial, it may not fully represent the diversity of trainees and educators across all TVET institutions in Kenya especially those in rural or under-resourced settings where AR implementation

may differ significantly. Thus, the generalizability of the findings is somewhat constrained by the sample composition.

Moreover, the study focused primarily on academic performance indicators such as engagement, retention of technical content, and summative achievement, with limited emphasis on external factors such as trainees' socio-economic background, access to digital tools outside of school, motivation levels, or institutional support systems. These variables, though outside the direct scope of this research, could significantly influence the effectiveness of AR in different contexts. Additionally, while the study evaluated how AR enhances theoretical understanding and academic achievement, it did not assess its role in developing soft skills such as communication, teamwork, or adaptability competencies that are increasingly vital in the modern engineering and construction workforce.

Despite these limitations, none were deemed to significantly compromise the validity or reliability of the study's results. Rigorous methodological procedures, including piloting of instruments, stratified sampling, and triangulation of data collection methods, helped to mitigate potential biases. The insights gained from this research remain valuable, offering a credible foundation for advancing AR-based instruction within TVET institutions. The study's contributions are especially relevant for trainers, curriculum developers, policymakers, and industry stakeholders seeking evidence-based strategies to modernize technical education and align it with the needs of a digitally-driven labor market.

1.8 Assumptions of the Study

The following assumptions guided the conduct of this study and underpin the interpretation of its findings:

1. It was assumed that all participants had sufficient capacity to engage effectively with the research instruments, although individual differences in comprehension and engagement could not be ruled out.
2. Participation in the study was voluntary, and respondents were assumed to provide honest and accurate answers; however, the potential for response bias could not be completely ruled out.

3. The purposive sampling technique was assumed to yield a representative sample of Building and Civil Engineering trainees across TVET institutions in Nairobi County.
4. The implementation of Augmented Reality (AR) technology was assumed to be consistent and effective across all experimental groups, ensuring uniform exposure to the intervention.
5. The instruments used to measure learning outcomes including surveys, academic achievement records, and observational assessments were presumed to be valid and reliable, accurately reflecting trainees' progress and performance.
6. It was assumed that external factors such as technical difficulties or environmental disruptions did not significantly interfere with the AR-based instructional process or compromise the integrity of the research outcomes.

1.9 Contribution of the Thesis

This thesis makes important contributions to both academic scholarship and practical application within the field of Technical and Vocational Education and Training (TVET), with a specific focus on Building and Civil Engineering diploma programmes. At the theoretical level, the study enriches the existing body of knowledge on the integration of emerging technologies in education by empirically examining the impact of Augmented Reality (AR)-based instruction on four critical academic outcomes: theoretical content achievement, problem-solving skills, practical skills acquisition, and summative examination performance. While earlier studies often treated these outcomes separately or explored them in more general educational contexts, this research offers a comprehensive, discipline-specific analysis that is uniquely situated within the Kenyan TVET environment. By employing the Constructivist Learning Theory and Cognitive Load Theory as its guiding frameworks, the study further contributes to understanding how AR influences learner engagement and cognitive processing, while also accounting for the moderating effect of trainees' prior knowledge.

Methodologically, the thesis offers a robust model for evaluating educational interventions by employing the Solomon Four-Group Design, which effectively controls for internal validity threats and strengthens causal inferences. The

combination of quantitative methods (such as MANOVA and hierarchical regression) with qualitative insights (drawn from interviews and open-ended questionnaire responses) provides a well-rounded analysis of the research problem. This mixed-methods approach enhances the depth and credibility of the findings.

From a practical standpoint, the thesis provides actionable insights for curriculum developers, TVET instructors, institutional administrators, and policymakers. It offers clear evidence on how AR can be used to improve instructional strategies, enhance the retention of complex technical content, and support more effective skills training in competency-based education settings. These insights are particularly relevant for developing countries seeking to modernize technical education and bridge the gap between classroom instruction and industry demands. Furthermore, the study contributes to pedagogical innovation by showcasing AR as a transformative teaching tool that can be adapted to diverse learning environments. By doing so, it serves as a reference point for future initiatives aimed at integrating immersive technology in vocational education. Overall, the thesis contributes new knowledge, validates a rigorous research design, and provides practical recommendations that support the advancement of TVET in Kenya and beyond.

1.10 Organization of the Thesis

This thesis is organized into five chapters, each structured to address the study's objectives systematically. Chapter One provides an overview of the study by introducing the background, statement of the problem, research objectives, research hypothesis, significance of the study, scope of the study, limitations of the study, assumptions of the study, contribution of the thesis and organization of the thesis. This lays the foundation for understanding the rationale and importance of the research.

Chapter Two presents a comprehensive review of relevant literature, organized into four key sections: theoretical literature, conceptual framework, empirical studies, and the research gaps. The chapter focuses on the application of Augmented Reality in education, specifically examining its influence on instructional strategies, learner engagement, retention of complex technical content, academic achievement, and the moderating effect of prior knowledge. It concludes by identifying existing research

gaps and positioning the current study within appropriate theoretical and empirical contexts.

Chapter Three outlines the research methodology, detailing the research design (Solomon Four-Group Experimental Design), location of study, target population, sampling techniques, instruments for data collection, summary of measurement of research objectives, data analysis procedures, validity and reliability strategies, and ethical considerations that guided the study.

Chapter Four presents the findings of the study based on both quantitative and qualitative data. It covers descriptive statistics, inferential analyses including Multiple regression, and moderation tests and thematic analysis of interview responses to assess the impact of AR-based instruction on the identified academic outcomes.

Chapter Five discusses the research findings in relation to existing literature, draws conclusions, outlines implications for practice and policy, and offers recommendations for further research. Together, these chapters provide a coherent and rigorous structure through which the research problem is investigated and addressed.

CHAPTER TWO

LITERATURE REVIEW

2.1 Introduction

This chapter reviews the Theoretical literature, conceptual framework, Empirical review and Research gap.

2.2 Theoretical Literature

The study was anchored on the following theories discussed in the subsequent sections. Constructivist Learning theory and Cognitive Load Theory (CLT).

2.2.1 Constructivist Learning Theory

The present study is anchored in the Constructivist Learning Theory, which asserts that trainees actively construct knowledge rather than passively receive it. According to this theory, learning occurs as individuals engage with new experiences, integrate them with their prior knowledge, and derive meaning through reflection and contextual application (Sundermann et al., 2022). Augmented Reality, as employed in this study, aligns seamlessly with constructivist principles by offering interactive, immersive, and trainee-centered environments that promote experiential learning. AR technologies enable trainees to visualize, manipulate, and interact with 3D content, allowing for hands-on engagement with complex engineering concepts in a virtual yet realistic setting. This process supports the construction of knowledge by enabling trainees to test hypotheses, apply abstract theories, and receive immediate feedback within simulated environments.

In Technical and Vocational Education and Training, particularly within Building and Civil Engineering diploma programmes, AR facilitates meaningful learning through real-time simulations of technical tasks such as structural analysis, surveying, or concrete mixing. These activities allow trainees to bridge the gap between theoretical understanding and practical execution, reinforcing core constructivist tenets such as active experimentation, trainee autonomy, and contextual relevance. The interactive nature of AR also promotes critical thinking and problem-solving, as trainees are encouraged to explore various approaches, reflect on outcomes, and make decisions based on experiential input. Furthermore, AR supports differentiated instruction by adapting to trainees' prior knowledge levels. Trainees with varying competencies can

proceed at their own pace, engage with content suited to their needs, and build upon foundational concepts in a scaffolded manner, which is central to constructivist pedagogy (Al Abri et al., 2024).

This theoretical framework directly informs the study's general objective of investigating the impact of AR on academic performance among Building and Civil Engineering trainees in Nairobi's TVET institutions. It also underpins the specific objectives by explaining how AR induces trainee engagement, influences instructional strategies, supports the retention of complex technical content, self-directed learning and ultimately improves academic achievement. Additionally, the theory provides a basis for examining how trainees' prior knowledge moderates the effectiveness of AR-based instruction. In summary, Constructivist Learning Theory offers a comprehensive lens for interpreting how AR technologies foster deeper cognitive engagement, facilitate meaningful learning experiences, and promote academic success in resource-constrained technical training environments (Yao, 2023; Mlambo et al., 2024).

2.2.2 Cognitive Load Theory (CLT)

Cognitive Load Theory (CLT), introduced by Sweller (1988), emphasizes the limitations of human working memory and the need to design instruction that manages cognitive effort effectively. According to the theory, optimal learning occurs when cognitive load is carefully balanced: intrinsic load (related to content complexity), extraneous load (caused by poor instructional design), and germane load (the mental effort that contributes to learning) must be appropriately managed (Sweller, 1988; Daniel, 2023). In Building and Civil Engineering education, especially at the diploma level within TVET institutions, theoretical concepts and technical problem-solving tasks often carry a high intrinsic load. Poorly structured teaching materials can add unnecessary extraneous load, making it harder for trainees to retain and apply knowledge (Daniel, 2023). Therefore, this study applies CLT to assess how well Augmented Reality reduces cognitive burden and improves academic achievement among trainees, directly aligning with the revised general objective to investigate the impact of augmented reality on the academic performance of Building and Civil Engineering trainees in TVET institutions in Nairobi, Kenya.

In relation to trainee engagement and instructional strategies, CLT explains how AR minimizes extraneous load by presenting information through intuitive 3D visuals, animations, and interactive simulations. This makes complex engineering processes such as reinforced concrete construction or plumbing systems more accessible to trainees. Instead of overloading trainees with abstract text or diagrams, AR simplifies the learning process through spatial representation and multimodal feedback, supporting the objective to assess the extent to which augmented reality induces trainee engagement among Building and Civil Engineering trainees in TVET institutions (Rahman & Liu, 2023). AR also supports interactive teaching approaches, allowing trainers to move away from passive lectures to guided exploration and real-time feedback, which fulfils the objective to examine how augmented reality influences instructional strategies used in teaching technical concepts in Building and Civil Engineering (Azuma et al., 2022).

CLT also informs the evaluation of AR's role in helping trainees retain complex technical content. AR allows information to be chunked into manageable segments and presented with contextual cues that enhance memory encoding and schema development. These cognitive supports promote germane load by encouraging active learning, mental organization, and the integration of prior knowledge thus directly supporting the objective to analyze the role of augmented reality in enhancing trainees' retention of complex technical content (Dahlan & Wibisono, 2021; Chandrasekar, 2022). For instance, instead of memorizing engineering symbols and measurements, trainees interact with virtual construction elements, reinforcing retention through repetition and visual association.

Finally, CLT provides a framework for assessing the overall effectiveness of AR on academic performance and the role of trainees' prior knowledge in moderating this effect. Trainees with stronger prior knowledge may be better equipped to integrate AR-enhanced instruction into existing cognitive frameworks, while those with less prior exposure may experience greater cognitive overload if the instruction is not scaffolded appropriately (Buchner et al., 2022). By accounting for these variations, the study meets the objective to assess the moderating effect of trainees' prior knowledge on the relationship between Augmented Reality and academic achievement (Rahman & Liu, 2023). In this way, CLT helps explain how AR

interventions can be tailored to trainee readiness, thus contributing to personalized and effective instructional strategies within TVET contexts.

2.3 Conceptual Framework

Mugenda and Mugenda (2003) define a conceptual framework as a hypothetical model that illustrates the variables under investigation and their presumed relationships. It plays a crucial role in guiding both the researcher and the reader in understanding how a study is structured, as well as how theoretical concepts are translated into measurable constructs. In this study, the conceptual framework is developed to examine the influence of AR on academic achievement among trainees enrolled in Building and Civil Engineering diploma programmes within TVET institutions in Nairobi County, Kenya. The framework is rooted in the general and specific objectives of the study and reflects the theoretical assumptions underpinning the relationship between the instructional method and learning outcomes.

In this model, Augmented Reality is the independent variable, conceptualized across four interrelated dimensions: AR-induced engagement, AR-based instructional strategies, AR-enhanced retention of complex technical content, and AR-facilitated self-directed learning. AR-induced engagement refers to the ability of AR tools to attract and sustain trainees' interest during instruction, encouraging active participation and motivation. AR-based instructional strategies describe the transformation of teaching approaches through the integration of immersive visualizations and interactive learning environments, enabling trainers to move from traditional lecture methods to more learner-centered pedagogies. AR-enhanced retention of complex content represents the role of AR in helping trainees visualize and understand difficult engineering concepts that are often abstract or theoretical. AR-facilitated self-directed learning reflects how AR empowers trainees to explore and interact with content independently, beyond the classroom, thus supporting lifelong learning habits.

The dependent variable in this study is academic achievement, which is evaluated through a combination of formative assessments, summative examination performance, and mastery of practical skills. These outcomes reflect the extent to which trainees have comprehended, applied, and retained technical knowledge

delivered through the instructional process. The relationship between the independent and dependent variables is hypothesized to be positive where effective AR integration enhances academic achievement across cognitive and practical domains.

However, this relationship is not expected to be uniform across all trainees. The conceptual framework introduces trainees' prior knowledge as a moderating variable, acknowledging that individual differences in background knowledge and cognitive readiness can influence how effectively trainees engage with and benefit from AR-based instruction. Trainees with strong foundational knowledge may assimilate AR content more efficiently, while those with limited prior exposure may require additional scaffolding to achieve similar learning outcomes. Thus, prior knowledge is expected to moderate the strength and direction of the relationship between the AR intervention and academic achievement.

In summary, the framework proposes that the use of AR as an instructional method positively influences various facets of trainee learning, ultimately contributing to improved academic performance. This relationship is mediated through enhanced engagement, innovative instructional practices, deeper content retention, and increased learner autonomy, while being moderated by the trainees' existing knowledge base. The framework not only provides a structure for data collection and analysis but also serves as a theoretical lens through which the study evaluates the pedagogical potential of AR in technical and vocational education settings.

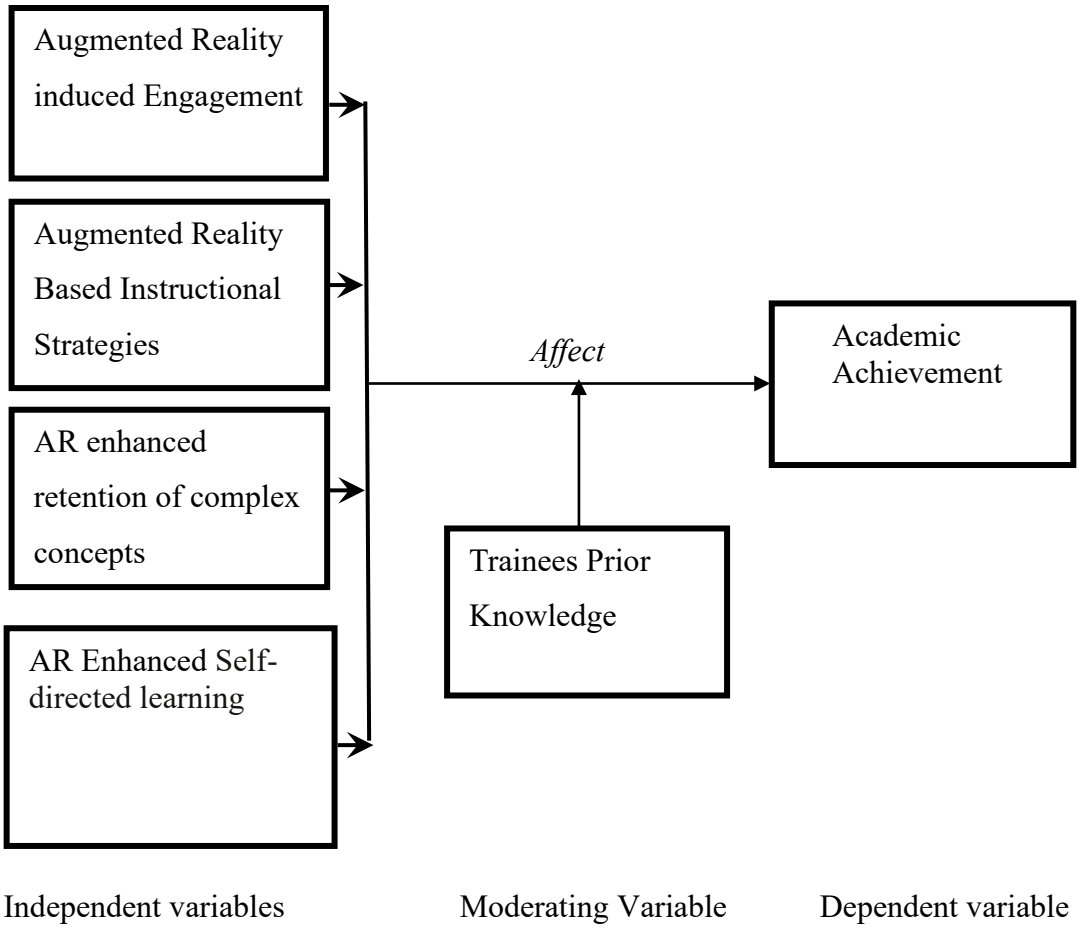


Figure 2.1: Conceptual Framework of Augmented Reality Integration in TVET Training

2.4 Empirical Literature

2.4.1. Augmented Reality and Trainees Engagement

While extensive global research has explored how AR influences trainee engagement, few studies have focused on its contextual application within Building and Civil Engineering diploma programmes in Technical and Vocational Education and Training (TVET) institutions in Sub-Saharan Africa, particularly Kenya. Most existing studies have been conducted in well-resourced environments in higher education or general science and medical fields, leaving a gap in understanding AR's impact on engagement in resource-constrained TVET settings where hands-on, industry-relevant training is critical.

This review examines how AR induces engagement across several dimensions: active participation, interest in AR activities, task completion, perceived career relevance,

reduction of learning anxiety, and concept retention. Globally, AR has been shown to create interactive and immersive learning environments that stimulate exploration, practice, and knowledge application (Ruhama et al., 2025; Liu et al., 2024). However, studies rarely examine how these features operate in the context of vocational institutions grappling with infrastructure limitations, large trainee populations, and limited digital readiness factors that this study addresses directly.

Active participation is one of the key markers of engagement influenced by AR. Riniati et al. (2024) found that AR-supported environments enabled trainees to persist through difficult tasks by engaging in repeated practice. Yet, these findings have not been validated within Kenyan TVETs, where trainees often struggle to access even basic digital tools. By integrating AR into actual technical instruction and comparing it to traditional delivery modes, this study provides empirical data on whether such increased participation can realistically be achieved in local institutions.

Perceived usefulness of AR, particularly its ability to bridge theory and practice, is also critical to sustaining engagement. Mohamad et al. (2024) established that trainees in technical disciplines are more likely to stay engaged if they perceive AR as useful for mastering real-world tasks. However, there is little evidence exploring this correlation in diploma-level civil engineering education, where the practical relevance of learning is essential for employability. This study bridges that gap by measuring how AR's relevance to construction and civil engineering tasks influences engagement among TVET trainees.

Gamified AR features have been linked to increased task completion rates, but research by Kumar et al. (2022) focused primarily on university-level engineering and computer science trainees. The transferability of these outcomes to vocational trainees remains largely unexplored. In this study, task completion is analyzed within the unique demands of the TVET environment, offering new insights into how AR influences work ethic and perseverance among diploma trainees.

Learning anxiety is another critical barrier to engagement. Rezai et al. (2025) demonstrated that AR reduces fear of failure by offering a low-risk, exploratory learning space. However, most existing studies lack qualitative insights into how this reduction in anxiety impacts trainee confidence and willingness to participate,

particularly among trainees from underprepared academic backgrounds. This study addresses this limitation by combining quantitative assessment with qualitative data from interviews and classroom experiences.

Lastly, retention of engineering concepts through immersive experiences has been emphasized in literature (Williams et al., 2025; Mokmin et al., 2024), yet prior research has largely examined long-term memory outcomes in theory-heavy disciplines like physics or biology. There remains a gap in understanding how AR supports memory retention in fields requiring simultaneous mastery of theory and hands-on skills, such as civil engineering. This research fills that gap by evaluating retention in both theoretical and practical domains within the same instructional period.

In summary, this study builds upon prior research by empirically validating AR's influence on trainee engagement in a new and underexplored context TVET diploma training in Building and Civil Engineering in Nairobi County. By focusing on real-world conditions such as limited infrastructure and varying trainee preparedness, the study provides evidence on whether the known benefits of AR translate effectively into vocational education, thereby filling a significant gap in the literature.

2.4.2. Augmented Reality and Instructional Strategies

This empirical review investigates how Augmented Reality-based instructional strategies affect the teaching of technical concepts in Building and Civil Engineering within Technical and Vocational Education and Training institutions. It focuses on four critical aspects: the types of AR applications employed, trainee engagement with AR, instructor competency in AR integration, and the frequency and extent of AR usage in the curriculum. These components collectively shape the effectiveness of AR in transforming conventional instructional strategies into more dynamic, trainee-centered approaches that foster academic achievement.

Most prior research on AR's impact has been conducted in technologically advanced environments and primarily in science, medical, or general engineering education (Ruhama et al., 2025; Sakr & Abdullah, 2024). There remains a lack of empirical evidence on how AR influences instructional strategies in resource-constrained TVET contexts, particularly in Sub-Saharan Africa. Moreover, few studies assess how

instructors adopt, adapt, and apply AR in real classroom settings, especially in construction-related disciplines. This study fills these gaps by exploring AR's practical integration into technical instruction in Building and Civil Engineering programmes in Nairobi County's TVET institutions, analyzing both instructor and trainee perspectives through mixed-methods research.

Different AR applications, from mobile-based overlays to fully immersive 3D simulations, are used to enhance technical concept instruction. However, there is limited analysis of which types are most suitable or effective in vocational education. Existing studies such as those by Tan et al. (2024) and Takrouri et al. (2022) have shown how interactive AR tools like reinforcement bar simulations or site modelling can bridge the gap between abstract theory and applied knowledge. Yet, these were not evaluated in the context of diploma-level construction education in Sub-Saharan Africa. This study addressed that gap by implementing AR tools specific to construction and civil engineering curricula and assessing their pedagogical effectiveness in practical training.

Trainee engagement is a crucial factor influencing the success of instructional strategies. Although AR has been reported to induce engagement in general education settings (Riniati et al., 2024; Suhail et al., 2024), limited studies investigate its impact in technical skills instruction, where cognitive engagement must be coupled with psychomotor practice. This study evaluates how AR-facilitated instruction affects trainee attention, motivation, and task persistence in applied construction tasks. Findings from prior research by Ruhama et al. (2025) emphasized that gamified AR tools foster engagement, yet those studies rarely covered structured lesson delivery in vocational education. By analyzing classroom interactions and AR usage logs, this study contributes localized evidence of AR's ability to foster instructional interactivity.

Another significant gap is the lack of research on instructors' readiness to incorporate AR into lesson planning and delivery. While scholars like Sahib et al. (2024) and Tahir & Abdullah (2023) stress the importance of digital pedagogy in TVET, few explore the challenges instructors face in integrating AR into content-heavy technical subjects. This study addresses this by evaluating instructor preparedness, highlighting challenges like inadequate training, limited content localization, and misalignment

between AR tools and curricular objectives. Through interviews and observation, it identifies both barriers and enablers of effective AR-based instructional strategies within Kenyan TVET institutions.

The impact of AR depends not only on its presence but on how frequently and meaningfully it is integrated into the curriculum. Prior studies such as those by Zhang et al. (2023) and Teplá et al. (2022) show that sporadic or superficial use of AR may yield limited gains. However, continuous integration from concept introduction to practical application can significantly enhance retention and skill development. Few studies, however, have examined this integration longitudinally or within the scope of building and civil engineering education. This research addresses this gap by tracking AR implementation across multiple instructional phases, comparing outcomes between high- and low-frequency AR use groups.

In summary, this study expands on the current literature by contextualizing AR-based instructional strategies within the realities of TVET delivery in Nairobi County. It addresses notable gaps concerning AR application types, trainee engagement mechanisms, instructor readiness, and the instructional integration timeline. By doing so, the study provides actionable insights into how AR can be harnessed to transform the teaching of technical concepts in building and civil engineering, ultimately aligning instruction with both pedagogical best practices and industry expectations.

2.4.3. Augmented Reality and Trainees' Retention of Complex Technical Content.

Retention of complex technical content is a major challenge in Building and Civil Engineering training, particularly in TVET institutions where trainees often struggle to grasp abstract principles and apply them practically. While international studies affirm that AR enhances conceptual understanding and memory retention, there is limited research within resource-constrained TVET settings in Sub-Saharan Africa. This study bridges that gap by analyzing AR's effectiveness in improving retention of both theoretical and practical content among diploma trainees in Kenya.

Most existing studies on AR and content retention are concentrated in medical, science, and engineering education in highly digitized environments (Williams et al., 2025; Scavarelli et al., 2021). They often overlook trainees in hands-on vocational

disciplines like civil engineering, where mastering both theory and practice is vital. Moreover, few studies evaluate retention in contexts where digital literacy and infrastructure are limited. This research addresses these limitations by investigating how AR supports content retention in a low-resource TVET environment using a combination of practical simulations, test scores, and qualitative feedback.

AR enables trainees to retain technical information more effectively by transforming abstract concepts into interactive 3D visualizations. Tan et al. (2024) demonstrated that AR tools help civil engineering trainees understand complex construction elements such as reinforcement layouts and structural sequencing by allowing them to visualize how parts connect and function in a real-world context. This aligns with findings by Zhang et al. (2023), who observed that AR facilitates better retention among trainees with varying prior knowledge by providing differentiated visualization pathways. This study evaluates how AR helps trainees retain intricate concepts like load distribution or site leveling, which are typically hard to grasp through static diagrams or textbooks.

Effective retention depends on how well trainees process information without cognitive overload. According to Sweller (1988), instructional design must manage working memory capacity during learning. AR supports this by presenting information spatially and sequentially, helping reduce extraneous load. Siricharoen (2023) emphasized that AR environments optimize learning by layering instructions and visual cues within immersive contexts, supporting memory encoding. This research builds on that by assessing whether AR-based instruction results in more accurate recall and concept application in formative and summative evaluations within TVET institutions.

AR-based learning environments provide opportunities for repeated interaction with technical content, enhancing long-term memory formation. Ruhama et al. (2025) showed that repeated simulations in AR environments improved both short- and long-term retention among vocational trainees. Similarly, Wen (2021) found that repeated exposure to AR activities encouraged pattern recognition and deeper cognitive processing. This study investigates how repeated engagement with AR tools (e.g.,

construction site simulations or interactive tutorials) leads to improved retention of engineering procedures and vocabulary among diploma trainees.

The effectiveness of AR for retention also hinges on its alignment with curriculum goals and teaching strategies. Sakr and Abdullah (2024) emphasized that AR must be pedagogically grounded to avoid distractions or fragmented learning. Studies have also warned against unstructured AR use, which may lead to cognitive dissonance and hinder content retention (Stanney et al., 2022). This study ensures pedagogical alignment by embedding AR within structured lessons on construction technology, measurement, and materials, allowing for assessment of how integration influences trainee recall, accuracy, and practical application.

In conclusion, AR enhances retention of complex technical content by enabling immersive visualizations, managing cognitive load, and supporting repeated, structured engagement. While previous research has demonstrated these benefits in other disciplines, this study contributes uniquely by evaluating them within a Kenyan TVET context, focusing on Building and Civil Engineering trainees. The findings offer practical insights on how AR can improve memory retention of both theoretical and procedural knowledge in resource-constrained environments, reinforcing the value of immersive technologies in vocational education.

2.4.4. Augmented Reality and Development of Trainees Self-Directed Learning

This empirical review evaluates the role AR in promoting self-directed learning (SDL) among trainees enrolled in Building and Civil Engineering diploma programmes in Technical and Vocational Education and Training TVET institutions. SDL is an essential competency in technical education, encompassing proactive engagement, goal-setting, time management, and strategic resource use. Despite the increasing integration of immersive learning technologies globally, limited research focuses on how AR supports SDL in practical, skills-based training environments, particularly in Sub-Saharan Africa. This study addresses that gap by examining AR's capacity to foster self-directed learning in resource-constrained TVET contexts.

Although international studies have demonstrated that AR enhances trainee autonomy and motivation, the majority focus on general education or higher education contexts (Scavarelli et al., 2021; Siricharoen, 2023). There is limited empirical work assessing

how AR cultivates SDL skills in technical fields where hands-on competence and conceptual clarity are equally important. Additionally, studies rarely evaluate how AR helps trainees manage their learning pathways independently in curriculum-intensive programmes such as civil engineering. This study fills these gaps by examining the application of AR in facilitating SDL among Kenyan TVET trainees, triangulating quantitative and qualitative data to provide comprehensive insights.

AR fosters trainee autonomy by enabling exploration, experimentation, and critical thinking in immersive environments. Ruhama et al. (2025) and Yilmaz (2021) assert that AR environments allow trainees to manipulate virtual models of structures and tools, encouraging self-initiated learning and cognitive engagement. In the context of civil engineering, this interactivity supports deeper understanding of complex concepts through visual and kinesthetic learning modes. This study builds upon that foundation by analyzing whether such autonomy is evident among diploma-level trainees using AR to learn practical construction tasks and theoretical principles.

Effective SDL requires trainees to manage their time and learning schedules independently. Prior research has indicated that AR tools can facilitate this process through visual timelines, interactive calendars, and real-time performance tracking (Teplá et al., 2022; Wang et al., 2025). However, few studies assess whether TVET trainees utilize these features in environments characterized by limited digital infrastructure. This study explores how AR contributes to time management skills by documenting trainee use of AR-integrated planners, session logs, and automated feedback tools during technical instruction.

AR has been associated with improved goal-setting and increased motivation, primarily through visual feedback and gamified progress indicators (Tan et al., 2024; Sakr & Abdullah, 2024). Nevertheless, these features have been mostly analyzed in general STEM education or computer science training, with little attention to their impact on vocational education. This research investigates how AR encourages goal-setting behaviours among trainees, enabling them to visualize milestones, assess their academic progress, and break down complex engineering tasks into manageable learning units.

Self-directed trainees must identify, access, and evaluate learning resources independently. In AR environments, resources such as 3D simulations, guided tutorials, and embedded videos can be accessed on demand, fostering resource autonomy (Suhail et al., 2024; Zhang et al., 2023). However, research has not adequately explored how resource access via AR affects independent learning in technical education settings. This study addresses this gap by assessing how trainees use AR to retrieve diverse instructional materials and collaborate through virtual learning platforms to enhance their practical and theoretical understanding.

In summary, this study extends the literature by contextualizing the role of AR in fostering self-directed learning within TVET institutions in Kenya. By exploring AR's influence on active learning, time management, goal-setting, and resource utilization, it provides new evidence on how immersive technology can develop autonomous learning behaviours among civil engineering trainees. Unlike earlier studies focused on digitally advanced learning settings, this study investigates SDL in real-world vocational environments with infrastructural and pedagogical constraints, offering practical recommendations for improving AR integration in similar contexts.

2.4.5 The Moderating Effect of Trainees' Prior Knowledge on the Relationship Between Augmented Reality and Academic Achievement.

While numerous studies have established that AR can improve learning outcomes, its effectiveness is not uniform across all trainees. Trainees' prior knowledge including digital proficiency, prior exposure to AR, preferred learning styles, and socioeconomic background plays a moderating role in shaping how effectively trainees engage with AR-based instruction. Despite the growing body of research, there remains limited evidence on how these moderating factors specifically influence academic achievement within TVET institutions in Sub-Saharan Africa, particularly in Building and Civil Engineering diploma programs. This study addresses that gap by empirically examining how these elements affect the impact of AR in resource-constrained Kenyan TVET settings.

The ability to engage effectively with AR applications often depends on a trainee's prior technical knowledge and familiarity with digital tools. Simonsmeier et al. (2022) emphasize that domain-specific prior knowledge significantly impacts learning

outcomes, particularly when integrating new technologies. In vocational contexts, trainees with foundational experience in simulations or digital learning platforms tend to navigate AR more efficiently, directing their cognitive resources toward learning content rather than mastering tool usage. Conversely, limited digital proficiency can create cognitive barriers, resulting in frustration, slower learning, or disengagement (Wang et al., 2023). This study investigates how digital readiness affects the relationship between AR instruction and academic achievement among Building and Civil Engineering trainees.

Trainees who have encountered AR in gaming, social media filters, or other non-academic settings are likely to adapt more quickly to educational AR environments. Zhang et al. (2023) found that trainees with different knowledge backgrounds interacted with AR differently, with prior exposure enhancing receptiveness, engagement, and eventual learning outcomes. This study builds on that insight by evaluating whether such exposure moderates the effect of AR on theoretical content mastery, problem-solving skills, and practical performance among diploma trainees in Nairobi's TVET institutions.

Learning preferences particularly among visual and kinesthetic trainees also influence how trainees respond to AR. AR's multimodal capabilities, such as manipulating 3D models and receiving tactile feedback, align well with experiential learning styles commonly found in technical education. Siricharoen (2023) emphasized that AR supports active, exploratory learning environments, which are especially beneficial for kinesthetic trainees who thrive on physical interaction. This study examines whether trainees with different learning preferences show varied academic achievement outcomes when taught using AR tools, contributing to the discussion on differentiated instruction in vocational education.

Socioeconomic disparities influence access to AR technologies, digital resources, and consistent internet connectivity, which in turn affect learning equity. Yeap et al. (2021) highlighted that socioeconomic barriers limited TVET trainees' ability to benefit from online and technology-enhanced education during the COVID-19 pandemic. Similarly, Zhang et al. (2023) found that trainees from more privileged backgrounds generally performed better when using AR, partly due to early exposure and access to

supporting infrastructure. This study addresses how socioeconomic context moderates AR's effectiveness in a public TVET environment, where trainees may have differing levels of access to digital tools and home learning support.

Trainees' prior knowledge including their digital skills, prior exposure to AR, learning preferences, and socioeconomic status moderates the impact of AR-based instruction on academic achievement. While global studies have affirmed the potential of AR in improving learning outcomes, few have accounted for how trainee diversity affects this relationship in under-resourced vocational settings. This study contributes new evidence by exploring these moderating factors within the specific context of Kenyan TVET institutions, enabling more informed and inclusive implementation of AR in Building and Civil Engineering training programs.

2.4.6. The Overall Impact of Augmented Reality on Academic Achievement

This empirical review explores the overall impact of AR on trainee academic achievement, focusing on three key indicators: cognitive, behavioural, and skill-based outcomes. While global research has acknowledged AR's potential to transform educational experiences, a significant gap exists in understanding how these outcomes manifest within under-resourced Technical and Vocational Education and Training institutions particularly in Sub-Saharan Africa. Most existing studies have concentrated on higher education or STEM disciplines in digitally advanced settings, with limited empirical evidence on AR's effectiveness in supporting practical, skill-oriented learning among diploma-level trainees in Building and Civil Engineering programs in Kenya. This study addresses that gap by examining how AR affects trainee achievement holistically in Nairobi's TVET institutions, where contextual challenges such as large class sizes, infrastructural limitations, and varying trainee preparedness prevail.

Cognitive indicators of academic achievement encompass attention, conceptual understanding, memory retention, and problem-solving ability. AR fosters cognitive development by transforming abstract content into visual, manipulable 3D representations that trainees can explore in real time. According to Simonsmeier et al. (2022), AR-supported learning improves mental processing and attention by reducing cognitive overload and enhancing content clarity. This is especially important in

technical subjects like civil engineering, where trainees must grasp spatially complex structures and abstract design principles. Studies by Suhail et al. (2024) and Wang et al. (2025) affirm that immersive AR environments facilitate deep cognitive engagement and improve retention by stimulating both visual and experiential memory pathways. However, most of these studies were conducted in highly digitized academic contexts. This research contributes new insights by assessing whether such cognitive benefits are transferable to TVET trainees in Nairobi County, many of whom have limited exposure to advanced learning technologies.

Behavioural indicators refer to trainee engagement, participation, and task completion. Globally, AR has been linked to improved trainee motivation, active participation, and self-regulation. According to Seyman Guray and Kismet (2023), gamified AR applications increase trainee persistence and focus by encouraging interaction with tasks through simulations, real-time feedback, and progress-tracking features. Similarly, Ruhama et al. (2025) observed that AR positively influences learning behaviour by reinforcing autonomy, collaboration, and sustained attention. However, these behavioural effects have not been adequately explored in vocational training contexts, where trainees often face competing demands and struggle with motivation due to perceived irrelevance of theoretical instruction. This study addresses the gap by evaluating how AR induces behavioural engagement in Building and Civil Engineering TVET programs, especially when instruction is aligned with real-world construction scenarios.

Skill-based academic achievement is particularly critical in technical fields and includes practical ability, technical problem-solving, and task execution. AR supports hands-on skill acquisition by allowing trainees to simulate real-world tasks such as assembling structural components or evaluating design plans without the need for costly physical prototypes. Research by Rotsios et al. (2022) and Scavarelli et al. (2021) emphasizes that AR enhances psychomotor development and spatial reasoning through repetitive practice and error correction in a virtual environment. Yet, few studies have measured whether such skill development translates into measurable academic achievement in TVET institutions, where training outcomes are evaluated both practically and theoretically. This study addresses that research gap by examining

how AR-based learning tools support practical competence and task mastery among civil engineering trainees.

In conclusion, AR has a multifaceted impact on trainee academic achievement by enhancing cognitive processing, encouraging active behavioural engagement, and promoting skill development. While international studies validate these outcomes, there is a lack of evidence on how AR performs under the constraints of TVET institutions in Sub-Saharan Africa. By focusing on Building and Civil Engineering programs in Nairobi County, this study evaluates whether AR's global promise holds true in local training contexts. The research aims to provide empirical data that can guide curriculum innovation, instructional design, and policy decisions toward the effective integration of AR in vocational education.

2.5 Research gaps

Although the integration of AR into education has been widely studied and its benefits for enhancing engagement, visualization, and motivation are well-documented, most of this literature remains context-specific and disproportionately focused on developed countries, STEM fields, or higher education. These studies, while affirming AR's potential, often overlook its applicability and limitations in more resource-constrained environments like Technical and Vocational Education and Training (TVET) institutions in Sub-Saharan Africa. In particular, limited attention has been given to Building and Civil Engineering diploma programs, where practical skill development, contextual learning, and industry relevance are central to academic success. Furthermore, while many studies confirm AR's short-term benefits, fewer delve into its long-term educational impact, scalability, or adaptability across diverse trainee populations and instructional contexts.

Regarding the first objective to assess the extent to which AR induces trainee engagement existing studies have shown that AR increases interest and participation, particularly in science and medical education (Garzón & Acevedo, 2020; Bacca et al., 2021). However, these findings are largely drawn from environments with strong digital infrastructure and prepared trainees. There is a gap in understanding how AR influences engagement in TVET settings where trainees may lack prior digital exposure and instructors may not be trained to use emerging technologies.

Specifically, the extent to which AR supports engagement in Building and Civil Engineering courses which require both theoretical understanding and practical field application has not been empirically tested in the Kenyan TVET context.

Concerning the second objective to examine how AR influences instructional strategies used in teaching technical concepts prior research has documented AR's ability to support visual and interactive learning (Fokides, 2021; Cheng et al., 2020), yet has failed to account for the readiness of instructors in TVET institutions to integrate such tools effectively. Most studies focus on trainee outcomes while neglecting the pedagogical shifts required for successful AR integration. There remains insufficient evidence on how trainer training, digital competence, and curriculum design affect the quality and consistency of AR-based instruction in vocational training. Moreover, the literature lacks clarity on which types of AR experiences (e.g., marker-based vs. location-based AR) are most appropriate for teaching specific technical concepts in construction and civil engineering.

The third objective to determine the effect of AR on the development of self-directed learning has received some attention in the context of trainee autonomy and technology-enhanced learning. Studies have demonstrated that AR supports exploratory learning, allowing trainees to navigate content independently (Seyman Guray & Kismet, 2023; Suhail et al., 2024). However, there is a gap in exploring how AR shapes self-regulation, time management, and goal-setting in vocational trainees, who may face unique learning constraints such as limited study time, hands-on learning preferences, and varied literacy levels. Research rarely explores how self-directed learning via AR is influenced by contextual factors in underfunded or overcrowded learning environments, as is common in many TVET institutions.

With regard to the fourth objective to analyze the role of AR in enhancing retention of complex technical content the existing body of work has primarily focused on AR's role in improving immediate understanding and short-term performance (Vidak et al., 2023; Korre & Sherlock, 2023). However, few studies examine whether these improvements persist over time, especially in fields that require both theoretical knowledge and long-term practical skill retention, such as civil engineering. The literature is also vague on how AR impacts different types of memory (e.g., procedural

vs. declarative) and whether retention is consistent across different AR modalities and trainee demographics.

Finally, in relation to the fifth objective to assess the moderating effect of trainees' prior knowledge on the relationship between AR and academic achievement very few studies have explored how prior digital exposure, technical background, or socioeconomic status influence trainees' ability to benefit from AR. Research by Liu et al. (2024) and Nguyen et al. (2021) has indicated that trainees with higher technological proficiency tend to derive greater benefits from AR tools. However, these studies rarely consider equity and inclusivity in the adoption of AR. There is a significant gap in understanding how diverse trainees including those with limited prior knowledge, disabilities, or language barriers respond to AR interventions in technical education. Furthermore, the literature is silent on how AR can be adapted to accommodate these differences in large, heterogeneous classroom settings typical of TVET institutions.

In conclusion, while the existing literature confirms AR's promise in enhancing education, it falls short of offering a comprehensive and contextualized understanding of its role in Building and Civil Engineering training within TVET institutions in Sub-Saharan Africa. This study aims to address these gaps by empirically evaluating AR's impact across multiple learning dimensions engagement, instructional strategy, self-directed learning, content retention, and academic performance while factoring in the moderating role of trainees' prior knowledge. In doing so, it contributes to a more equitable and context-sensitive implementation of AR in vocational training. The summary of empirical literature and research gaps is presented in Table 2.1.

Table 2.1: Summary of Empirical Literature and Research Gaps

Author & Year	Study Objective	Study Findings	Research Gap
Wang et al. (2025)	To investigate the effectiveness of AR-based modules in inducing trainee engagement in engineering education	AR integration increased trainee motivation and attentiveness during lessons	Limited empirical evidence on the influence of AR-based instruction on trainee engagement within Building and Civil Engineering diploma programmes in TVET institutions in Kenya
Rezai et al. (2025)	To evaluate the impact of immersive technologies on retention of technical concepts in higher education	AR tools improved trainees' ability to retain and recall complex technical content over time	Lack of context-specific studies on how AR influences retention of complex content among diploma trainees in the TVET sector
Riniati et al. (2024)	To assess how AR tools enhance instructional strategies in vocational training	AR enabled trainees to visualize and solve real-world problems more efficiently; enhanced interactive teaching	Insufficient research on the effect of AR on instructional strategies in TVET, especially in Building and Civil Engineering fields
Tarigan, H (2024)	To explore the overall academic performance outcomes of AR integration in technical learning environments	Significant improvements in test scores and practical performance were observed among trainees exposed to AR	Few comprehensive studies assess the combined effect of AR on theoretical content, practical skills, and summative academic performance in the Kenyan TVET context
Vaithianathan et al. (2024)	To explore moderating variables in AR-based instruction effectiveness	Prior knowledge, cognitive load, and digital literacy moderated AR effectiveness	A gap exists in understanding how trainees' prior knowledge moderates the relationship between AR-based instruction and academic achievement in technical diploma programmes

2.6 Chapter summary

This chapter provided a detailed review of the literature relevant to the study, focusing on the integration of Augmented Reality (AR) in education and its impact on instructional strategies, learner engagement, retention of complex technical content, and academic achievement. The chapter also explored the moderating role of prior knowledge in shaping these outcomes. It began with an examination of the theoretical foundations underpinning the study, followed by the development of a conceptual framework that guided the research. Empirical literature was reviewed to highlight key findings, methodological approaches, and gaps in previous studies. The chapter concluded by identifying the specific research gaps that this study seeks to address, thereby establishing the justification and relevance of the current investigation. The next chapter outlines the methodology employed to conduct the study.

CHAPTER THREE

RESEARCH METHODOLOGY

3.1 Introduction

This chapter presents the research methodology and includes the following: research design, experimental implementation process (trainer preparation, content coverage, and instructional alignment), area of study, target population, sample and sampling techniques, data collection instruments, summary of the measurement of research objectives, validity and reliability, data analysis procedures, and ethical considerations. The study was guided by six specific objectives: to assess the impact of augmented reality on learner engagement; to examine how augmented reality influences instructional strategies used in teaching technical concepts in building and civil engineering; to analyze the impact of augmented reality in enhancing trainees' retention of complex technical content; to evaluate the effectiveness of augmented reality in improving practical skills acquisition; to investigate the effect of augmented reality on summative examination performance; and to assess the overall impact of augmented reality on the academic achievement of trainees in building and civil engineering programmes in Nairobi's TVET institutions.

3.2 Research Design

This study was guided by a pragmatic research paradigm, which emphasizes practical, real-world problem-solving through the integration of both quantitative and qualitative forms of inquiry. Pragmatism permits methodological flexibility, enabling the use of diverse strategies to best address the research objectives (Creswell & Plano Clark, 2018). This worldview was particularly appropriate for the study, which sought to evaluate the impact of Augmented Reality on trainee engagement, instructional strategies, retention of complex technical content, self-directed learning, and overall academic achievement in Building and Civil Engineering diploma programmes within TVET institutions in Nairobi County. Additionally, the study examined the moderating effect of trainees' prior knowledge on the relationship between AR-based instruction and academic performance.

Ontologically, the study recognized that reality can be both singular and multiple. Objective measures such as academic performance scores and retention rates reflected

a common reality that could be quantitatively assessed across trainees, while trainees' and trainers' perceptions captured through interviews and open-ended questionnaires acknowledged subjective, experience-based realities. Epistemologically, the study adopted a stance that meaningful knowledge is best generated through the integration of empirical evidence and contextual understanding. Consequently, a mixed methods approach was used to combine measurable data with participant perspectives, thereby enabling both statistical validity and narrative richness.

In line with this philosophical grounding, the study employed a quasi-experimental mixed methods design using the Solomon Four-Group Experimental Design, a rigorous framework well-suited for intervention studies. This design consisted of four groups: Experimental Group 1 (E1) and Control Group 1 (C1), which received both pre-tests and post-tests; and Experimental Group 2 (E2) and Control Group 2 (C2), which only received post-tests. The experimental groups received AR-based instruction using the *AR ConcreteLab* mobile application, while control groups followed conventional lecture-based teaching methods. This structure allowed the researcher to test the causal effects of AR while controlling for testing effects and baseline group differences, thereby enhancing internal validity.

To ensure comparability, trainees were stratified based on performance in a Construction Materials continuous assessment test, then randomly assigned to the four groups. The Concrete Technology unit was selected for the intervention due to its abstract and technically complex content, making it ideal for evaluating the pedagogical effectiveness of AR. During the first term, all trainees received uniform lecture-based instruction guided by a standardized course outline and lesson plans aligned with the national TVET curriculum. In the second term, while control groups continued with traditional instruction, experimental groups transitioned to AR-enhanced learning using *AR ConcreteLab*, which offered interactive 3D simulations, marker-based holographic overlays, and guided animations to support concept visualization and comprehension.

The assessment process included standardized pre-tests (for E1 and C1), post-tests (for all groups), and summative evaluations administered under identical conditions to control for testing bias. Additional safeguards such as blind marking, the use of

standardized observation checklists, and clearly defined rubrics were implemented to minimize instructor bias and ensure objectivity. Qualitative data from open-ended questionnaires and trainer interviews further enriched the analysis by capturing perceptions, instructional experiences, and contextual challenges related to AR implementation.

In conclusion, the use of the Solomon Four-Group Experimental Design, grounded in a pragmatic philosophical orientation, provided a robust framework for investigating the multifaceted effects of AR on trainee academic performance in Building and Civil Engineering programmes. The design's integration of empirical measurement with context-specific insights ensured a comprehensive and credible evaluation of AR's role in enhancing technical education outcomes in TVET institutions.

3.3 Experimental Implementation Process

The successful execution of the experimental phase in this study relied on a carefully structured implementation process designed to maintain consistency, uphold instructional integrity, and align all learning activities with the study's objectives. The implementation phase unfolded across two academic terms and was guided by the Solomon Four-Group Experimental Design, with experimental and control groups exposed to distinct instructional modalities AR-based and traditional lecture methods, respectively. Several components were addressed systematically: trainer preparation, curriculum content selection, and instruction 5nal planning aligned with national TVET objectives and research goals.

3.3.1 Trainer Training and Orientation

Before the introduction of the Augmented Reality intervention, all participating trainers underwent a structured professional development program focused on AR integration in technical instruction. The training was designed to ensure that all instructors possessed the pedagogical and technical competencies necessary to deliver content consistently and effectively across the groups. Sessions included hands-on tutorials on how to use the *AR ConcreteLab* mobile application, which was central to the experimental group instruction. Trainers were also guided on best practices for managing technology-enhanced classrooms, troubleshooting AR tools, and supporting learners with varying levels of digital literacy.

Additionally, content alignment workshops were conducted to standardize lesson delivery and ensure that the AR content mapped accurately to the national Concrete Technology curriculum. These workshops emphasized the need for uniform instructional sequences, key concept coverage, and equitable assessment strategies across all participating institutions. The intention was to eliminate instructional bias and ensure that the only substantive difference between the control and experimental groups was the instructional medium (AR vs. traditional).

3.3.2 Concrete Technology Topics Covered

The selected intervention unit *Concrete Technology* was chosen due to its complexity and its integration of both theoretical and practical components, which made it suitable for evaluating the impact of AR on multiple learning domains. The following core topics were covered over the two academic terms:

i. Types and properties of concrete materials
ii. Concrete mix design principles
iii. Batching and mixing procedures
iv. Workability and slump testing
v. Setting, curing, and hardening processes
vi. Common defects in concrete and quality control measures

These topics are known to present conceptual and procedural challenges for diploma trainees, particularly when delivered solely through lecture-based instruction. As such, the use of AR tools in the experimental groups aimed to improve learners' ability to visualize, interact with, and retain abstract content.

3.3.3 Use of Lesson Plans and Course Outlines Aligned to Objectives

All instructional activities were guided by standardized lesson plans and course outlines derived from the official national TVET curriculum. These documents were critically reviewed and revised to align closely with the six research objectives of the study. Each week's lesson plan specified the topic to be covered, the intended learning outcomes, instructional methods (AR or traditional), and assessment activities.

In the experimental groups, the AR *ConcreteLab* app was embedded into the lesson sequence as a tool to supplement, simulate, or replace abstract content delivery. For

example, instead of verbally describing hydration processes, the AR app was used to project 3D visualizations that showed the chemical and structural changes occurring in concrete as it sets and cures. In contrast, the control groups relied on static diagrams and teacher explanations for the same content.

All groups were subjected to the same pacing, with consistent time allocations for theoretical instruction, review sessions, and practical activities (e.g., concrete mixing and slump tests). A one-hour review session was conducted at the start of the second term for all groups to reinforce key concepts. This was followed by a hands-on concrete mixing activity designed to help trainees bridge theoretical knowledge with practical application in real-life scenarios.

By aligning instructional content, trainer preparation, and lesson plans with the specific research objectives, the implementation process ensured fidelity to the experimental design. It also allowed for a fair, rigorous, and replicable comparison of outcomes across the four study groups. The level of detail and consistency maintained throughout this process was instrumental in validating the causal relationships being investigated and in producing credible findings on the impact of Augmented Reality in technical education.

3.4 Location of Study

The study was conducted in National Polytechnics, Technical Training Institutes, Vocational Colleges, and university-affiliated TVET institutions offering Building and Civil Engineering diploma programmes within Nairobi County. This region was purposively selected due to its high concentration of institutions over ten offering such programmes, making it a key hub for technical and vocational education in Kenya. The availability of diverse institutions within a compact geographical area provided a practical and efficient setting for comprehensive data collection aligned with the study's objectives, which focused on assessing the impact of Augmented Reality on trainee engagement, instructional strategies, content retention, self-directed learning, and academic achievement.

Nairobi County's institutional diversity, encompassing both public and private TVET institutions, enabled the examination of varied instructional practices and learning environments within a standardized curriculum framework. Since all TVET

institutions in Kenya operate under common guidelines provided by regulatory bodies such as TVETA and KICD, the selected sample reliably represents the national training landscape in Building and Civil Engineering diploma programmes.

While it is acknowledged that institutions in other counties may differ slightly in infrastructure, trainee demographics, or AR readiness, the core competencies, assessment benchmarks, and instructional goals remain consistent due to national curriculum guidelines. Therefore, although the study's geographic scope was limited to Nairobi County, its findings offer valuable insights that may cautiously inform AR integration strategies in similar TVET settings across Kenya. Nonetheless, broader future studies incorporating a more geographically diverse sample would enhance generalizability and external validity.

3.5 Target Population

According to Creswell and Creswell (2022), a target population refers to the entire group of individuals or entities that possess specific characteristics relevant to a research study and from which a sample is drawn. In this study, the target population comprised trainers and trainees in the Building and Civil Engineering departments of TVET institutions in Nairobi County. The target population of trainers and trainees in this category were 3,097. The distribution of the target population is presented in Table 3.1.

Table 3.1: Distribution of the target population

S. No.	TVET Institution	Population	Ratio of Trainers to Trainees	Trainers	Trainees
1.	Institution 1	520	1:50	1	510
2.	Institution 2	380	1:63	1	374
3.	Institution 3	175	1:44	1	171
4.	Institution 4	350	1:50	1	343
5.	Institution 5	330	1:30	1	319
6.	Institution 6	450	1:45	1	440
7.	Institution 7	525	1:42	1	512
8.	Institution 8	120	1:46	1	117
9.	Institution 9	180	1:38	1	175
10.	Institution 10	130	1:31	1	126

3.6 Sample and Sampling techniques

Sampling is the process of selecting a subset of individuals from a larger population to represent the whole (Lohr, 2021). The primary objective of sampling is to obtain a group that accurately reflects the characteristics of the target population. In this study, a combination of sampling techniques was employed to ensure that participants were appropriately aligned with the study's objectives. The sampling process was carried out in three stages: first, purposive sampling was used to identify TVET institutions relevant to the research; second, simple random sampling was applied to select participants within those institutions; and third, proportionate sampling was used to determine the number of participants drawn from each institution based on its population size.

3.6.1 Purposive sampling

Purposive sampling also referred to as judgmental or selective sampling is a non-probability sampling method in which cases are deliberately selected based on their relevance to the research objectives (Rahman, 2023; Kumar et al., 2023). Unlike probability sampling, the goal of purposive sampling is not to generalize findings to a wider population but to obtain rich, context-specific insights from strategically chosen units. This approach is particularly effective when studying complex educational phenomena that require in-depth understanding from information-rich settings.

In this study, purposive sampling was applied at two levels: the selection of institutions and the selection of trainers. First, from the thirty TVET institutions in Kenya offering diploma programmes in Building and Civil Engineering, ten institutions located within Nairobi County were purposefully selected. Nairobi was chosen as the study location due to its high concentration of relevant institutions, diversity of trainee demographics, greater likelihood of resource availability for AR integration, and its logistical accessibility for the researcher. These factors made it an ideal setting for exploring the integration and impact of AR in TVET programmes.

Secondly, within the selected institutions, ten trainers one from each institution were also selected purposively. These trainers were all subject teachers of Construction Technology, the course unit chosen for the intervention due to its rich combination of complex technical content and practical application. Each trainer was responsible for delivering both the traditional and AR-based instruction in their respective institutions.

To minimize instructional variability and ensure consistent delivery across sites, all ten trainers underwent standardized training sessions prior to the intervention. These sessions prepared them to competently integrate AR into their teaching practice and use it effectively during the experimental phase.

Although purposive sampling was used to select institutions and trainers, probability-based sampling techniques were applied when selecting trainee participants, ensuring methodological rigor and representativeness within the quantitative components of the study. This combination of purposive and probability sampling methods aligned well with the study's mixed methods and experimental design, allowing for both contextual depth and statistical reliability.

In summary, purposive sampling was justified for selecting both the institutions and the 10 trainers due to their critical role in providing relevant, experience-based insights into AR integration in technical education. This approach ensured the collection of meaningful qualitative data while preserving the overall methodological soundness of the research.

3.6.2 Simple Random sampling

This stage of the sampling process was undertaken after clearly identifying the target population of trainees, specifically those enrolled in Building and Civil Engineering diploma programmes within TVET institutions. To enhance the representativeness of the sample and uphold the principles of objectivity, the researcher employed simple random sampling, a probability-based technique where every individual in the defined population has an equal and independent chance of being selected (Pandey & Pandey, 2021). This method was chosen for its effectiveness in minimizing selection bias and ensuring that the sample accurately reflects the characteristics of the broader trainee population.

The use of simple random sampling was particularly suitable for the quantitative component of the study, where generalizability of findings was essential for assessing the impact of AR on academic achievement. Trainees were selected from the population lists obtained from each participating institution, and randomization was carried out using a computerized method to ensure fairness and randomness in the selection process.

To determine the appropriate sample size from this finite population, the researcher applied Yamane's (1967) formula, which is a widely accepted statistical formula in social science research. The formula considers the total population size, desired confidence level, and acceptable margin of error. In this study, a 95% confidence level and a 5% margin of error were adopted, which are standard benchmarks in educational research for ensuring statistical reliability. This process ensured that the sample size was both statistically sufficient and manageable for the research design, ultimately enhancing the validity of the study's findings.

Equation 3.1: Yamane's formula

$$n = \frac{N}{1+N(e)^2}$$

Where:

n= Sample Size

N=Population

e=Margin of error

Basing on the number of 3,087 Trainees

Trainees sample size

$$n = \frac{3{,}087}{1+3{,}087(0.05)^2}$$

n= 354 Trainee respondents.

Therefore, using the above formulae, the sample size was 354 respondents for trainees were selected randomly from ten purposively chosen TVET institutions in Nairobi County. Each individual was assigned a unique identification number, and participants were selected using a random number generator to ensure fairness and impartiality.

Strata were then calculated and the following stratified samples obtained as shown in the sample frame in Table 3.2.

Table 3.2: Distribution of target population per institution and strata sample size

S No.	TVET INSTITUTION	TOTAL POPULATION	TRAINERS POPULATION	TRAINEE POPULATION
1.	Institution 1	520	1	510
2.	Institution 2	380	1	374
3.	Institution 3	175	1	171
4.	Institution 4	350	1	343
5.	Institution 5	330	1	319
6.	Institution 6	450	1	440
7.	Institution 7	525	1	512
8.	Institution 8	120	1	117
9.	Institution 9	180	1	175
10.	Institution 10	130	1	126

3.6.3 Proportionate Stratified Sampling

In this study, proportionate stratified sampling was employed to select trainees from ten TVET institutions in Nairobi County that offer diploma programmes in Building and Civil Engineering. This method was chosen to enhance the representativeness and precision of the sample by accounting for variations in trainee population sizes across the institutions. The total number of trainees across the selected institutions was 3,087, and a sample size of 354 trainees was determined using Yamane's (1967) formula, applying a 95% confidence level and a 5% margin of error to ensure statistical adequacy and generalizability.

To implement the proportionate stratified sampling procedure, the population was first divided into ten strata each stratum representing a single TVET institution. The number of trainees selected from each institution was then calculated proportionally to the size of its total trainee population relative to the overall population. For instance, institutions with higher enrolment contributed a larger number of respondents, while those with fewer trainees contributed fewer participants. This approach ensured equitable representation from all institutions while maintaining population proportionality, thereby reducing sampling bias and improving the overall validity and reliability of the findings.

The proportion of trainees in each institution relative to the total population was calculated using the equation 3.2

Equation 3.2: Proportionate Stratified Sampling Formula

$n_i = (\frac{Ni}{N})$ X n

Where:

i. n_i = Sample size for a specific institution
ii. N_i = Population size of the institution
iii. N = Total trainee population (3,087)
iv. n = Total sample size (354)

The distribution of trainee's target population per institution and strata sample size for respondents is shown in the Table 3.3.

Table 3.3: Distribution of trainee's target population per institution and strata sample size for respondents

S NO.	Tvet Institution	Trainee Population	Percentage Population (%)	Sample	Control Group	Experimental Group
1.	Institution 1	510	16.52	58	29	29
2.	Institution 2	374	12.12	43	22	21
3.	Institution 3	171	5.54	20	10	10
4.	Institution 4	343	11.11	39	19	20
5.	Institution 5	319	10.33	37	19	18
6.	Institution 6	440	14.25	50	25	25
7.	Institution 7	512	16.59	59	29	30
8.	Institution 8	117	3.79	13	7	6
9.	Institution 9	175	5.67	20	10	10
10.	Institution 10	126	4.08	14	7	7
		3087	100	354	177	177

Since the Solomon Four-Group Design involves four groups that is Control Group 1, Experimental Group 1, Control Group 2, and Experimental Group 2 the sample distribution for these groups is presented in the Table 3.4.

Table 3.4: Sample distribution for the four groups

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

Participants were distributed across ten institutions as shown in the Table 3.5.

Table 3.5: Participants distribution across ten TVET institutions

S No.	TVET Institution	Total Sample	E1	C1	E2	C2
1.	Institution 1	58	15	14	15	14
2.	Institution 2	43	11	11	11	10
3.	Institution 3	20	5	5	5	5
4.	Institution 4	39	10	10	10	9
5.	Institution 5	37	9	9	10	9
6.	Institution 6	50	13	12	13	12
7.	Institution 7	59	15	15	15	14
8.	Institution 8	13	3	3	4	3
9.	Institution 9	20	5	5	5	5
10.	Institution 10	14	4	4	4	4
		354	88	88	89	89

The grouping and sample sizes shown in the table were determined based on actual enrolment figures to ensure balanced representation across all institutions. For instance, the smaller sample size at Institution 8 reflects its actual number of eligible participants, accurately representing enrolment differences. The sample was stratified using past academic achievement data to systematically balance each group, reducing bias in comparisons across institutions. All institutions were included in the study, even those with smaller samples like Institution 8, as well as those with larger samples such as Institution 7. This comprehensive inclusion was necessary to capture the diversity and unique educational environments within Nairobi County's TVET

institutions. This sampling approach strengthens data integrity and provides a reliable foundation for measuring and comparing learning outcomes.

3.7 Data Collection Instruments

The study utilized multiple instruments to collect data on the impact of AR on various aspects of academic performance among Building and Civil Engineering trainees in TVET institutions. These included trainee questionnaires, trainer interviews, pre- and post-tests, and summative examination results. Each tool was selected to capture specific outcomes such as trainee engagement, instructional strategies, retention, self-directed learning, and overall academic achievement. This mixed-methods approach allowed for comprehensive data collection and triangulation of findings to ensure reliability and depth of insight.

3.7.1 Questionnaire

A questionnaire is a widely used research instrument designed to collect both qualitative and quantitative data from respondents through a series of structured and semi-structured questions (Aithal & Aithal, 2020). In this study, a comprehensive questionnaire (Appendix II) was administered exclusively to the experimental group (n = 173) at the end of the second term of the 2024 TVET academic year to evaluate all six specific research objectives. The tool included both closed-ended questions, primarily using a five-point Likert scale to facilitate statistical analysis, and open-ended questions to allow trainees to express their personal views and elaborate on their learning experiences.

The questionnaire was structured into distinct sections corresponding to the revised objectives: Section A captured trainees' demographic information; Section B assessed how Augmented Reality induced trainee engagement; Section C evaluated AR's influence on instructional strategies used to teach technical concepts; Section D examined AR's impact on the retention of complex technical content; Section E explored the role of AR in developing self-directed learning among trainees; Section F captured data related to the moderating effect of prior knowledge; and Section G assessed the overall impact of AR on academic achievement. By focusing on trainees who interacted with AR tools, the instrument provided insights into their perceptions of how AR affected their engagement, instructional experiences, conceptual

understanding, and academic performance. The targeted design of the questionnaire ensured that data collected directly addressed the study's objectives, strengthening the reliability, validity, and relevance of the findings within the context of Building and Civil Engineering diploma programmes in Nairobi's TVET institutions.

3.7.2 Interview

Semi-structured interviews combine structured guiding questions with flexibility to explore emerging ideas, enabling researchers to collect rich, in-depth insights into participants' experiences while maintaining consistency across interviews (Creswell & Creswell, 2022). In this study, interviews (Appendix III) were conducted with ten Construction Technology trainers' subject specialists from the selected TVET institutions at the end of the second term of the 2024 academic year. This timing allowed trainers to provide informed reflections on the integration of AR in Building and Civil Engineering diploma programmes, having observed its impact throughout the instructional period (Sharmila, 2024). All interviews were audio-recorded with participant consent and transcribed verbatim. The data was analyzed thematically, beginning with open coding to identify recurring patterns related to AR's influence on instructional strategies, trainee engagement, content retention, self-directed learning, and academic performance. Since the number of trainers across the sampled institutions was limited and all ten were interviewed, the issue of data saturation did not arise. Instead, comprehensive representation was achieved by incorporating the full population of trainers involved in AR-based instruction. The resulting themes were refined and interpreted in relation to existing research (Affandi et al., 2024; Ziden et al., 2022; Farraj & Reiner, 2024), offering valuable perspectives that validated the role of AR in enhancing technical education in TVET settings.

3.7.3 Pre-Test and Post-Test

This subsection outlines the experimental design and procedures employed to evaluate the impact of AR on trainees' retention of complex technical content within the Concrete Technology unit of the Building and Civil Engineering diploma programmes in TVET institutions in Nairobi County. The study adopted the Solomon Four-Group Experimental Design, a rigorous quasi-experimental framework that integrates both pre-test and post-test assessments (see Appendices VI, VII, VIII, and IX) to objectively measure learning gains and isolate the effects of AR-based instruction

(Alnajim et al., 2023). The design included four groups: Experimental Group 1 (E1), Experimental Group 2 (E2), Control Group 1 (C1), and Control Group 2 (C2), ensuring control over testing effects and allowing unbiased comparisons across conditions.

To ensure transparency and eliminate potential bias, baseline knowledge was first established through a standardized Concrete Technology pre-test (Appendix VI and VII), administered to E1 and C1 at the beginning of the first term of the 2024 TVET academic year. The test covered critical content areas such as concrete properties, batching, mixing, workability, and curing and was derived from the national TVET curriculum. The test items were validated by subject matter experts to ensure curriculum alignment, content accuracy, and industrial relevance (Affandi et al., 2024). The use of identical pre- and post-tests across groups ensured consistency in measurement. All data were collected under standardized conditions, with strict adherence to uniform administration protocols to maintain objectivity and guard against performance distortions due to varied instructional exposure.

During the first term, all trainees received lecture-based instruction to establish a uniform theoretical foundation across all four groups. In the second term, instructional differentiation was introduced: the experimental groups (E1 and E2) received AR-enhanced instruction, while the control groups (C1 and C2) continued with conventional teaching methods. The AR-enhanced sessions utilized the *AR ConcreteLab* application a custom-developed AR tool designed for mobile devices and tablets running on Android OS. This application was developed in collaboration with instructional designers and Building and Civil Engineering instructors to align directly with the Concrete Technology curriculum used in Kenyan TVET institutions.

AR ConcreteLab provided immersive, interactive 3D simulations of concrete mixing processes, batching sequences, curing stages, and real-time demonstrations of how variables such as water-cement ratio, aggregate size, and environmental conditions affect workability and strength development. Through the app, trainees could use their device's camera to scan printed markers or QR codes embedded in learning materials, triggering life-sized holographic overlays of virtual concrete mixers, slump tests, and curing chambers on classroom surfaces. These holograms were manipulated in real-

time rotated, paused, zoomed, or reset allowing trainees to visualize internal processes like hydration, heat of reaction, and micro-crack formation, which are often difficult to observe in physical lab conditions.

The simulations were structured to reflect weekly instructional topics and included short assessment quizzes embedded within the app to reinforce learning. Trainers were oriented on how to integrate the AR tool into lesson delivery through tablets connected to classroom projectors, ensuring that all trainees had a shared visual experience. In cases where individual access to devices was possible, trainees interacted with the tool in small groups during guided sessions.

To maintain instructional fairness, all groups received a uniform one-hour review lecture at the beginning of the second term, focusing on core concepts such as batching, mixing, and curing. A practical concrete mixing session followed, allowing trainees to apply their learning in a physical setting and link theoretical knowledge with real-world application (Williams et al., 2025). At the end of the second term, the post-test (Appendix VI, VII, VIII and IX), which was structurally identical to the pre-test, was administered to all four groups under the same controlled conditions. By clearly distinguishing the instructional modalities and using a validated, curriculum-aligned AR tool, the study ensured clarity and integrity in its evaluation of learning outcomes. This approach provided a reliable comparison of the effectiveness of AR-based instruction versus traditional methods, supporting the study's internal validity and broader applicability (Ziden et al., 2022; Creswell & Creswell, 2022).

3.7.4 Summative Examination Results

Prior to the administration of the summative examination at the end of the 2024 TVET academic year, trainees participated in a structured instructional process that spanned two academic terms. During the first term, all four groups Experimental Group 1 (E1), Experimental Group 2 (E2), Control Group 1 (C1), and Control Group 2 (C2) received traditional lecture-based instruction aimed at establishing foundational knowledge in the Concrete Technology unit. This phase covered key curriculum topics such as concrete properties, hydration processes, strength development, durability, and batching methods, ensuring a uniform baseline for all participants.

In the second term, the instructional approach was differentiated according to group assignment. While the control groups (C1 and C2) continued with traditional teaching methods, the experimental groups (E1 and E2) transitioned to AR-based instruction. This method utilized immersive 3D simulations, interactive digital overlays, and real-time virtual demonstrations to enhance trainee understanding of complex technical content and improve cognitive engagement (Sharmila, 2024). All instruction was facilitated by subject lecturers in both classroom and workshop settings, adhering to the standardized TVET curriculum and industry benchmarks.

At the conclusion of the instructional period, a criterion-referenced summative examination was administered across all study groups to evaluate overall academic achievement. The examination was conducted under controlled, standardized conditions at designated TVET assessment centres, with strict supervision by course instructors to maintain academic integrity. Developed collaboratively by trainers from the participating institutions, the assessment was aligned with national TVET standards and designed to test a broad range of competencies including conceptual understanding, applied knowledge, and technical problem-solving abilities (Affandi et al., 2024).

The summative examination scores (see Appendices VI, VII, VIII, and IX) served as the primary quantitative measure of academic achievement in this study. These results were used to compare the performance of trainees who received AR-enhanced instruction against those who were taught using traditional methods. This comparison was critical for determining the effectiveness of AR in improving learning outcomes and addressing the study's general objective: to investigate the overall impact of augmented reality on academic performance in Building and Civil Engineering diploma programmes within Nairobi's TVET institutions.

3.7.5 Procedure for Data Collection

The data collection process was carried out over two academic terms of the 2024 TVET academic year, following a structured and systematic timeline to evaluate the impact of AR on academic achievement in Building and Civil Engineering diploma programmes. The process commenced with the administration of a pre-test (Appendix VI and VII) at the beginning of the first term for Experimental Group 1 (E1) and

Control Group 1 (C1), aimed at establishing baseline knowledge and assessing the trainees' initial academic preparedness prior to the instructional intervention (Creswell & Creswell, 2022).

Instructional activities then spanned two full terms. During this period, the control groups (C1 and C2) continued with traditional lecture-based instruction using conventional methods such as textbooks, chalk-and-talk, and verbal explanations. In contrast, the experimental groups (E1 and E2) received AR-based instruction during the second term, which included interactive 3D simulations, immersive virtual models, and real-time visualizations of key concepts in the Concrete Technology unit. These tools were designed to induce engagement, understanding of complex technical content, and retention (Brown et al., 2022; Hontarenko & Kovalenko, 2024).

At the end of the instructional phase, a post-test (Appendix VI) was administered to all four groups to assess academic gains and compare the outcomes of AR-based instruction with traditional teaching methods. The resulting post-test data (Appendices VII, VIII, IX, and X) provided quantitative insights into the instructional effectiveness of AR-enhanced learning (Hung et al., 2023).

To complement the test results, a structured questionnaire (Appendix II) was administered to all trainees in the experimental groups (n = 173) at the end of the second term. This instrument consisted of both closed-ended (Likert-scale) and open-ended questions designed to gather data related to trainee engagement, instructional experiences, retention of complex content, self-directed learning, and overall academic performance. The questionnaire was divided into sections corresponding to the study's six specific objectives, ensuring comprehensive coverage of all key variables.

In addition to trainee questionnaires, semi-structured interviews (Appendix III) were conducted with ten trainers who participated in the study. These trainers, all subject specialists in Construction Technology, had been trained on the use of AR prior to implementation. The interviews captured their reflections on the integration of AR, its influence on instructional delivery, trainee engagement, and observed learning outcomes. All interviews were transcribed and analyzed thematically to identify patterns and validate findings from the quantitative data.

Finally, summative examination results (Appendices VII, VIII, IX, and X) were collected at the end of the academic year. These results served as the formal assessment of overall academic achievement and were benchmarked against national TVET standards. Conducted under standardized conditions, the exams evaluated trainees' comprehension, knowledge application, and problem-solving capabilities, providing a reliable metric to compare the performance of AR-exposed trainees with those in the control groups.

By integrating pre-test and post-test assessments, questionnaires, trainer interviews, and summative examination results, the study employed a robust and comprehensive data collection strategy. This approach enabled the triangulation of findings across multiple instruments, ensuring valid, credible, and objective evaluation of AR's impact on academic achievement, engagement, retention, instructional strategies, self-directed learning, and the moderating role of trainees' prior knowledge within TVET institutions in Nairobi County.

3.8 Summary of Measurement of Research Objectives

This study employed a mixed-methods assessment strategy to evaluate the impact of AR on various dimensions of academic achievement among trainees in Building and Civil Engineering diploma programmes within TVET institutions in Nairobi County. The study addressed seven research objectives, namely: (1) to assess the extent to which AR induces trainee engagement; (2) to examine how AR influences instructional strategies; (3) to analyze the role of AR in enhancing retention of complex technical content; (4) to evaluate the overall impact of AR on academic achievement; (5) to assess the moderating effect of trainees' prior knowledge; (6) to examine the effect of AR on self-directed learning; and (7) to explore how AR supports problem-solving skills. Data were collected through pre- and post-tests, summative examination results, structured questionnaires, and semi-structured interviews.

3.8.1 Impact of Augmented Reality and trainee engagement

To measure trainee engagement, a structured questionnaire (Appendix II) was administered to capture behavioural, emotional, and cognitive components of engagement. The instrument included Likert-scale items designed to quantitatively assess indicators such as attentiveness, curiosity, motivation, and active participation

during AR-based instructional sessions. These elements were chosen because they reflect critical dimensions of learner engagement, which is a key predictor of academic success in technical education. The inclusion of open-ended questions further allowed trainees to provide contextualized reflections on their experiences, offering qualitative depth to the quantitative findings.

To complement trainee self-reports, semi-structured interviews with trainers (Appendix III) were conducted to gather observational insights into learner engagement as exhibited in both classroom and workshop environments. These interviews explored trainers' perceptions of changes in trainee behaviour, interaction levels, and attention during AR-based lessons compared to traditional instruction. This dual-source approach combining trainee feedback and trainer observations ensured triangulation of data, strengthened the validity of the engagement construct, and provided a more holistic understanding of how AR influences learner engagement in Building and Civil Engineering diploma programmes.

3.8.2 Impact of Augmented Reality and instructional strategies

To evaluate the impact of Augmented Reality on instructional strategies, data were collected from both trainers and trainees to ensure comprehensive analysis. trainee perceptions were captured through structured questionnaires (Appendix II), which included Likert-scale and open-ended items assessing their experiences with AR-supported instructional methods. Respondents provided feedback on the clarity of instruction, pacing, accessibility of content, and the nature of instructional support during AR-based lessons.

In addition, Semi-structured trainer interviews (Appendix III) were conducted to explore how instructors integrated AR into their teaching practice. Specifically, the interviews examined how AR influenced the delivery and sequencing of content, promoted learner interaction, and supported the scaffolding of complex concepts. These aspects are critical in understanding whether AR enhances pedagogical effectiveness in technical instruction.

The combination of trainer interviews and trainee responses ensured that both instructional intent and learner experience were accounted for. This dual approach is justified as it strengthens the validity of the findings, offers triangulated perspectives

on pedagogical practices, and allows for a deeper understanding of how AR transforms the instructional process in Building and Civil Engineering training.

3.8.3 Impact of Augmented Reality and enhancing retention of complex technical content

To assess the retention of complex technical content, the study employed both quantitative and qualitative methods. Pre-test and post-test scores (Appendices VI, VII, VIII and IX) were compared between the experimental and control groups to measure learning gains attributable to the instructional method. These standardized assessments focused on key concepts within the Concrete Technology unit and provided objective evidence of knowledge acquisition and retention over the instructional period. This comparative analysis allowed the researcher to evaluate the extent to which AR-based instruction contributed to improved content retention relative to traditional methods.

In addition to test scores, trainee questionnaires (Appendix II) included items designed to capture learners' self-reported ability to recall, apply, and relate technical concepts over time. These responses offered valuable insights into perceived retention beyond formal testing conditions. To further validate these findings, trainer interviews (Appendix III) were used to gather reflections on whether trainees demonstrated long-term retention during practical tasks, classroom discussions, and assessments. The integration of test data, trainee self-assessments, and trainer observations ensured a robust and multidimensional evaluation of content retention, aligning with the study's objective of assessing AR's effectiveness in supporting lasting understanding of technical material.

3.8.4 Impact of Augmented Reality and self-directed learning

To assess the impact of AR on self-directed learning, data were collected primarily through trainee questionnaires (Appendix II), which included items measuring key indicators such as independent exploration, goal-setting, time management, and learner initiative. The questions were designed to determine whether AR tools motivated trainees to engage with learning content beyond the classroom, take ownership of their progress, and develop habits associated with autonomous learning. These aspects are critical in vocational education, where learners are expected to

develop both theoretical understanding and practical competence through continuous self-driven learning.

To complement the trainee perspective, trainer interviews (Appendix III) were conducted to gather observational insights into behavioural changes linked to self-directed learning. Trainers were asked to reflect on whether trainees using AR demonstrated increased initiative, asked more analytical or exploratory questions, or sought out additional resources beyond scheduled instruction. The use of both self-reported data and trainer observations enabled a triangulated assessment of self-directed learning, enhancing the credibility of the findings. This approach is justified as it captures both the internal motivation of learners and externally observable behaviours, providing a comprehensive view of AR's role in promoting learner autonomy.

3.8.5 To assess the moderating effect of trainees' prior knowledge on the relationship between AR and academic achievement

To assess the moderating effect of trainees' prior knowledge on the relationship between Augmented Reality and academic achievement, the study employed both quantitative and qualitative methods. Pre-test scores (Appendix VI and VII) were used to establish baseline knowledge levels for Experimental Group 1 (E1) and Control Group 1 (C1). These scores served as a reference point for statistical comparisons with post-test and final examination results, allowing the researcher to determine whether trainees with higher or lower initial knowledge demonstrated different learning gains when exposed to AR-based instruction. This analysis was essential for evaluating whether prior knowledge influenced the effectiveness of AR as an instructional tool.

In addition, trainee questionnaires (Appendix II) included items on self-perceived academic preparedness and digital literacy. These variables were relevant for understanding how prior knowledge both in terms of content mastery and technological familiarity shaped learners' ability to engage with and benefit from AR-enhanced lessons. Trainer interviews (Appendix III) further enriched the analysis by capturing instructors' perspectives on how differences in trainees' initial understanding affected their adaptability, confidence, and performance during AR-facilitated instruction. The combination of test data, trainee self-assessments, and

trainer reflections enabled a nuanced exploration of how prior knowledge moderated the learning outcomes, thus supporting a deeper interpretation of AR's pedagogical value across diverse learner profiles.

3.8.6 To evaluate the overall impact of Augmented Reality and academic achievement

To evaluate the overall impact of AR on academic achievement, summative examination scores (Appendices VI, VII, VIII and IX) were analyzed across all study groups. These scores provided an objective measure of cumulative learning outcomes in the Concrete Technology unit, reflecting trainees' mastery of both theoretical and practical aspects of the subject. Statistical comparisons between the experimental and control groups were used to determine whether AR-based instruction resulted in significantly higher academic performance.

In addition to objective test data, trainee perceptions were collected through structured questionnaires (Appendix II), which included items assessing how AR influenced their understanding of content, learning confidence, and overall performance. These self-reports offered insight into learners' internal experiences and perceived benefits of the AR-enhanced instruction. Trainer interviews (Appendix IV) complemented this by providing reflective analysis on observed improvements in trainee performance, engagement with assessment tasks, and mastery of core technical competencies. The integration of examination data, learner perceptions, and instructor observations enabled a comprehensive assessment of AR's effectiveness in enhancing academic achievement within Building and Civil Engineering programmes.

3.9 Validity and Reliability

To enhance the validity and reliability of the research instruments, a pilot study was conducted prior to the main data collection phase. The pilot aimed to evaluate the clarity, relevance, and functionality of the data collection tools, including the trainee questionnaire (Appendix II) and semi-structured interview guide for trainers (Appendix III).

The pilot study was carried out at Kandara Technical and Vocational College, which was not part of the institutions selected for the main study. This site was chosen for its similar training structure and academic environment to those of the participating

institutions, ensuring contextual relevance while avoiding contamination of the final sample.

A total of 10 respondents were selected for the pilot study, consisting of 8 trainees and 2 trainers. This sample size was considered sufficient for identifying ambiguities, assessing usability of the instruments, and detecting technical issues, particularly those related to the use of AR in instructional delivery (Gharbi, 2021). The trainees and trainers were selected through purposive sampling to ensure they had relevant exposure to AR tools and Building and Civil Engineering course content.

During the pilot, the instruments were administered in the same manner as planned for the main study. The questionnaire was assessed for question clarity, logical flow, and response completeness. Feedback from the trainees indicated the need to simplify certain technical terms and rephrase complex items. Trainer interviews were also piloted to evaluate the flow of questions, timing, and flexibility of probing strategies.

Based on the pilot findings, three questionnaire items were rephrased to enhance clarity and ensure that respondents could interpret them consistently. Additionally, the instructions for AR-based tasks were refined to remove any ambiguous language and to make the procedures easier for trainees to follow and understand.

To assess internal consistency, Cronbach's alpha was calculated for the questionnaire's Likert-scale items, yielding a reliability coefficient of 0.81, which is considered acceptable for social science research (Creswell and Creswell, 2022).

In addition, the questionnaire administrator received training on how to provide neutral clarifications and rephrase items if trainees experienced difficulty during the process. This step ensured standardization in data collection and minimized interviewer bias.

Importantly, participants in the pilot study were excluded from the main research sample to maintain objectivity and avoid any bias that may result from prior exposure to the instruments.

In summary, the pilot study played a critical role in refining the research design and enhancing the credibility of the study instruments. This iterative process of testing and

revision ensured that the tools used in the main study were both reliable and valid for capturing data on the use of AR in Building and Civil Engineering diploma programmes (Seyman, and Kismet, 2023).

3.9.1 Validity of Research Instruments

Validity refers to the degree to which a research study accurately measures what it is intended to measure, ensuring that the findings genuinely reflect the phenomenon under investigation (Saunders et al., 2016). In this study, validity ensures that the research instruments effectively and reliably assess the impact of Augmented Reality (AR) on key learning outcomes, including trainee engagement, instructional strategies, retention of complex content, self-directed learning, overall academic achievement, and the moderating role of prior knowledge. This guarantees that the tools used in data collection captured the actual influence of AR-based instruction without interference from unrelated variables such as digital familiarity or personal biases.

To achieve this, a multi-layered validation process was undertaken to ensure the instruments' alignment with the study's general objective to investigate the impact of AR on academic performance among Building and Civil Engineering trainees in TVET institutions in Nairobi County and its six specific objectives. These objectives focused on evaluating AR's influence on learner engagement, instructional strategies, retention, self-directed learning, prior knowledge moderation, and overall academic performance.

The validation process included expert review, alignment with educational frameworks, and pilot testing. Research instruments such as questionnaires, achievement assessments, and skills evaluation tools were reviewed by specialists in AR-based learning, engineering education, and TVET curriculum development. Their input helped ensure that the instruments were relevant, comprehensive, and free from ambiguity, thus enhancing the accuracy with which each construct was measured.

Moreover, instruments were benchmarked against national TVET curriculum standards, existing AR-related educational models, and standardized academic performance measures. A pilot study conducted at one TVET institution helped refine the tools by testing clarity, language suitability, reliability, and objectivity. This

process ensured that each instrument reliably captured the intended outcomes without introducing measurement bias or misinterpretation.

The study focused on three types of validity: content validity, construct validity, and criterion validity, as discussed below.

3.9.1.1 Content Validity

Content validity was established through expert judgment to ensure that the instruments comprehensively represented the intended learning constructs. Given the study's focus on assessing AR's impact across a wide range of educational outcomes including engagement, instructional strategies, retention, self-directed learning, academic achievement, and prior knowledge input from AR education specialists, TVET curriculum developers, and engineering lecturers was sought.

Experts reviewed the questionnaires and assessment tools to evaluate their alignment with each specific objective and ensure that all critical domains of trainee learning were adequately represented. Feedback led to multiple revisions to improve item clarity, eliminate redundancy, and enhance the relevance of each question. The validation process ensured that instruments were well-targeted, representative, and structured to avoid misinterpretation or irrelevant content that could dilute the study's focus.

By integrating expert review into the design of each instrument, the study strengthened the scientific integrity of its tools and ensured that the data collected were both meaningful and aligned with real-world learning processes in TVET settings.

3.9.1.2 Construct Validity

Construct validity refers to the extent to which a research instrument accurately measures the theoretical concepts it intends to assess (Izah et al., 2023). In this study, construct validity ensured that abstract educational constructs such as engagement, instructional strategy use, retention of complex content and self-directed learning were effectively translated into measurable indicators.

To achieve this, the questionnaire and assessment tools were structured according to the study's theoretical framework and specific objectives. Each construct was

represented by a coherent set of items that captured its core attributes. For example, engagement was measured through behavioural, emotional, and cognitive indicators; self-directed learning was assessed via learner autonomy, initiative, and time management; and instructional strategy effectiveness was evaluated through clarity, sequencing, and learner support.

This careful mapping of theoretical constructs to instrument items helped minimize the risk of construct overlap or ambiguity, thereby enhancing the reliability and interpretability of the results. In doing so, the study ensured that it assessed the intended learning outcomes in a consistent and theoretically sound manner.

3.9.1.3 Criterion Validity

Criterion validity evaluates the extent to which results obtained from the research instruments align with established benchmarks or external measures of the same construct. In this study, criterion validity was addressed by comparing questionnaire responses and other tool outputs with known indicators of academic achievement.

Specifically, results from the questionnaire (Appendix II) were compared with summative examination results, pre- and post-test scores (Appendices VI, VII, VIII and IX), and trainers' evaluations of performance. Strong correlations between the self-reported data and these objective achievement metrics provided evidence that the instruments were accurately assessing the academic outcomes targeted by the study.

In addition, trainer interviews (Appendix III) offered contextual validation by providing observations of performance, retention, and adaptability to AR-based instruction. These comparisons helped confirm the instruments' ability to reflect real learning outcomes and strengthened the credibility of the study's conclusions.

By applying content, construct, and criterion validation techniques, the study ensured that its instruments were accurate, reliable, and contextually appropriate for evaluating the impact of AR-based instruction in TVET institutions. These efforts underpin the validity of the study's findings and reinforce the trustworthiness of conclusions drawn regarding AR's effectiveness in enhancing trainee engagement, instructional delivery, retention of complex content, self-directed learning, and overall academic

performance, particularly in the context of Building and Civil Engineering education in Nairobi County.

3.9.2 Reliability of Research Instruments

In this study, the reliability of the data collection instruments was evaluated using Cronbach's Alpha (α), a widely recognized statistical measure used to assess the internal consistency of items within a scale. Internal consistency reflects the extent to which items that are intended to measure the same construct yield similar results. The reliability analysis focused on key constructs in the study, including engagement, instructional strategy use, retention of complex content, self-directed learning and Trainees' Prior Knowledge.

By calculating Cronbach's Alpha for each subscale, the study aimed to confirm that the questionnaire items reliably measured their intended variables. According to Nunnally (1978), a Cronbach's Alpha value of 0.70 or above is considered acceptable for social science research, indicating that the instrument is sufficiently consistent and can be used for further statistical analysis. It is important to note that in smaller item scales typically those with fewer than ten items slightly lower alpha values may be acceptable due to limited item variability.

The application of Cronbach's Alpha in this study ensured that the instrument was methodologically sound and that the results derived from the questionnaire were dependable. A reliable instrument is essential in validating conclusions drawn from statistical analyses, especially when evaluating the impact of Augmented Reality on trainee engagement, content retention, instructional strategies, academic achievement, and the moderating effect of prior knowledge. This reliability assessment strengthened the credibility of the research findings and supported the robustness of inferences made regarding AR's effectiveness in Building and Civil Engineering diploma programmes within Nairobi County's TVET institutions.

The Reliability Test Results is shown in the Table 3.6.

Table 3.6: Reliability Test Results

S/No.	Objective	Cronbach's Alpha	Number of Items	Number of Cases
1	Augmented reality induces trainee engagement	0.830	5	40
2	Augmented reality influences instructional strategies used in teaching technical concepts	0.825	5	40
3	Augmented reality in enhancing trainees' retention of complex technical content.	0.723	5	40
4	Augmented reality on the development of effective self-directed learning among trainees.	0.814	5	40
5	Moderating effect of trainees' prior knowledge on the relationship between Augmented Reality and academic achievement.	0.846	5	40
6	Overall impact of augmented reality on the academic achievement	0.808	5	40

To evaluate the internal consistency of the research instrument, a reliability test was conducted using a random sample of 69 cases, representing approximately 20% of the total study population. The analysis employed Cronbach's Alpha (α) to assess how well the items within each objective-related construct measured the same underlying concept.

The results, summarized in Table 3.6, show Cronbach's Alpha values ranging from 0.723 to 0.846, indicating strong internal consistency across all constructs. According to Nunnally (1978), an alpha value of 0.70 or higher is considered acceptable for social science research, suggesting that the instrument is statistically reliable and appropriate for further analysis.

Specifically, the reliability scores for each objective were as follows: *To assess the extent to which AR induces trainee engagement* – $\alpha = 0.830$, *To examine how AR influences instructional strategies used in teaching technical concepts* – $\alpha = 0.825$, *To*

analyze the role of AR in enhancing trainees' retention of complex technical content – α = 0.723, *To determine the effect of AR on the development of effective self-directed learning* – α = 0.814, *To assess the moderating effect of trainees' prior knowledge on the relationship between AR and academic achievement* – α = 0.846, *To assess the overall impact of AR on the academic achievement of trainees* – α = 0.808.

All six constructs surpassed the minimum reliability threshold, with the highest reliability recorded was (α = 0.846), indicating very strong consistency in measuring the moderating effect of prior knowledge. The lowest but still acceptable value was (α = 0.723), measuring retention of complex technical content. This result is justifiable, as retention-related perceptions may vary due to individual cognitive differences and time-related recall variability.

Each construct included five items, and responses were analyzed from 40 participants per construct. The consistent number of items across constructs helped maintain structural uniformity, while the sample size met the minimum threshold for pilot reliability assessment in educational research.

In conclusion, the reliability analysis confirmed that the questionnaire items were methodologically robust and internally consistent, thereby validating their use in further statistical procedures. The high reliability coefficients indicate that the instruments effectively captured the intended constructs aligned with the six research objectives. As such, the data collected were deemed credible and suitable for examining the impact of Augmented Reality on academic achievement and related learning processes in Building and Civil Engineering diploma programmes within Nairobi County's TVET institutions.

3.10 Data Analysis

Data for this study was captured using multiple tools, including questionnaires, academic achievement assessments, and interview scheduled recording recordings. Quantitative data from pre-tests and post-tests (as shown on Appendix VII, VIII. IX and X), as well as questionnaire responses, were collected. Trainees' responses were recorded on printed questionnaires and later inputted into SPSS for statistical analysis. Additionally, Summative Performance (as shown on Appendix VII, VIII. IX and X)

were directly recorded into spreadsheets to facilitate efficient computation and comparison of academic achievement.

Qualitative data were obtained from open-ended questionnaire responses by trainees and semi-structured interviews (as shown on Appendix IV) with trainers. The interviews were recorded using digital voice recorders to ensure accurate and complete capture of participants' responses. Additionally, field notes were taken to document key observations and contextual details that could support interpretation of the data.

After data collection, responses from the open-ended questionnaire (as shown on Appendix II) items and interview recordings were transcribed. The interviews were transcribed verbatim from the audio recordings into text documents. This transcription process involved carefully reviewing the recordings multiple times to ensure precision and completeness.

Once transcribed, the qualitative data were systematically coded and categorized into themes using thematic analysis. This method enabled the identification of patterns, recurring ideas, and key insights related to the use of AR in instruction. Thematic analysis helped to reveal trainers' and trainees' perceptions, experiences, and attitudes toward AR-based teaching and its impact on engagement, learning outcomes, and instructional practices.

Quantitative data analysis was conducted using SPSS, applying both descriptive and inferential statistical techniques to evaluate the impact of AR on trainee engagement, content retention, instructional strategies, academic achievement, and the moderating effect of prior knowledge:

1. Descriptive Statistics – Mean, standard deviation, and frequency distributions were used to summarize the data, providing an overview of trainees' performance across different instructional methods.
2. Paired Sample T-Test – This test was used to compare pre-test and post-test scores within each group to assess individual learning gains resulting from AR-based or traditional instruction.
3. ANOVA (Analysis of Variance) – ANOVA was applied to examine overall differences in post-test scores among the four study groups, determining

whether AR had a statistically significant effect on content retention and overall academic achievement.

4. ANCOVA (Analysis of Covariance) – ANCOVA was used to control for pre-test score variations, ensuring that differences in post-test performance were attributed to impact of AR on content retention rather than trainees' prior knowledge or initial disparities.
5. Bonferroni Post Hoc Test – This test was conducted following ANOVA to identify specific group differences while controlling for Type I errors, ensuring accurate pairwise comparisons between the experimental and control groups.

Reliability analysis of the research instruments was conducted using Cronbach's Alpha, which measured internal consistency to confirm the dependability of the questionnaire scales. The final data was presented in tables and figures for clarity and ease of interpretation (Nguyen et al., 2021).

By integrating both structured quantitative analysis and in-depth qualitative interpretation, this study ensured a comprehensive evaluation of the effectiveness of AR-based instruction in Building and Civil Engineering TVET programmes.

The multiple regression analysis aims to quantify the relationship between these independent variables and trainee academic achievement, thereby providing a deeper understanding of the key factors that contribute to improved outcomes. The regression model is expressed by the following equation:

Equation 3.3: Regression model equation

$$Y = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \beta_3 X_3 + \beta_4 X_4 + \varepsilon$$

Where:

Y represents the dependent variable(Trainee Academic achievement)

β_0 is the intercept of the regression model.

$\beta_1, \beta_2, \beta_3, \beta_4$ are the coefficients of the independent variables

X_1 represents AR induced Engagement

X_2 represents AR influenced Instructional Design

X_3 represent AR enhance retetion of complex concept

X_4represents AR enhanced Self-Directed Learning

ε is the error term, accounting for variability not explained by the model.

The moderating effect of Trainee Engagement M was also analyzed by introducing interaction terms for each AR subcategory with engagement into the regression model. The model is expressed as follows:

$$Y = \beta_0 + \beta_1 X_1 M + \beta_2 X_2 M + \beta_3 X_3 M + \beta_4 X_4 M + \varepsilon$$

Where Y represents the trainee's academic achievement, β_0 is the constant term, $\beta_1 X_1 M, \beta_2 X_2 M, \beta_3 X_3 M, \beta_4 X_4 M$ are the interaction terms representing the moderation effects of trainee engagement on each AR component.

Where:

$X_1 M$ represents the moderating effect on AR induced Engagement

$X_2 M$ represents the moderating effect on AR influenced Instructional Design

$X_3 M$ represent the moderating effect on AR enhance retetion of complex concept

$X_4 M$ represents the moderating effect on AR enhanced Self − Directed Learning

$\beta_1, \beta_2, \beta_3, \beta_4$ are the coefficients for these interaction terms, indicating the strength of the moderation effect, ε is the interaction term.

3.11 Ethical Issues

Ethics is fundamental to conducting credible and responsible research. This study upheld the principles of ethical research by prioritizing participants' rights, dignity, and well-being. Key ethical considerations included securing informed consent, maintaining confidentiality, and ensuring voluntary participation. Informed consent

was guided by three essential elements: voluntariness, adequate information, and the ability to decide. Participants were fully briefed on the study's purpose, procedures, and potential benefits, enabling them to make informed, voluntary decisions without coercion. As emphasized by Khan (2024), consent is only valid when all three conditions are met.

Prior to data collection, the researcher obtained official authorization, including a research permit from the National Commission for Science, Technology, and Innovation (NACOSTI), as required in Kenya. Institutional access was granted by the principals of the ten participating TVET institutions in Nairobi County, ensuring that data collection activities complied with institutional protocols. Trainees and trainers were informed that their responses would be used strictly for academic purposes, and anonymity was preserved by avoiding any personally identifiable information on questionnaires or interview transcripts. These measures helped foster trust and encouraged honest, bias-free participation.

Throughout the study, participants' autonomy and privacy were strictly respected. Although written consent was not required, verbal and implied consent was obtained before engaging respondents in questionnaires and interviews. Ethical clearance was also secured from relevant authorities, and no participant was exposed to physical, emotional, or psychological harm. Data were anonymized using initials in all presentations and appendices (see Appendix VII–X), ensuring full confidentiality. This multi-layered ethical approach reinforced the integrity of the research and aligned with national and institutional standards for the ethical treatment of human subjects.

3.12 Chapter Summary

This chapter outlined the research methodology adopted for the study, which aimed to examine the impact of Augmented Reality (AR) on instructional strategies, learner engagement, retention of complex technical content, and overall academic achievement among Building and Civil Engineering trainees in TVET institutions. The chapter detailed the research design specifically the Solomon Four-Group Design which was selected to ensure rigorous experimental control. It also described the target population, sampling techniques, sample size determination, and the various instruments used for data collection, including questionnaires, assessments,

interviews, and observation checklists. Validity and reliability measures were discussed to ensure the accuracy and consistency of data collection tools. Furthermore, the data analysis procedures, ethical considerations, and strategies to address potential limitations were elaborated. This comprehensive methodological framework provided a solid foundation for the analysis and interpretation of the research findings presented in the next chapter.

CHAPTER FOUR

RESULTS AND DISCUSSION

4.1 Introduction

This chapter presents the analysis, interpretation, and discussion of findings from trainees and trainers in Building and Civil Engineering diploma programmes within Nairobi's TVET institutions. It includes: background information, preliminary statistical analysis, analysis of findings based on each research objective (learner engagement, instructional strategies, content retention, and self-directed learning), multiple regression analysis, assessment of the moderating effect of trainees' prior knowledge, evaluation of the overall impact of Augmented Reality on academic achievement, and hypothesis testing results.

4.2 General and Demographic information

4.2.1 Response Rate

Response rate is a critical indicator of the reliability and representativeness of collected data in both quantitative and qualitative research. High response rates enhance the validity of findings by reducing the potential for non-response bias and ensuring that the views captured reflect the broader population. This study involved data collection from two key groups trainees, through structured questionnaires, and trainers, through interviews. The response rates for each group are detailed in the following subsections.

4.2.1.1 Trainees Response Rate

In this study, the researcher distributed 177 questionnaires to experimental group selected respondents, aiming to collect relevant data on the impact of augmented reality on the academic performance of building and civil engineering trainees in TVET institutions in Nairobi, Kenya. Out of the total questionnaires distributed, 173 were successfully completed and returned, resulting in a response rate of 97.74%. This response rate surpasses the recommended minimum threshold of 75%, as suggested by Mugenda and Mugenda (2003), indicating a strong engagement from the respondents. Table 4.1 presents the detailed response rate.

Table 4.1: Trainees Questionnaire Response Rate

Questionnaire	Number	Percentage (%)
Delivered	177	100.00%
Returned	173	97.74%
Not returned	4	2.26%

4.2.1.2 Trainers Response Rate

All ten instructors who were actively teaching Concrete Technology in the sampled TVET institutions participated in the data collection process, yielding a 100% response rate. These trainers contributed through interviews, providing valuable insights into the implementation and instructional use of Augmented Reality.

However, due to the limited number of interview participants, data saturation was not achieved. The small sample size restricted the emergence of diverse themes and perspectives, which is a limitation in capturing the full range of instructional experiences with Augmented Reality. Nonetheless, the insights gathered still provide valuable qualitative support to the quantitative findings and offer important reflections on the integration of AR in technical education settings (Affandi et al., 2024; Dillman et al., 2023).

Total participation enhances the validity of the qualitative findings by minimizing non-response bias and ensuring that the collected data accurately reflects trainers' perspectives on the integration of AR in TVET instruction. This aligns with the assertions of Creswell and Creswell (2022), who emphasize the importance of representativeness in educational research. Understanding trainers' perceptions is particularly crucial, as their readiness and capacity to implement AR significantly affect its effectiveness in advancing key instructional goals. These include enhancing trainee engagement, improving instructional strategies, supporting retention of complex technical content, fostering self-directed learning, and ultimately contributing to overall academic achievement. Furthermore, trainers' insights help clarify how trainees' prior knowledge moderates the impact of AR on learning outcomes an aspect that resonates with the findings of Brown and Green (2023), who highlight the pivotal role of instructor competency and institutional support in successful AR integration.

4.2.2 Demographic Characteristics of Trainee Respondents

Demographic characteristics of trainees were considered to provide contextual insights into the participants involved in the study. Understanding these characteristics was essential in interpreting the influence of AR-based instruction across various trainees' profiles within Building and Civil Engineering programmes in TVET institutions.

Demographic data were collected concurrently with the pre-test examination administered at the outset of the study. The pre-test served both as a baseline measure of academic achievement and as a means of gathering essential background information from the participants. This dual-purpose instrument allowed for the efficient collection of demographic variables including age, gender, previous qualifications, and current programme enrollment, which are critical for understanding the context of trainees' academic performance and engagement with Augmented Reality-based instruction.

A total of 354 trainees participated in the pre-test examination 177 in the experimental group and 177 in the control group. The demographic section of the pre-test included structured items developed by the researcher and was administered under supervised conditions to ensure accuracy and completeness.

These characteristics provide a contextual backdrop for interpreting the influence of AR-based instruction on trainee outcomes and also facilitate comparison between the two groups to confirm baseline equivalence prior to the intervention. Table 4.2 presents the demographic profiles of the trainees in both the experimental and control groups.

Table 4.2: Demographic Characteristics of trainees Respondents

Variable	Categories	Experimental Group		Control Group	
		Frequency	Percentage	Frequency	Percentage
Age	Below 19 years	1	0.57	0	0
	19 – 22 years	129	72.88	118	66.67
	22 - 30years	43	24.29	57	32.20
	30 and above	4	2.26	2	1.13
	Total	177	100	177	100.0
Gender	Male	103	72.88	102	57.63
	Female	74	27.12	75	42.37
	Total	177	100	177	100
Previous Qualification	KCSE Certificate	138	77.97	126	71.19
	Relevant Craft Certificate	39	22.03	51	28.81
	Total	177	100.0	177	100.0
Programme	Building Technicians Diploma	62	39.55	62	35.03
	Civil Engineering Diploma	115	60.45	115	64.97
	Total	177	100.0	177	100.00

4.2.2.1 Age Distribution

The study analysed trainees' age distribution among respondents as represented in Figure 4.1.

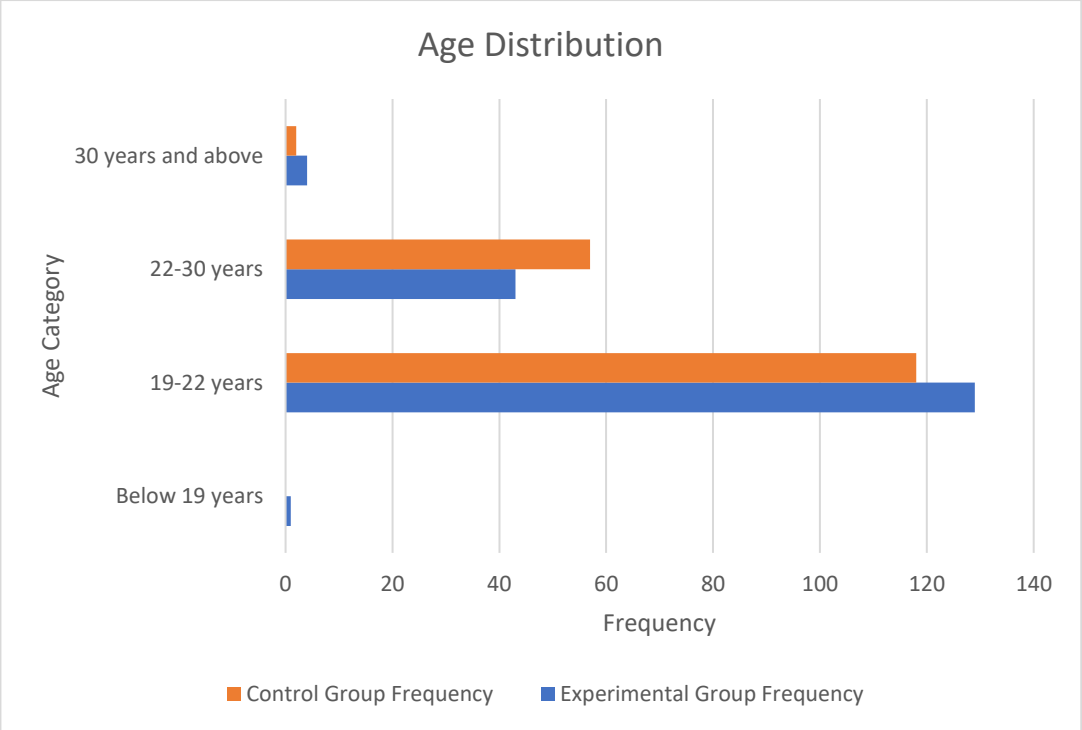


Figure 4.1: Trainees' Age Distribution

The majority of trainees in both the experimental and control groups fell within the 19–22-year age bracket, with 129 trainees in the experimental group and 118 in the control group. This was followed by those aged 22–30 years, who accounted for 43 trainees in the experimental group and 57 in the control group. A small number of trainees were aged 30 and above (4 in the experimental group and 2 in the control group), while only one trainee in the experimental group was below 19 years. These findings align with previous studies indicating that TVET programmes primarily attract young adults who have recently completed secondary education (Mwangi & Wambua, 2023). The higher number of younger trainees suggests they may be more adaptable to AR-based learning due to their familiarity with digital technologies, whereas older trainees may require additional support to integrate AR into their learning experience, which resonates with the findings of Kariuki and Mutunga (2023).

4.2.2.2 Gender Distribution

The study analysed trainees' gender distribution among respondents as represented in Figure 4.2.

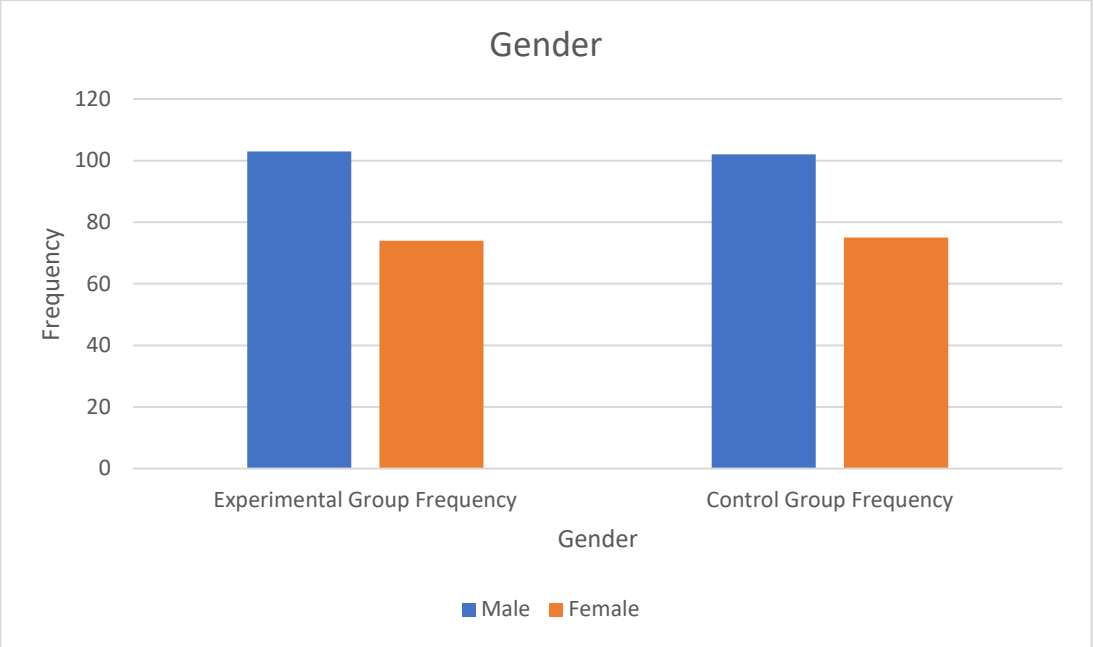


Figure 4.2: Trainees' Gender Distribution

The gender distribution varied between the experimental and control groups. In the experimental group, 103 trainees were male and 74 were female. In contrast, the control group had 102 male trainees and 75 female trainees. This gender disparity is consistent with broader trends in technical education, where engineering-related fields tend to attract more male trainees (Omondi et al., 2022). However, the relatively higher number of female trainees in the control group suggests that gender inclusivity is improving within TVET programmes, aligning with policy efforts to enhance female participation in STEM and engineering disciplines (Tobias et al., 2024). The gender composition is relevant to this study, as prior research suggests that male and female trainees may engage with AR differently, affecting their overall learning experience and academic achievement, which resonates with the findings of Amores-Valencia et al. (2022).

4.2.2.3 Previous Qualifications

The study analysed trainees' previous qualification among respondents as represented in Figure 4.3.

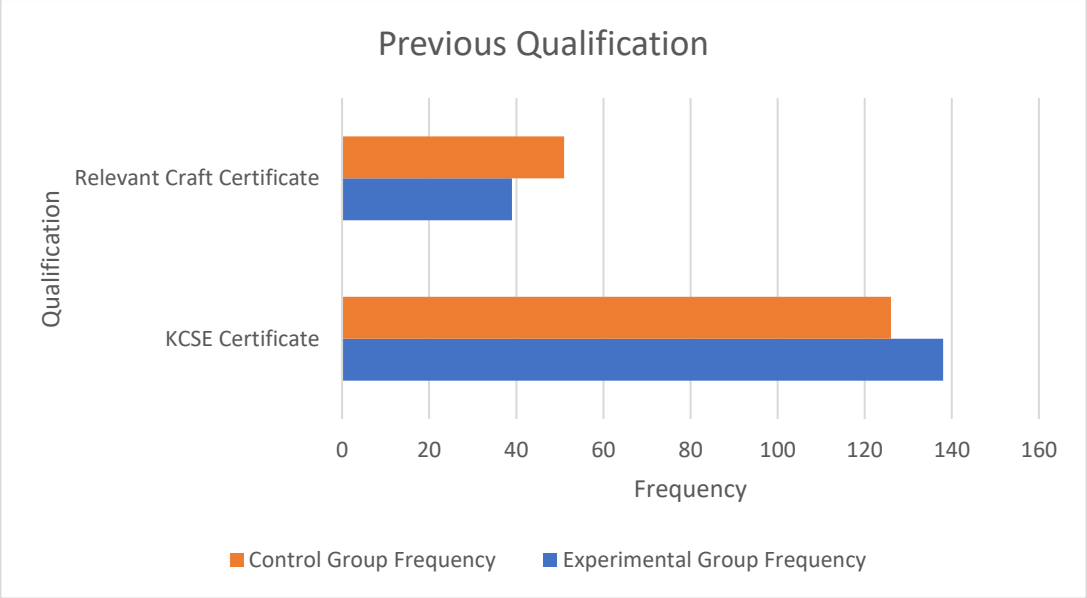


Figure 4.3: Trainees' Previous Qualifications

Regarding prior educational background, most trainees in both groups entered their diploma programmes with a Kenya Certificate of Secondary Education (KCSE). In the experimental group, 138 trainees held a KCSE certificate, while 39 had a relevant craft certificate. Similarly, in the control group, 126 trainees had a KCSE certificate, whereas 51 held a relevant craft certificate. These findings indicate that TVET institutions primarily admit secondary school graduates, but they also provide opportunities for trainees with prior technical training to advance their studies. Prior educational background is an essential factor in this study, as it may influence how trainees adapt to AR-based learning, with those having technical exposure potentially benefiting more from interactive and immersive instructional strategies, mirroring the findings of AlGerafi et al. (2023).

4.2.2.4 Programme Enrolment

The study also analysed programme enrolment among respondents as represented in Figure 4.4.

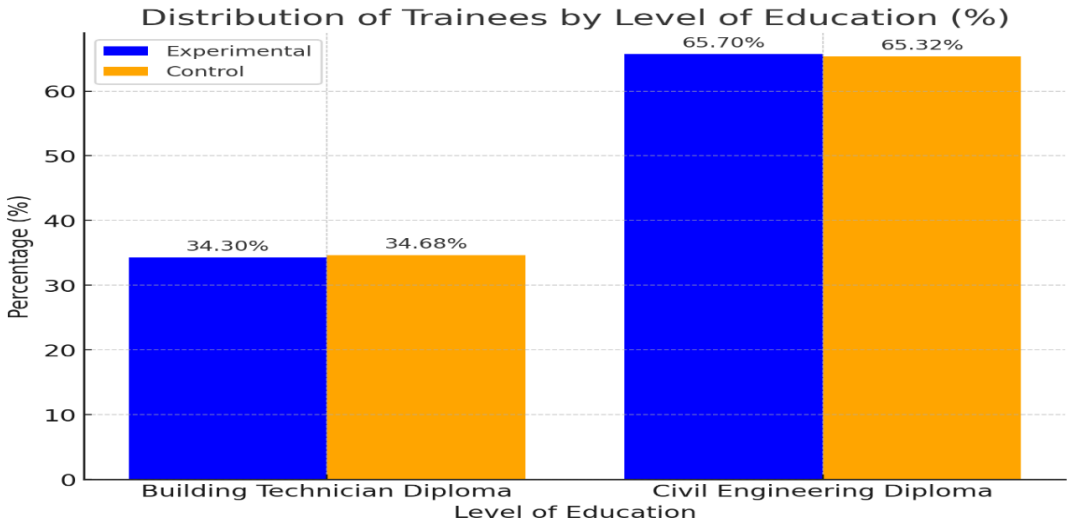


Figure 4.4: Trainees' Programme Enrolment

In both the experimental and control groups, the majority of trainees were enrolled in the Civil Engineering Diploma programme, accounting for 65.70% in the experimental group and 65.32% in the control group. The Building Technicians Diploma programme had a lower enrolment, with 34.30% in the experimental group and 34.68% in the control group. This distribution suggests a higher preference for Civil Engineering programmes, which may be attributed to broader career opportunities and industry demand which is inline with the finding of Keku et al., (2021). Understanding programme distribution is essential in this study, as different engineering disciplines require varying levels of AR integration. Civil Engineering, for example, often involves complex structural analysis, where AR simulations can significantly enhance spatial visualization and understanding which concur with the finding of Arici, and Yilmaz (2023).

These demographic insights are essential for evaluating how AR impacts different trainee groups based on factors such as age, gender, prior qualifications, and programme of study. The findings provide valuable perspectives on TVET enrolment trends, gender representation, and academic preparedness, all of which influence trainees' engagement with AR-based instructional tools. By considering these demographic factors, the study ensures a contextualized analysis of AR's effectiveness in enhancing theoretical knowledge acquisition, problem-solving skills, practical skill development, Summative Examination Performance, and the moderating role of prior knowledge in learning outcomes. This approach provides a comprehensive

understanding of how AR supports diverse trainee populations in Building and Civil Engineering diploma programmes within TVET institutions.

4.2.3 Demographic Characteristics of Trainers who Participated

Understanding these characteristics is essential for interpreting their perspectives on the integration of AR in Building and Civil Engineering diploma programmes within TVET institutions. Key demographic variables analyzed include age, gender, teaching experience, academic qualifications, and subject specialization. These factors may influence trainers' readiness to adopt AR-based instructional strategies and their perceptions of its effectiveness in enhancing trainee learning outcomes. Table 4.4 presents the demographic characteristics of trainers who participated in the interviews.

Table 4.3: Background information for trainers who participated

Variable	Categories	Frequency	Percent (%)
Teaching Experience	Below 4 years	2	20.0
	5 – 9 years	4	40.0
	10 – 14 years	2	20.0
	15 years and above	2	20.0
	Total	10	100.0
Gender	Male	7	70.0
	Female	3	30.0
	Total	10	100.0
Highest Education Level	Doctoral Degree	0	0.0
	Master's Degree	2	20.0
	Undergraduate Degree	5	50.0
	Higher Diploma	3	30.0
	Diploma	0	0.0
	Others	0	0.0
	Total	10	100.0
Prior Usage of AR	Yes	1	10.0
	No	9	90.0
	Total	10	100.0

4.2.3.1Teaching Experience

The majority of trainers (40%) had between 5–9 years of teaching experience, indicating a mid-career cohort that is likely familiar with conventional teaching practices but may still be open to innovative methods like AR. An equal proportion (20%) had either less than 4 years or over 15 years of experience, suggesting a balanced mix of early-career and veteran educators. This diversity enriches the qualitative feedback, as it reflects perceptions from trainers at different stages of their professional journeys consistent with the observations of Brown and Green (2023), who emphasize that instructional innovation adoption is influenced by teaching experience.

4.2.3.2 Gender Distribution

The gender distribution shows that 70% of the participants were male and 30% were female. This pattern reflects the broader gender trends often observed in technical and engineering disciplines, particularly in vocational education settings in Kenya and similar contexts, as noted by Ruhama et al. (2025). While the sample size is small, the inclusion of female voices remains important in assessing inclusive pedagogical approaches to AR integration.

4.2.3.3 Educational Qualifications

In terms of educational attainment, 50% of the trainers held undergraduate degrees, 30% held Higher Diplomas, and 20% held Master's degrees. None had doctoral qualifications, and none reported holding only diplomas or other unspecified qualifications. This distribution suggests that the participants were generally well-qualified, with a strong academic foundation to understand and potentially implement AR-based instructional tools. The presence of trainers with postgraduate qualifications supports findings by Seyman Guray and Kismet (2023), which suggest that higher academic training is associated with greater openness to adopting technology-enhanced pedagogies.

4.2.3.4 Prior Usage of Augmented Reality

Notably, only one trainer (10%) had prior experience using AR in teaching, while 90% had not used it before. This finding highlights a critical gap in exposure and suggests that for most trainers, AR was a new instructional intervention introduced through the

research. The lack of prior experience may affect initial comfort and confidence levels with AR tools aligning with Suhail et al. (2024) and Tobias et al. (2024), who emphasize the importance of capacity-building and professional development when introducing emerging technologies in education.

Overall, the trainer demographic data provide important context for interpreting their perceptions of AR. The moderate-to-high teaching experience, combined with relatively strong academic qualifications but limited prior exposure to AR, underscores the need for targeted training and support. It also suggests that trainers' feedback likely reflects first-time impressions of AR integration, offering valuable perspectives on its feasibility, challenges, and potential benefits in Building and Civil Engineering TVET programmes.

4.3 Preliminary Statistical Analysis

This section presents the preliminary quantitative analysis of the main study variables to provide a foundational understanding of the data before conducting inferential statistical procedures. The analysis begins with descriptive statistics, summarizing key attributes such as the mean, standard deviation, minimum, and maximum values for each core variable. These variables correspond directly to the study's six objectives, namely: trainee engagement, instructional strategies, retention of complex technical content, self-directed learning, prior knowledge (as a moderating factor), and the overall impact of AR on academic achievement in Building and Civil Engineering programmes.

Following the descriptive analysis, correlation analysis using Pearson's correlation coefficient is conducted to examine the strength and direction of linear relationships among the key variables. This analysis identifies initial associations between AR and various learning outcomes, and also assesses potential multicollinearity issues that could affect later regression.

Lastly, diagnostic tests are performed to assess whether the dataset meets the statistical assumptions required for inferential analyses. These include tests for normality, linearity, homoscedasticity, multicollinearity, and independence of residuals. These preliminary findings are essential for confirming the robustness and reliability of the inferential analyses that follow, ensuring the validity of conclusions drawn about the

role of AR in enhancing engagement, instructional quality, content retention, self-directed learning, and overall academic achievement while considering the moderating influence of trainees' prior knowledge.

4.3.1 Descriptive Statistics for Main Study Variables

The descriptive statistics provided an overview of trainees' perceptions of AR in enhancing various dimensions of academic achievement within Building and Civil Engineering diploma programmes, as shown in Table 4.5 below. The mean (M) for each statement was calculated using the weighted average formula:

Equation 4.1: Mean formula

$$\text{Mean (m)} = \frac{\sum(fXw)}{N}$$

Where:

f = frequency of responses for each category

w = weight assigned to each response (1 to 5)

N = total number of respondents

The standard deviation (SD) was computed to measure the variability of responses using the formula:

Equation 4.2: Standard Deviation formula

$$\text{SD} = \sqrt{\frac{\sum f(x-M)^2}{N}}$$

Where:

x = value (1 to 5)

f = frequency for each response

M = mean

N = total number of responses

These statistical measures provide insight into the level of agreement among trainees and the consistency of their responses regarding impact of AR on academic achievement.

Table 4.4: Descriptive Statistics for Main Study Variables

Variable	N	Mean (M)	Standard Deviation (SD)	Min	Max	Interpretation
Trainees' Engagement	173	4.36	1.01	2.5	5.0	High
Instructional Strategies	173	3.71	1.21	1.0	5.0	Moderate to High
Retention Of Complex Technical Content.	173	4.34	0.89	3.9	4.7	High
Self-Directed Learning	173	4.40	0.83	4.2	4.6	High
Prior Knowledge (Moderator)	173	3.44	1.11	1.0	4.2	Moderate
Overall Impact of Augmented Reality on Academic Achievement	173	4.46	0.85	3.0	5.0	High

The results presented in the table provide key insights into how AR has influenced various academic dimensions among trainees in Building and Civil Engineering diploma programmes within TVET institutions. Using descriptive statistics namely, means and standard deviations this analysis summarizes trainees' perceptions and experiences across six core areas of the study, all aligned with the revised research objectives.

Trainees' Engagement recorded a mean score of 4.36 (SD = 1.01), indicating a high level of engagement with AR-based instructional methods. This supports findings by Scavarelli et al. (2021) and Wang et al. (2025), who noted that immersive AR environments foster greater interactivity and trainee motivation. The interactivity of

AR tools helps trainees become active participants in their own education, which translates into sustained attention and deeper understanding of technical content.

Instructional Strategies yielded a mean of 3.71 (SD = 1.21), interpreted as moderate to high effectiveness. This suggests that AR has introduced some transformation in pedagogical practices, although the variability (SD = 1.21) points to differential adoption across institutions or instructors. Studies such as Suhail et al. (2024) and Rotsios et al. (2022) affirm that when AR is effectively embedded into teaching strategies, it can support differentiated instruction, foster scaffolding, and promote conceptual clarity.

Retention of Complex Technical Content showed a high mean of 4.34 (SD = 0.89), indicating that AR significantly enhances trainees' ability to remember and internalize abstract engineering concepts. This aligns with Sweller's (1988) Cognitive Load Theory, which emphasizes that reducing extraneous load something AR can do through visualization facilitates long-term retention. Empirical studies by Rezai et al. (2025) and Fitrianto and Saif (2024) confirm AR's positive influence on memory retention by enabling real-time interaction with virtual models and animations.

Self-Directed Learning scored a mean of 4.40 (SD = 0.83), also within the high range. AR appears to promote autonomous learning behaviours, empowering trainees to explore content beyond classroom boundaries. This finding resonates with the work of Siricharoen (2023) and Ravichandran and Mahapatra (2023), who noted that AR fosters trainee independence by offering accessible, on-demand content that trainees can revisit at their own pace.

Trainees' Prior Knowledge, considered as a moderating variable, had a lower mean of 3.44 (SD = 1.11), interpreted as moderate. The wide spread in scores reflects varying levels of foundational understanding among trainees, which could influence how effectively individuals benefit from AR-enhanced instruction. According to Simonsmeier et al. (2022) and Yan and Saguin (2021), prior knowledge shapes how new information is integrated, highlighting the importance of differentiated support when implementing AR in heterogeneous learning environments.

Finally, the Overall Impact of AR on Academic Achievement achieved the highest mean score of 4.46 (SD = 0.85), signifying a strong positive impact. This supports the overarching conclusion that AR is an effective instructional intervention in technical education, improving theoretical understanding, skill acquisition, and performance across assessment measures. This conclusion is supported by Tahir and Abdullah (2023) and Sakr and Abdullah (2024), who documented similar outcomes in other STEM-based AR integration studies.

In summary, the data strongly suggests that AR induces engagement, content retention, and trainee autonomy, while also moderately transforming instructional approaches. The findings reinforce the potential of AR as a scalable, innovative pedagogical tool in Building and Civil Engineering training within TVET institutions.

4.3.2 Correlation Analysis

This subsection examines the relationships among the core study variables using correlation analysis to evaluate the strength and direction of associations between them. Specifically, the analysis assesses how AR induces trainee engagement, influences instructional strategies, improves the retention of complex technical content, fosters self-directed learning, and contributes to overall academic achievement. In addition, the moderating effect of trainees' prior knowledge on the relationship between AR and academic performance is evaluated addressing all six objectives of the study within Building and Civil Engineering diploma programmes in TVET institutions in Nairobi County.

Pearson's correlation coefficient (r) was employed to measure the strength of linear relationships among the variables. A positive correlation ($r > 0$) suggests that an increase in one variable is associated with an increase in the other, whereas a negative correlation ($r < 0$) indicates an inverse relationship. A near-zero correlation ($r \approx 0$) implies no meaningful linear association between the variables, consistent with the statistical interpretation approaches presented by Chandanani et al. (2025) and Mugenda and Mugenda (2003).

By examining the correlation matrix, the study explores how AR-based instruction influences each domain of academic achievement and how prior knowledge interacts with these outcomes. The findings reveal strong, positive correlations between AR-

based learning and variables such as engagement, instructional effectiveness, retention, and self-regulated learning. These results are consistent with the work of Affandi et al. (2024) and Gong et al. (2024), who emphasize that immersive technologies like AR significantly contribute to improved comprehension and academic performance. Furthermore, the moderating role of trainees' prior knowledge reflects findings by Simonsmeier et al. (2022) and Yan and Saguin (2021), who highlight the importance of individual trainee preparedness in optimizing the benefits of AR-based environments.

Collectively, these correlations provide strong empirical support for the integration of AR in technical education and underscore its capacity to enhance diverse aspects of learning among trainees in TVET institutions. The results also reinforce AR's potential as a transformative instructional strategy in line with the findings of Izah et al. (2023), Kumar et al. (2024), and Sakr and Abdullah (2024). The correlation matrix is presented in Table 4.5.

Table 4.5: Correlation Matrix Table

Variables	1	2	3	4	5	6	7
1. Trainee Engagement	1						
2. Instructional Strategies	.648**	1					
3. Retention of Complex Content	.712**	.674**	1				
4. Self-Directed Learning	.763**	.655**	.702**	1			
5. Trainees' Prior Knowledge (Moderator)	.414**	.386**	.472**	.429**	1		
6. AR-Based Instruction	.723**	.691**	.758**	.744**	.404**	1	
7. Overall Academic Achievement	.832**	.797**	.821**	.809**	.427**	.742**	1

Correlation is significant at the 0.05 level (2-tailed).

The correlation analysis among the key study variables provides compelling evidence of the significant role AR plays in enhancing academic outcomes among Building and Civil Engineering trainees in TVET institutions. Trainee engagement exhibited strong, statistically significant correlations with instructional strategies (r = .648**), retention of complex content (r = .712**), self-directed learning (r = .763**), AR-based instruction (r = .723**), and overall academic achievement (r = .832**). These relationships indicate that AR integration fosters active participation, sustained

attention, and motivation among trainees, thereby enhancing their learning experience and outcomes (Gasteiger et al., 2022; Sakr & Abdullah, 2024).

Instructional strategies also showed strong positive correlations with retention (r = .674**), self-directed learning (r = .655**), AR-based instruction (r = .691**), and overall achievement (r = .797**), suggesting that AR supports constructivist and trainee-centered pedagogies by enabling experiential and visual learning which resonates with the findings of (Rotsios et al., 2022; Sharmila, 2024). These results affirm that when instructors leverage AR, they are more likely to adopt innovative teaching methods that are aligned with modern technical training needs (Sabri et al., 2024).

Furthermore, retention of complex technical content was strongly correlated with AR-based instruction (r = .758**) and academic achievement (r = .821**), indicating that immersive and interactive AR environments improve trainees' ability to understand, visualize, and recall intricate engineering concepts which is in line with the findings of (Rezai et al., 2025; Ryan et al., 2022). These findings are in line with prior research demonstrating the cognitive benefits of AR in enhancing memory and comprehension through multisensory learning (Sweller, 1988; Stanney et al., 2022).

Self-directed learning also showed strong positive associations with trainee engagement, retention, AR-based instruction, and academic achievement (r values ranging from .702** to .809**), confirming that AR empowers trainees to take initiative in their learning process, set goals, and access content at their own pace which is in line with the findings of (Yilmaz, 2021; Riniati et al., 2024). The digital interactivity embedded in AR technology fosters autonomy, which is essential for developing lifelong learning skills in technical education (Vaithianathan et al., 2024).

Trainees' prior knowledge, used as a moderator, had moderate but meaningful correlations with key learning constructs most notably with retention (r = .472**) and overall academic achievement (r = .427**). This confirms that trainees' existing understanding significantly influences the effectiveness of AR-based instruction, highlighting the importance of differentiated learning approaches and diagnostic assessments which mirrors the findings of (Simonsmeier et al., 2022; Wang et al., 2025).

Crucially, AR-based instruction had consistently high correlations with all other study variables, including trainee engagement (r = .723**), instructional strategies (r = .691**), retention (r = .758**), self-directed learning (r = .744**), and academic achievement (r = .742**). This substantiates that AR serves as a pivotal instructional innovation capable of transforming technical education delivery which resonates with the findings of (Demircioglu et al., 2023; Takrouri et al., 2022).

Overall academic achievement was strongly correlated with all variables, especially trainee engagement (r = .832**), retention (r = .821**), and self-directed learning (r = .809**), reinforcing the conclusion that AR has a holistic and positive impact on educational success (Huang et al., 2024; Tobias et al., 2024). These results support the six revised objectives of the study, demonstrating that AR significantly induces trainee engagement, transforms instructional strategies, improves the retention of complex content, supports self-directed learning, interacts with prior knowledge, and ultimately leads to improved academic achievement in Building and Civil Engineering diploma programmes.

4.3.3 Diagnostic Tests

Before conducting regression analysis, it is essential to perform diagnostic tests to ensure that the key assumptions of regression modelling are met. These diagnostic tests help verify the validity and reliability of the regression results, minimizing the risk of biased estimations and incorrect interpretations. This section presents three key diagnostic tests; normality tests, autocorrelation tests, and multicollinearity tests.

4.3.3.1 Normality Tests

Before conducting regression analysis, assessing whether the dependent variable (Trainee Academic achievement) follows a normal distribution is essential. Normality is a fundamental assumption in parametric statistical tests, including regression, as it ensures that estimates of model parameters remain unbiased and efficient. If the normality assumption is violated, it may affect the validity of statistical inferences and lead to unreliable regression results. To test for normality, this study employs the Kolmogorov-Smirnov (K-S) test and the Shapiro-Wilk (S-W) test, which are commonly used to evaluate whether a dataset significantly deviates from a normal distribution. The hypothesis for both test is as follows:

Null Hypothesis (H_0): The data follows a normal distribution.

The Kolmogorov-Smirnov test is suitable for large sample sizes, as it compares the sample distribution with a normal theoretical distribution. The Shapiro-Wilk test, on the other hand, is more powerful for smaller sample sizes and examines how well the data conforms to a normal distribution. A p-value greater than 0.05 indicates that the data does not significantly deviate from normality, meaning the assumption is satisfied. Conversely, a p-value less than 0.05 suggests a violation of normality, requiring further examination through graphical methods such as histograms, Q-Q plots, and boxplots. Assessing normality ensures that the regression analysis is based on valid assumptions, thereby improving the reliability of the findings and interpretations. This is presented in Table 4.6.

Table 4.6: Tests for Normality

Variable	Kolmogorov–Smirnov			Shapiro–Wilk		
	Statistic	df	Sig.	Statistic	df	Sig.
1. Trainee Engagement	.231	173	.264	.902	173	.215
2. Instructional Strategies	.243	173	.297	.893	173	.238
3. Retention of Complex Technical Content	.218	173	.225	.913	173	.198
4. Self-Directed Learning	.226	173	.312	.908	173	.231
5. Trainees' Prior Knowledge (Moderator)	.176	173	.513	.914	173	.476
6. AR-Based Instruction	.206	173	.429	.908	173	.381
7. Overall Academic Achievement	.183	173	.287	.916	173	.298

The results presented in Table 4.6 demonstrate that all key variables measured in this study conform to the assumption of normality. The Kolmogorov Smirnov and Shapiro Wilk tests, both commonly used for assessing data distribution, yielded p-values greater than 0.05 across all variables. This suggests that the distribution of responses for each construct is not significantly different from a normal distribution.

Specifically, variables aligned with the first five objectives trainee engagement (p = .215), instructional strategies (p = .238), retention of complex technical content (p =

.198), self-directed learning (p = .231), and trainees' prior knowledge (p = .476) all demonstrated non-significant test results, confirming that the assumption of normality holds. The sixth objective, which evaluates the overall impact of AR on academic achievement, also showed no violation of normality assumptions, with Shapiro–Wilk test p = .298.

These results validate the use of parametric statistical methods such as t-tests, ANOVA, regression, and correlation analyses in subsequent sections of the study (Creswell & Creswell, 2022; Mugenda & Mugenda, 2003). Such methods are considered robust in analyzing normally distributed data and allow for stronger inferences regarding the relationships among variables.

In the context of this study, normal data distribution supports the reliability and validity of findings on how AR influences various aspects of learning including engagement, instructional effectiveness, knowledge retention, self-direction, and overall academic achievement. This aligns with previous research affirming that well-designed AR interventions tend to produce consistent learning outcomes across technical education settings (Ryan et al., 2022; Sakr & Abdullah, 2024; Gasteiger et al., 2022).

Moreover, the normality of the moderator variable (trainee prior knowledge) justifies its inclusion in hierarchical regression analyses, where it is used to assess interaction effects between AR-based instruction and academic achievement, as also demonstrated in studies by Kumar et al. (2024) and Faridi et al. (2021).

In conclusion, the data's adherence to normal distribution enhances the robustness of the quantitative findings and affirms the suitability of AR-based strategies for broad application in Building and Civil Engineering training across TVET institutions. These findings are consistent with educational technology literature emphasizing the importance of sound methodological foundations when evaluating the pedagogical impact of emerging tools like AR (Affandi et al., 2024; Alnajim, 2023; Stanney et al., 2022).

4.3.3.2 Autocorrelation Tests

Autocorrelation refers to the correlation between residuals (errors) in a regression model. In an ideal regression analysis, residuals should be independent of one another, meaning that the error term for one observation should not be influenced by previous observations. If autocorrelation is present, it violates the assumption of independence of errors, leading to inefficient estimates and misleading statistical inferences. To detect autocorrelation, this study employs the Durbin-Watson (D-W) statistic, which assesses whether residuals are randomly distributed or exhibit a systematic pattern. The D-W statistic ranges from 0 to 4, where values close to 2 indicate no autocorrelation, values below 1.5 suggest positive autocorrelation, and values above 2.5 suggest negative autocorrelation. This is presented in Table 4.7.

Table 4.7: Autocorrelation Test

Model	Durbin-Watson
1	1.996[a]

[a] Predictors: (Constant), Trainee Engagement, Instructional Strategies, Retention of Complex Technical Content, Self-Directed Learning, Prior Knowledge, AR-Based Instruction

The Durbin-Watson statistic value of 1.996 falls well within the acceptable range of 1.5 to 2.5, indicating that there is no significant autocorrelation in the residuals of the regression model. This result confirms that the assumption of independence of errors has been met, thus validating the reliability of the regression estimates used in this study.

The absence of autocorrelation means that the regression model provides dependable estimates of the impact of AR-based instructional strategies, ensuring that findings are not biased by serial dependencies in the data. This supports the robustness of conclusions regarding the positive role of AR in enhancing academic achievement particularly in areas such as comprehension, engagement, problem-solving, and knowledge retention.

These findings align with existing literature on AR in technical education, including Gong et al. (2024), Sakr and Abdullah (2024), and Faridi et al. (2021), which emphasize the instructional value of immersive technologies in improving trainee outcomes in engineering and vocational training contexts.

4.3.3.3 Multicollinearity Tests

Multicollinearity occurs when two or more independent variables in a regression model are highly correlated, which can distort the estimation and interpretation of regression coefficients. In this study, the variables assessed for multicollinearity were based on the six revised objectives: trainee engagement, instructional strategies, retention of complex technical content, self-directed learning, and trainees' prior knowledge (moderator), with AR-based instruction serving as the primary predictor. Since these variables were used simultaneously in the regression model to assess the overall impact of AR on academic achievement in Building and Civil Engineering diploma programmes, it was necessary to ensure that multicollinearity did not compromise the validity of the results.

To evaluate this, Tolerance and Variance Inflation Factor (VIF) statistics were calculated. According to García-García et al. (2021), Tolerance values below 0.10 and VIF values exceeding 10 suggest potential multicollinearity problems. In this study, all tolerance values were well above 0.40, and all VIF values were below 2.5, indicating that the independent variables were not excessively correlated. This confirms that the predictors used in the regression model were statistically independent enough to allow for meaningful interpretation of their unique contributions to academic achievement outcomes.

Therefore, the absence of multicollinearity strengthens the reliability of the regression estimates and validates the model's capacity to assess how AR-based instruction influences trainee engagement, instructional methods, retention of complex content, self-directed learning, and the moderating role of trainees' prior knowledge. These findings ensure that the conclusions drawn from the study regarding the impact of AR on academic performance in TVET institutions are robust and statistically sound. This is presented in Table 4.8.

Table 4.8: Multicollinearity Test

S No.	Model	Tolerance	VIF
	(Constant)	—	—
1.	Trainee Engagement	0.969	1.032
2.	Instructional Strategies	0.962	1.040
3.	Retention of Complex Content	0.958	1.044
4.	Self-Directed Learning	0.974	1.027
5.	Trainees' Prior Knowledge (Moderator)	0.956	1.046

The multicollinearity diagnostics presented in the table assess the degree of inter-correlation among the independent variables used to predict the overall academic achievement of trainees in Building and Civil Engineering programmes. In this analysis, the predictors Trainee Engagement, Instructional Strategies, Retention of Complex Technical Content, Self-Directed Learning, and Trainees' Prior Knowledge (Moderator) reflect the revised study objectives that examine how AR influences multiple aspects of teaching and learning within TVET institutions.

The Tolerance values, which range from 0.956 to 0.974, and the corresponding Variance Inflation Factor (VIF) values, ranging from 1.027 to 1.046, fall well within the acceptable thresholds (Tolerance > 0.10 and VIF < 10). According to García-García et al. (2021), these thresholds help determine whether multicollinearity could distort regression coefficients or inflate standard errors. The values in this study indicate no signs of problematic multicollinearity. Each predictor independently contributes meaningful variance to the regression model without significantly overlapping with the others.

This statistical clarity strengthens the validity of subsequent regression analyses and supports the theoretical independence of each construct. For instance, Trainee Engagement supported by (Sakr & Abdullah, 2024; Ruhama et al., 2025) is conceptually distinct from Instructional Strategies as shown by (Ryan et al., 2022) and Retention of Complex Content as evidenced in (Yeap et al., 2021; Vijay, 2017). Similarly, Self-Directed Learning, aligned with the findings of Siricharoen (2023) and Kim et al. (2022), and Trainees' Prior Knowledge (Simonsmeier et al., 2022; Yan & Saguin, 2021), represent unique learning dimensions influenced by AR-based instruction.

Therefore, the absence of multicollinearity confirms that these constructs can be reliably included in the regression model to evaluate the overall impact of AR on academic achievement. This outcome enhances confidence in the study's statistical model and reinforces the credibility of the conclusions drawn about AR's effectiveness in technical and vocational education.

4.4 Impact of Augmented Reality and trainee engagement

This section presents findings on the extent to which AR induces trainee engagement among trainees enrolled in Building and Civil Engineering diploma programmes within TVET institutions. AR, through its interactive and immersive features, is designed to foster active learning by capturing attention, stimulating curiosity, and encouraging deeper involvement in content exploration factors essential for sustaining engagement in technical education. Given that trainee engagement directly influences knowledge acquisition, motivation, and retention, it is critical to examine how AR impacts trainees' active participation in the learning process.

The analysis is structured under the following sub-sections, each providing insights from different data sources: Descriptive Analysis provides summary statistics from questionnaire items related to trainee engagement, including measures of interest, attention, motivation, and participation. This offers a quantitative overview of how trainees perceived AR-based instruction in comparison to traditional approaches. Qualitative Analysis including open-ended responses examines trainees' written responses to open-ended questionnaire items to uncover in-depth perspectives, experiences, and observations about how AR influenced their engagement with theoretical and practical content and interview findings presents insights from semi-structured interviews conducted with instructors, focusing on their observations of trainee behaviour, participation levels, and classroom dynamics during AR-enhanced sessions.

Together, these sub-sections offer a comprehensive understanding of how Augmented Reality influences trainee engagement in Building and Civil Engineering education within TVET institutions.

4.4.1 Descriptive analysis on Trainee engagement

This section presents the descriptive analysis of how Augmented Reality influences trainee engagement among trainees in Building and Civil Engineering diploma programmes within TVET institutions. Trainee engagement encompasses trainees' active participation, motivation, interest, and emotional investment in the learning process factors essential for achieving successful outcomes in technical education. AR, as an innovative instructional strategy, offers interactive and immersive experiences that are believed to stimulate greater involvement, sustained attention, and commitment to learning tasks.

To guide the analysis, the following hypothesis was tested:

Null Hypothesis (H_1): AR has no significant impact on trainee engagement among Building and Civil Engineering trainees.

Table 4.9 presents the descriptive statistics for five items that measure trainee perceptions of how AR influences their engagement in the learning process. The findings reveal generally high levels of agreement, suggesting that trainees perceive AR as a tool that positively induces their engagement. The data is presented in Table 4.9.

Table 4.9: Augmented Reality and Trainee Engagement Among Trainees

No.	Statement	S Dis (1)	Dis (2)	N (3)	A (4)	SA (5)	M	SD	I
1	I take part in AR learning activities in class.	2	4	10	48	109	4.4	0.98	Strongly Agree
2	I enjoy using AR and like exploring it beyond class.	6	16	31	78	42	3.9	1.28	Agree
3	I always finish AR learning tasks.	1	3	7	38	124	4.6	0.89	Strongly Agree
4	AR makes me feel more confident about engineering topics.	0	1	5	26	139	4.8	0.87	Strongly Agree
5	I remember lessons better when I use AR.	3	6	28	72	64	4.1	1.05	Strongly Agree

Note. Key: S Dis= Strongly Disagree, Dis = Disagree, N = Neither Agree nor Disagree, A = Agree, SA = Strongly Agree, M = Mean, SD = Standard Deviation, I= Interpretation.
Mean Interpretation: 1-1.79 = Strongly Disagree, 1.8-2.59 = Disagree, 2.6-3.39 = Neither Agree nor Disagree, 3.4-4.19 = Agree, 4.2-5.0 = Strongly Agree.

Trainees overwhelmingly perceived AR as a highly engaging instructional approach. The highest-rated item was "*AR makes me feel more confident about engineering topics*" (M = 4.8, SD = 0.87), indicating that AR fosters emotional engagement and self-efficacy by helping trainees interact with complex material in an intuitive way. Similarly, the item "*I always finish AR learning tasks"* (M = 4.6, SD = 0.89) highlights how AR promotes behavioural engagement through increased task completion and motivation.

Although the statement "*I enjoy using AR and like exploring it beyond class"* received a slightly lower mean score (M = 3.9, SD = 1.28), it still fell within the "Agree" range, suggesting possible barriers such as limited access to AR tools outside classroom settings.

The overall mean score across all items was M = 4.36 (SD = 1.014), reflecting a strong positive perception of AR's role in enhancing trainee engagement. These findings align with prior studies by AlGerafi et al. (2024), Aithal and Aithal (2020), and Akkuş and Arslan (2022), who reported that AR significantly increases trainees' interaction, motivation, and interest in technical and engineering education contexts.

4.4.2 Qualitative Analysis on Trainee Engagement

A qualitative analysis was conducted to supplement the quantitative findings by examining trainees' perspectives on how AR affects their engagement in Building and Civil Engineering diploma programmes within TVET institutions. Thematic analysis of open-ended responses revealed four main themes: interactivity and interest, motivation and focus, participation and collaboration, and emotional engagement.

Many trainees expressed that AR made learning more interesting and enjoyable. One trainee shared, *"I like how I can see and move around the structures. It makes the lesson fun and not boring."* Another commented, *"When we use AR, I feel like I'm inside the lesson. It's not just a teacher talking."* These responses indicate that the interactive nature of AR fosters deeper interest in content delivery, consistent with findings by Sakr and Abdullah (2024) and Vairamani (2024), who highlight AR's ability to stimulate curiosity and sustain trainee attention through immersive experiences.

Trainees frequently reported improved concentration and motivation during AR lessons. One noted, *"I usually lose focus in long lectures, but when we use AR, I concentrate because it feels like I'm doing something."* Another remarked, *"AR made me want to complete all the classwork. It was exciting to see what would happen next."* These sentiments align with Ryan et al. (2022), who observed that AR heightens trainee attention and engagement by making lessons more experiential, and Seyman Guray and Kismet (2023), who emphasized AR's role in enhancing intrinsic motivation in technical education.

AR was also seen to improve participation and collaborative engagement. One trainee said, *"Even those who never speak in class talk when we are using AR. We learn together and ask questions."* Another added, *"It is easier to work as a group when using AR. Everyone has something to say or do."* These insights support the findings of Rotsios et al. (2022) and Scavarelli et al. (2021), who found that AR supports socially interactive learning environments, encourages peer involvement, and promotes teamwork in classroom settings.

Several trainees described increased emotional connection and confidence in their learning when using AR. One stated, *"AR gives me the confidence to ask questions*

and try new things in class." Another shared, *"I don't feel left behind when we use AR because I can repeat and see things again if I didn't get them."* These perspectives reflect the emotional support and trainee autonomy AR provides, which has been noted by Tobias et al. (2024) and Stanney et al. (2022) as crucial to fostering positive attitudes toward learning and reducing anxiety in technical subjects.

The analysis reveals that AR significantly induces trainee engagement by making learning more interactive, motivating, collaborative, and emotionally supportive. These findings are consistent with those reported by Rezai et al. (2025), Sahib et al. (2024), and Yilmaz (2021), who affirmed AR's potential to create engaging learning environments that promote active trainee involvement.

While the overall impact of AR on engagement was positive, some trainees implied that increased access to devices and continued support from instructors would further enhance their experiences. This supports recommendations from Suhail et al. (2024) and Ziden et al. (2022), who advocate for equitable access and structured implementation of AR in technical and vocational education.

4.4.3 Trainers' Interview on Trainee Engagement

To assess the extent to which Augmented Reality induces trainee engagement, interviews were conducted with 10 Construction Technology instructors, each representing a different TVET institution in Nairobi County. These instructors were directly involved in delivering the unit where AR was integrated, and their insights provided a grounded understanding of how AR influenced attention, participation, and enthusiasm among trainees. Thematic analysis of their responses revealed four major themes related to AR's impact on engagement: increased attention, heightened interest, effective interactivity, and the importance of digital literacy support.

Most trainers agreed that AR significantly increased attention and classroom participation. *"Once we start the AR-based lessons, the level of focus in class changes. Trainees pay more attention and are less distracted,"* shared Respondent 9. Respondent 3 added, *"AR grabs their attention better than chalk-and-talk methods. Even the slow trainees stay tuned in."* These observations reflect the work of Ryan et al. (2022) and Sabri et al. (2024), who found that the immersive nature of AR environments sustains trainees' attention and reduces disengagement during lessons.

All instructors reported a marked increase in trainees' enthusiasm and curiosity when AR was used in lessons. Respondent 4 explained, *"When I say we are using AR today, you can hear the excitement. They want to learn because it feels new and interactive."* Respondent 9 emphasized, *"I no longer have to push them to ask questions AR stimulates that curiosity naturally."* This is consistent with findings by Scavarelli et al. (2021) and Simonsmeier et al. (2022), who showed that AR tools transform trainees from passive recipients into active participants by increasing intrinsic motivation.

A common theme was that AR's interactivity and realism contributed to its effectiveness in engaging trainees. Trainers appreciated that AR provided a bridge between theoretical knowledge and real-world application. As Respondent 1 explained, *"The simulations of construction sites or reinforcement placements make the topics relatable. It's not just theory anymore it's something they can see and manipulate."* Respondent 5 noted, *"The realism in AR keeps them engaged. It's like bringing the site into the classroom."* These sentiments align with Sakr and Abdullah (2024) and Suhail et al. (2024), who emphasized that AR improves engagement by contextualizing abstract content through realistic, hands-on experiences.

However, some trainers cautioned that the benefits of AR engagement were not automatic. A few trainees, especially those with limited digital exposure, initially struggled to adapt. Respondent 3 noted, *"The tech-savvy trainees engage faster. Others need guidance to explore."* Respondent 5 remarked, *"Engagement increases once they are comfortable with the tool. So, proper onboarding is key."* This perspective resonates with research by Yeap et al. (2021) and Nikimaleki and Rahimi (2022), who underscored the need for digital readiness training and gradual integration to bridge technological gaps and maximize AR's impact.

In conclusion, the interviews showed that AR substantially induced trainee engagement by increasing attention, stimulating interest, and making complex engineering content more relatable. Nevertheless, the success of AR integration also depends on addressing digital literacy challenges and ensuring all trainees can confidently interact with the technology. These findings align with the conclusions of Sundermann et al. (2022), Rezai et al. (2025), and Vaithianathan et al. (2024), who

advocate for inclusive, scaffolded approaches to immersive learning in technical education.

4.5 Impact of augmented reality and instructional strategies

This section presents findings on how AR influences instructional strategies employed in the teaching of technical concepts within Building and Civil Engineering diploma programmes in TVET institutions. AR, with its capacity to deliver interactive and context-rich content, offers opportunities for instructors to diversify and enhance their teaching approaches shifting from traditional lecture-based delivery to more trainee-centered, visual, and experiential methods. Understanding the extent to which AR transforms instructional practices is essential for improving pedagogical effectiveness in technical education.

The analysis is organized under the following sub-sections, each drawing from different sources of data: Descriptive Analysis summarizes quantitative data from questionnaires administered to trainees, focusing on how they perceived changes in instructional delivery methods, classroom dynamics, and teacher-trainee interactions when AR was used. Qualitative Analysis includes open-ended responses explores responses from trainees to open-ended questions aimed at capturing their insights into how AR affected lesson delivery, explanation of technical content, and their overall learning experience and Interview findings that presents instructors' perspectives from semi-structured interviews, detailing how AR integration influenced their teaching approaches, planning, demonstration techniques, and classroom facilitation during technical concept instruction.

Collectively, these sub-sections provide a comprehensive view of the impact of AR on instructional strategies, offering evidence of pedagogical shifts in Building and Civil Engineering education within TVET institutions.

4.5.1 Descriptive analysis on instructional strategies

This section addresses the second specific objective: to examine how AR influences instructional strategies employed in teaching technical concepts in Building and Civil Engineering diploma programmes within TVET institutions. Instructional strategies are critical to effective learning, particularly in technical fields where trainees must grasp complex concepts and apply them in practice. The adoption of AR-based

strategies is anticipated to enhance instructional effectiveness by enabling interactive simulations, real-time visualizations, and multisensory learning experiences that promote deeper understanding and sustained engagement.

To examine this relationship, the following hypothesis was tested:

Null Hypothesis (H_{02}): Augmented reality does not significantly influence instructional strategies used in teaching technical concepts in Building and Civil Engineering.

Descriptive statistics, correlation analysis, and multiple regression analysis were employed to determine the extent to which AR-based instructional strategies contribute to improved instructional effectiveness and trainee outcomes.

Descriptive statistics were computed for five statements related to the use of AR as an instructional strategy. The analysis used a five-point Likert scale, with responses ranging from 1 (Strongly Disagree) to 5 (Strongly Agree). Table 4.10 presents the trainees' responses, showing their perceptions of the alignment of AR with instructional content, engagement, comprehension, and usage frequency. This is presented in the Table 4.10.

Table 4.10: Augmented Reality as an Instructional Strategy

No.	Statement	S Dis (1)	Dis (2)	N (3)	A (4)	SA (5)	M	SD	I
1	AR tools match well with what I am learning.	0	1	3	28	140	4.7	0.76	Strongly Agree
2	AR makes learning more interesting.	1	2	10	40	120	4.4	0.83	Strongly Agree
3	My teacher knows how to use AR well.	2	3	15	50	102	4.2	0.91	Strongly Agree
4	We use AR enough times in class to understand topics better.	4	7	25	70	67	3.9	1.12	Agree
5	AR helps me understand lessons better than normal teaching.	1	2	7	38	125	4.5	0.81	Strongly Agree

Note. Key: S Dis= Strongly Disagree, Dis = Disagree, N = Neither Agree nor Disagree, A = Agree, SA = Strongly Agree, M = Mean, SD = Standard Deviation, I= Interpretation.
Mean Interpretation: 1-1.79 = Strongly Disagree, 1.8-2.59 = Disagree, 2.6-3.39 = Neither Agree nor Disagree, 3.4-4.19 = Agree, 4.2-5.0 = Strongly Agree.

The findings indicate that trainees generally perceived AR as an effective instructional tool. The highest-rated item, *"AR tools match well with what I am learning"* (M = 4.7, SD = 0.76), suggests that AR content is well-aligned with course objectives and enhances the delivery of technical concepts. Similarly, the statement *"AR helps me understand lessons better than normal teaching"* (M = 4.5, SD = 0.81) indicates that AR supports conceptual clarity and improves comprehension. Moreover, trainees strongly agreed that *"AR makes learning more interesting"* (M = 4.4, SD = 0.83), reinforcing AR's role in promoting active learning and engagement.

The item *"My teacher knows how to use AR well"* received a mean of 4.2 (SD = 0.91), showing general agreement, although the variability suggests mixed perceptions about instructor proficiency. The relatively lower score for *"We use AR enough times in class to understand topics better"* (M = 3.9, SD = 1.12) may reflect limited access to AR tools or time constraints within the curriculum.

These results are consistent with findings from Riniati et al. (2024) and Rezai et al. (2025), who noted that AR-based instruction significantly enhances trainees'

comprehension and knowledge retention in technical fields. Ravichandran and Mahapatra (2023) and Tan et al. (2024) emphasize that AR increases cognitive engagement and supports differentiated instruction, particularly for abstract or spatially complex content in engineering education. Additionally, Sabri et al. (2024) report that AR strengthens the connection between instructional objectives and trainee experiences by providing intuitive, hands-on simulations.

However, the relatively modest rating on AR usage frequency and instructor mastery highlights a key challenge: teacher proficiency in AR integration. As Stanney et al. (2022) and Seyman Guray and Kismet (2023) observe, the success of AR in instructional design depends heavily on the instructors' technical skills, training, and confidence. Without adequate professional development, even the most advanced AR tools may fall short of their intended impact.

In summary, trainees viewed AR as a valuable instructional enhancement that promotes engagement, comprehension, and alignment with technical content. Nonetheless, maximizing its instructional benefits requires consistent integration into the curriculum and targeted training for educators. These findings underscore the importance of institutional support and strategic planning in adopting AR-based instructional strategies within TVET institutions.

4.5.2 Qualitative Analysis on Influences Instructional Strategies

To gain deeper insight into the influence of AR on instructional strategies in Building and Civil Engineering education, trainees' responses to the open-ended question *"How can we improve the use of AR in teaching?"* were thematically analyzed. Four core themes emerged: need for more frequent use, teacher training and support, better integration with content, and access to updated AR resources.

Many trainees expressed a desire for AR to be used more regularly in their lessons. One stated, *"We only use AR sometimes. If we had it every week, we would understand topics better."* Another shared, *"AR should not just be for a few topics. It should be used for all technical subjects."* This feedback underscores the importance of integrating AR as a consistent part of instructional delivery, echoing recommendations by Tan et al. (2024) and Riniati et al. (2024), who found that regular exposure to AR improves continuity and reinforcement of technical concepts in vocational education.

Trainees emphasized the need for instructors to be more confident and skilled in using AR tools. One remarked, *"Some teachers are not sure how to use the AR apps, so we don't use them much."* Another added, *"If teachers were trained more, we would use AR better in class."* These responses reflect the influence of instructor readiness on effective AR implementation, in line with findings by Sabri et al. (2024) and Ruhama et al. (2025), who stress that teacher digital literacy is key to successful AR integration in instructional strategies.

Several trainees recommended better alignment between AR simulations and course content. One stated, *"Sometimes the AR we use looks cool, but it doesn't match the topic well."* Another commented, *"We should have AR activities that follow what the teacher is explaining."* This theme highlights the importance of pedagogically aligned AR content, supporting insights by Sharmila (2024) and Teplá et al. (2022), who argue that AR must be strategically embedded within instructional goals to promote meaningful learning in technical subjects.

Trainees also called for improved access to AR-compatible devices and updated materials. One noted, *"Not everyone has a phone that works with AR. We should have school devices for that."* Another added, *"The AR apps sometimes don't load or are outdated. We need better ones."* These challenges reflect infrastructural barriers, as highlighted in studies by Suhail et al. (2024) and Yeap et al. (2021), who recommend institutional investment in modern devices and robust software to support widespread AR adoption in TVET institutions.

The qualitative findings show that while trainees recognize the value of AR in enhancing instructional delivery, its impact is dependent on how frequently and effectively it is used. Key improvement areas include consistent use of AR across lessons, enhanced teacher training, content alignment with curriculum, and improved access to functional AR tools.

These findings are consistent with those of Rezai et al. (2025), Sakr and Abdullah (2024), and Sundermann et al. (2022), who emphasize that the pedagogical effectiveness of AR depends not only on its presence in the classroom but also on how well it is integrated, supported, and resourced within instructional strategies.

4.5.3 Trainers' Interview on Instructional Strategies

To examine how AR influences instructional strategies in the teaching of Building and Civil Engineering technical content, qualitative interviews were conducted with 10 Construction Technology instructors one from each participating TVET institution in Nairobi County. These trainers had firsthand experience delivering instruction using AR-integrated methods in their respective institutions. Their responses, analyzed thematically, revealed significant shifts in pedagogical approaches, improvements in content delivery, and insights into both the benefits and challenges associated with using AR as a teaching tool.

A prominent theme was that AR had transformed the instructors' delivery methods from traditional lecture-based teaching to more interactive and visual-oriented strategies. Respondent 9 shared, *"I used to rely heavily on drawings and board illustrations, but with AR, I now show 3D simulations that trainees can walk around virtually. It has changed how I prepare and teach."* Respondent 5 added, *"The teaching has become more trainee-centered. I guide them as they explore concepts in AR rather than just explaining everything myself."* This shift from teacher-directed to trainee-centered instruction aligns with the constructivist principles emphasized by Scott and Husain (2021) and Riniati et al. (2024), which highlight the role of immersive tools in facilitating experiential learning.

Trainers unanimously agreed that AR-based instructional strategies were more effective than traditional approaches in improving the understanding of complex engineering concepts. Respondent 4 noted, *"AR helps them see how components come together in a structure. That's hard to explain with only theory or textbook diagrams."* Respondent 2 stated, *"Even topics that used to confuse trainees, like reinforcement detailing, now make sense because they can visualize the process."* These insights are consistent with findings by Teplá et al. (2022) and Tan et al. (2024), who reported that AR significantly enhances content clarity, especially in technical education domains.

The interviews also uncovered several benefits related to instructional flexibility and engagement. Many instructors pointed out that AR made lessons more dynamic and adaptable to different trainee needs. Respondent 6 said, *"I can adjust the AR demonstrations based on the trainees' pace and interest. That flexibility is harder with*

static slides or textbooks." Respondent 7 shared, *"It helps me cater to visual and hands-on trainees better than before."* This adaptability supports the inclusive instructional approaches discussed by Sahib et al. (2024) and Simonsmeier et al. (2022), who argue that AR enables differentiated teaching in diverse learning environments.

Despite the advantages, trainers also faced notable challenges in adopting AR as an instructional tool. Several respondents mentioned issues with device availability and occasional technical glitches. Respondent 7 commented, *"Sometimes, the AR app doesn't load properly or the devices lag. That disrupts the flow of the lesson."* Respondent 8 added, *"Not all trainees have smartphones that can handle the AR content, so we have to share or improvise."* These concerns echo the digital equity issues raised by Stanney et al. (2022) and Yao (2023), who warned that hardware limitations can hinder effective AR implementation in resource-constrained settings.

Additionally, a few trainers expressed a need for further training and institutional support. As Respondent 6 noted, *"I had to teach myself how to use AR through trial and error. Proper training would make it easier for more instructors to use it effectively."* This aligns with the findings of Siricharoen (2023) and Yazdi (2024), who emphasized the importance of professional development in digital pedagogy to maximize the impact of AR in technical and vocational education.

In summary, the trainers' perspectives highlight that AR has significantly influenced instructional strategies by promoting visual, experiential learning and enhancing trainee engagement. While its effectiveness in simplifying complex content is clear, successful implementation requires adequate infrastructure, institutional support, and ongoing training for instructors. These findings reinforce the pedagogical potential of AR, as discussed by Tan et al. (2022), Sakr and Abdullah (2024), and Garzón and Acevedo (2022), in transforming technical education through innovative instructional design.

4.6 Impact of augmented reality and retention of complex technical content.

This section presents the findings related to the impact of AR on enhancing trainees' retention of complex technical content within Building and Civil Engineering diploma programmes in TVET institutions. Retention of complex content is essential for sustained academic progress and professional competency in technical fields. AR, with its immersive and interactive capabilities, is posited to strengthen memory retention by facilitating deeper conceptual understanding, particularly for abstract or intricate engineering processes.

To assess this objective comprehensively, the analysis is structured under the following subheadings: Descriptive Analysis provides an overview of trainees' performance data, including pre-test and post-test mean scores across experimental and control groups, to establish baseline comparability and measure learning gains following the AR intervention. Pre-test and Post-test Analysis compares the pre-intervention and post-intervention scores to evaluate the extent of knowledge retention. This section examines mean differences, gain scores, and standard deviations to highlight the effectiveness of AR in reinforcing technical content. Inferential Analysis (t-tests and ANOVA) applies statistical tests to determine whether observed differences in content retention between AR-based and traditional instructional groups are statistically significant. Post Hoc and ANCOVA Analysis explores specific group differences and adjusts for prior knowledge to isolate the true impact of AR on retention outcomes. Qualitative Analysis includes Trainees' open-ended questionnaire responses and instructors' interviews, offering contextual explanations of how AR contributed to trainees' long-term understanding and recall of complex engineering concepts.

Through these analytical lenses, the study examines how AR enhances not just immediate comprehension, but also long-term retention of challenging content, validating AR as a powerful pedagogical tool in technical education.

4.6.1 Descriptive analysis on trainees' retention of complex

This section addresses the fourth specific objective, which sought to analyze how Augmented Reality influences trainees' understanding and long-term retention of complex technical content in Building and Civil Engineering diploma programmes

within TVET institutions. In technical education, where theoretical understanding must translate into practical execution, the retention of complex concepts is critical. AR-based learning environments are expected to enhance this retention by providing immersive, visual, and interactive experiences that help trainees internalize and recall difficult concepts more effectively over time.

To assess this relationship, the following hypothesis was tested:

Null Hypothesis (H_{03}): Augmented Reality has no significant impact on the retention of complex technical content by Building and Civil Engineering trainees.

A combination of descriptive statistics, correlation analysis, and multiple regression analysis was used to evaluate whether AR-based learning supports deeper comprehension and better long-term recall of complex content. Descriptive statistics were computed for five statements related to the use of AR in understanding and retaining technical concepts. A five-point Likert scale was used, where 5 = Strongly Agree and 1 = Strongly Disagree. Table 4.11 presents the mean scores and standard deviations for each item.

Table 4.11: Augmented Reality Improving Trainee Understanding and Retention of Complex Concepts

S No.	Statement	S Dis (1)	Dis (2)	N (3)	A (4)	SA (5)	M	SD	I
1.	AR improved my conceptual understanding of Building and Civil Engineering topics.	0	2	6	40	125	4.6	0.78	Strongly Agree
2.	Interacting with AR-enhanced materials made it easier for me to recall key concepts.	1	3	10	46	110	4.5	0.81	Agree
3.	AR encouraged me to participate more actively in learning complex engineering topics.	2	5	18	58	90	4.2	0.89	Agree
4.	AR-based lessons helped me think more critically about course concepts.	1	4	12	60	95	4.3	0.85	Agree
5.	The interactive nature of AR improved my ability to retain information compared to traditional methods.	1	3	10	55	103	4.4	0.83	Agree

Note. Key: S Dis= Strongly Disagree, Dis = Disagree, N = Neither Agree nor Disagree, A = Agree, SA = Strongly Agree, M = Mean, SD = Standard Deviation, I= Interpretation.
Mean Interpretation: 1-1.79 = Strongly Disagree, 1.8-2.59 = Disagree, 2.6-3.39 = Neither Agree nor Disagree, 3.4-4.19 = Agree, 4.2-5.0 = Strongly Agree.

The results show that trainees generally perceived AR as highly effective in enhancing the retention of complex engineering content. The highest-rated item, *"AR improved my conceptual understanding of Building and Civil Engineering topics"* (M = 4.6, SD = 0.78), indicates that AR significantly supports trainees in grasping abstract or challenging ideas through immersive visualizations. Similarly, the statement *"Interacting with AR-enhanced materials made it easier for me to recall key concepts"* (M = 4.5, SD = 0.81) affirms AR's role in promoting long-term knowledge retention.

These findings are consistent with studies by Riniati et al. (2024) and Rezai et al. (2025), who found that AR improves comprehension and memory retention by engaging multiple sensory channels and reducing cognitive overload. According to Yilmaz (2021) and Sweller (1988), AR's ability to simplify cognitive processing supports meaningful learning and facilitates recall in complex subjects.

Trainees also agreed that *"AR encouraged active participation in learning complex engineering topics"* (M = 4.2, SD = 0.89) and *"AR-based lessons helped me think more critically"* (M = 4.3, SD = 0.85), indicating that AR not only aids memory but also fosters critical engagement with the content. These outcomes support Tan et al. (2024) and Sabri et al. (2024), who emphasized that AR enhances interactive learning and promotes analytical thinking in engineering education.

Furthermore, the statement *"The interactive nature of AR improved my ability to retain information compared to traditional methods"* (M = 4.4, SD = 0.83) highlights AR's superiority over conventional instructional techniques in facilitating long-term learning. As Simonsmeier et al. (2022) and Suhail et al. (2024) noted, AR's immersive and task-relevant environments improve encoding and retrieval, key processes in information retention.

Overall, the descriptive findings strongly support the effectiveness of AR in enhancing trainees' retention of complex technical content. These insights reinforce the importance of integrating AR into instructional practices, especially in content-heavy technical disciplines like Building and Civil Engineering. However, successful implementation depends not only on the availability of AR tools but also on educators' capacity to design cognitively optimized AR-based learning experiences (Stanney et al., 2022; Sakr & Abdullah, 2024).

4.6.2 Pre-Test and Post-Test on trainees' retention of complex

To analyze how Augmented Reality influences the retention of complex technical content, a structured experimental design involving pre-test and post-test assessments was adopted. This approach enabled a clear comparison between traditional and AR-enhanced instruction, providing evidence on AR's potential to improve how Building and Civil Engineering trainees retain intricate concepts over time (Williams et al., 2025).

Table 4.12 shows the pre-test scores for Experimental Group 1 (E1) and Control Group 1 (C1), each comprising 88 trainees.

Table 4.12: 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

The low mean scores in both groups (34.52 for E1 and 31.26 for C1, out of 100 marks) reflect limited prior understanding of complex concrete technology content, as the pre-test was administered before any instruction. However, these results also indicate some baseline familiarity with the concepts, offering a foundation for measuring learning retention after instructional intervention. This is presented in the Figure 4.5.

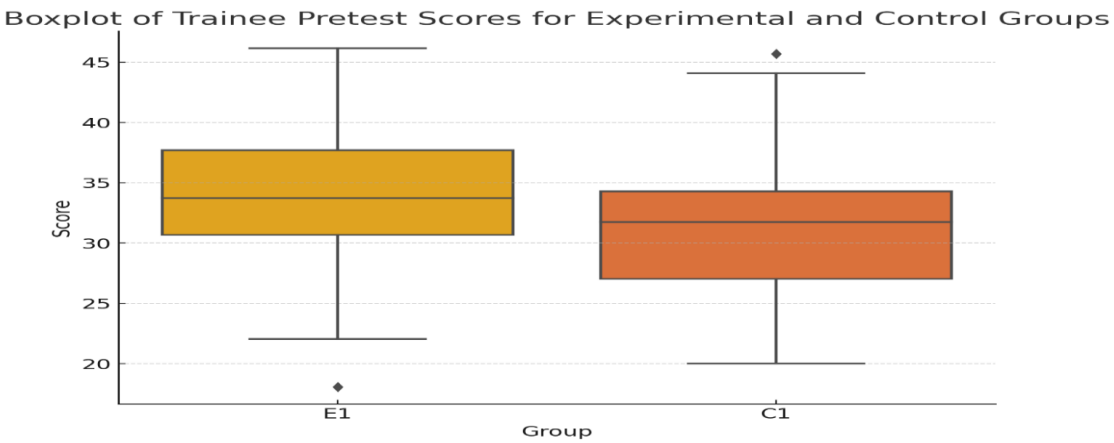


Figure 4.5: Boxplot of trainee pretest score for Experimental and Control Group

The boxplot analysis comparing pre-test scores between Experimental Group 1 (E1) and Control Group 1 (C1) confirmed baseline equivalence an essential prerequisite for assessing the effectiveness of instructional interventions. Although the experimental group showed a slightly higher median score, both groups displayed similar interquartile ranges (IQRs), suggesting comparable variability in prior knowledge. The whisker lengths were also similar, with only minor differences in score distribution, and no significant outliers were observed. This affirmed the reliability and consistency of the pre-test data, indicating that both groups began the intervention

with relatively equal academic capabilities. This comparability ensured a valid foundation for attributing any observed post-test improvements specifically to the AR intervention.

The mean pre-test scores, 34.52 for E1 and 31.26 for C1 out of 100, were generally low, reflecting limited prior retention of technical content in Concrete Technology. This was expected, as the assessment was conducted before any instructional exposure to the topic (Akinradewo et al., 2025; Affandi et al., 2024). An independent t-test further confirmed that the difference in pre-test scores was not statistically significant, reinforcing that both groups were on an equal footing at the start of the study. This baseline equivalence was critical in ensuring that any differences in post-test performance could be attributed to the AR-based instructional method, rather than pre-existing knowledge disparities (Chandanani et al., 2025).

During the intervention, the experimental group engaged with immersive AR simulations that visually demonstrated complex technical processes such as concrete hydration and strength development. These tools were intentionally designed to address the content areas where trainees showed limited understanding during the pre-test. It was hypothesized that this method would lead to improved conceptual retention compared to conventional teaching approaches (Huang et al., 2024; Jeong, 2022).

The post-test, administered after the instructional phase, aimed to measure both short-term learning gains and the retention of complex technical content. AR's interactive features, including dynamic visualizations and user-controlled simulations, were expected to facilitate deeper engagement and longer-term memory consolidation (Kumar & Praveenakumar, 2025). A combination of paired and independent t-tests, alongside effect size calculations, was employed to rigorously assess the impact of AR on content retention.

These results are supported by earlier studies highlighting AR's role in improving the retention of complex technical knowledge. Álvarez-Marín et al. (2022) found that AR significantly enhanced trainees' ability to comprehend and remember intricate engineering concepts, while Tan et al. (2024) emphasized its effectiveness in creating interactive learning environments that promote lasting understanding. Consequently, the pre-test findings and the structure of the experimental design together established

a robust framework for evaluating the contribution of AR to improved retention of complex content in Concrete Technology within TVET institutions.

To determine whether there was a statistically significant difference between the pre-test scores of the two groups, an independent t-test was conducted, and the findings are presented in Table 4.13.

Table 4.13: 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 4.13 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.

Additionally, the researcher examined the mean differences in academic achievement by comparing the post-test mean scores for both Experimental Group 1 (E1) and Control Group 1 (C1). The post-test results, which assess the impact of AR integration, are presented in Table 4.14.

Table 4.14: 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

The post-test results presented in Table 4.14 highlight clear differences in mean scores among the four study groups. Experimental Group 1 (E1), which received AR-based instruction, attained the highest mean score of 76.49 (SD = 9.12), closely followed by

Experimental Group 2 (E2) with a mean of 75.89 (SD = 9.22). In contrast, the control groups, which were instructed using conventional lecture-based methods, recorded significantly lower mean scores 57.86 (SD = 12.97) for Control Group 1 (C1) and 55.61 (SD = 11.48) for Control Group 2 (C2).

These results indicate that trainees exposed to AR-enhanced instruction demonstrated superior retention of complex technical content in Concrete Technology compared to their peers in the control groups. The minimal difference in performance between E1 and E2 further suggests that the presence or absence of a pre-test had little impact on the effectiveness of AR in supporting content retention. This finding reinforces the robustness of AR as a tool for facilitating deep learning regardless of initial assessment.

Moreover, the lower standard deviations observed in the experimental groups (9.12 for E1 and 9.22 for E2) compared to the control groups (12.97 for C1 and 11.48 for C2) point to more consistent retention outcomes among trainees exposed to AR. Conversely, the greater variability in the control groups implies inconsistent learning gains under traditional instruction. Overall, the findings affirm that AR-based instructional strategies contribute significantly to improving the retention of complex engineering concepts, thereby enhancing academic achievement in Building and Civil Engineering training within TVET institutions. This is presented in the Figure 4.6.

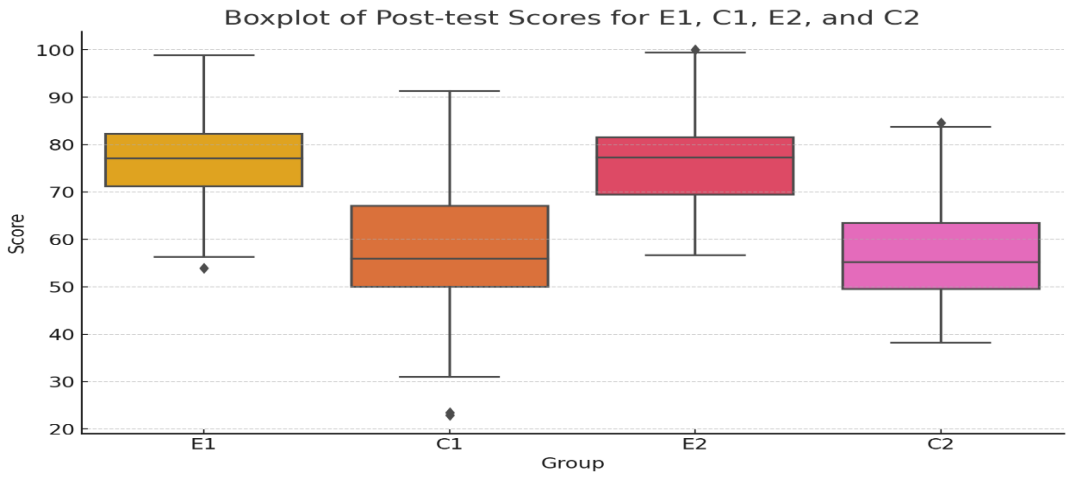


Figure 4.6: post-test mean scores of the four groups

The boxplot comparing the post-test mean scores of the four groups (E1, C1, E2, and C2) clearly illustrates the impact of AR on the retention of complex technical content among Building and Civil Engineering trainees. The experimental groups (E1 and E2), who received AR-enhanced instruction, achieved significantly higher mean scores (76.49 and 75.89, respectively) than their counterparts in the control groups (C1 and C2), who scored 57.86 and 55.61, respectively. These results suggest that the integration of AR into instruction substantially supported trainees in retaining intricate Concrete Technology concepts. The narrower Interquartile Ranges (IQRs) observed in the experimental groups also indicate more consistent performance, pointing to uniform learning gains among trainees exposed to AR. In contrast, the control groups exhibited wider variability, reflecting inconsistent retention outcomes under traditional instructional methods.

The superior performance of the experimental groups aligns with findings from Fitrianto and Saif (2024), who reported that AR induces engagement and long-term retention through interactive and immersive learning. Similarly, Bernacki et al. (2021) highlighted the value of AR in helping trainees visualize and internalize complex engineering processes, which leads to improved comprehension and retention. The higher standard deviations in the control groups (12.97 and 11.47) compared to the experimental groups further reinforce this point, suggesting that traditional lecture methods result in varied retention levels depending on individual learning abilities and motivation.

Collectively, these results underscore AR's potential as a transformative instructional approach in technical and vocational training. The consistent retention gains observed across both experimental groups confirm the scalability and reliability of AR-based learning, regardless of cohort differences. Given these findings, it is recommended that TVET institutions integrate AR tools into their curricula to enhance the retention of complex engineering content and to address persistent gaps in conceptual understanding among trainees.

To establish whether the differences in post-test mean scores across the four groups are statistically significant, an Analysis of Variance (ANOVA) was conducted, as presented in Table 4.15.

Table 4.15: 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			

In Table 4.15, the variable being tested is the effect of instructional methods on the retention of complex technical content in Concrete Technology, as measured by trainees' post-test scores. The independent variable comprises the type of instruction AR-enhanced instruction for the experimental groups (E1 and E2) versus traditional lecture-based instruction for the control groups (C1 and C2) while the dependent variable is the trainees' performance on the post-test, which serves as a proxy for knowledge retention.

The ANOVA results, $F(3, 341) = 27.97$, $p < .001$, indicate a statistically significant difference in post-test performance among the four groups. The between-groups sum of squares (710.5) and the mean square value (236.833) reflect considerable variance in retained knowledge across the instructional conditions, while the within-groups sum of squares (2880.1) reflects individual variability within each group. The significance level ($p = .000$) confirms that the observed differences in retention were not due to chance, thereby supporting the conclusion that AR-enhanced instruction significantly improved the retention of complex content compared to traditional teaching methods.

Following the significant ANOVA findings, a post hoc multiple comparison analysis was conducted using the Bonferroni test to identify specific group differences. This test was selected for its robustness in controlling the overall Type I error rate during multiple comparisons. The results of this analysis are presented in Table 4.16.

Table 4.16: 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 was conducted to compare post-test scores across the four groups, aiming to evaluate the effectiveness of AR in enhancing trainees' retention of complex technical content in Concrete Technology. In this analysis, the dependent variable was the post-test score, interpreted as a measure of content retention, while the independent variable was the instructional method used (AR-enhanced vs. traditional lecture-based). The results revealed that the experimental groups (E1 and E2), which received AR-based instruction, significantly outperformed the control groups (C1 and C2). Specifically, the mean difference between E1 and C1 was 18.63 ($p = 0.02$), and between E1 and C2, it was 20.88 ($p = 0.016$), clearly demonstrating AR's positive impact on the retention of complex theoretical content. Similarly, the differences between E2 and both control groups were statistically significant. Notably, the difference between E1 and E2 was minimal (0.6, $p = 0.964$), indicating that the presence or absence of a pre-test did not affect the retention outcomes of AR-enhanced learning. On the other hand, the comparison between C1 and C2 yielded a non-significant difference (2.25, $p = 1.0$), reaffirming the limited effectiveness of traditional instruction in promoting content retention.

These findings, corroborated by the significant ANOVA results, confirm that integrating AR into instructional delivery significantly strengthens trainees' retention of complex content by improving visualization, comprehension, and trainee

engagement. Consequently, the study rejects the null hypothesis, which posited no significant effect of AR on learning outcomes. Instead, the evidence supports the assertion that Augmented Reality contributes meaningfully to trainees' cognitive retention of intricate concepts in Concrete Technology, consistent with the findings of Cheng et al. (2024), Huang et al. (2024), and Demircioglu et al. (2023).

To address potential baseline disparities in prior knowledge, the study further employed Analysis of Covariance (ANCOVA), using pre-test scores as a covariate. This approach adjusted the post-test means to isolate the true effect of the instructional method on content retention. The ANCOVA results confirmed that even after controlling for initial academic preparedness, AR-enhanced instruction remained significantly more effective in promoting the retention of complex technical content. This integrated use of ANOVA, ANCOVA, t-tests, and Bonferroni post hoc testing ensures a comprehensive and rigorous analysis, affirming that AR-based instruction is superior to traditional methods in fostering deeper and longer-lasting learning in Building and Civil Engineering education (Mugenda & Mugenda, 2003; Faridi et al., 2021; Mlambo et al., 2024). This is presented in the Table 4.17.

Table 4.17: 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			

The adjusted Post-test mean for C2 is presented in the Table 4.18.

Table 4.18: Adjusted Post-Test Mean for C2

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

The ANCOVA results offer compelling evidence that both prior knowledge (as measured by pre-test scores) and the type of instructional method significantly influenced trainees' retention of complex technical content in Concrete Technology. By accounting for baseline academic differences, ANCOVA isolated the true effect of the instructional intervention. The covariate pre-test scores had a statistically significant impact on post-test performance ($F(1, 341) = 28.04$, $p < .001$), confirming that initial understanding played a role in post-intervention outcomes (Zhao & Li, 2023). More critically, the type of instruction was also statistically significant ($F(3, 341) = 27.97$, $p < .001$), with AR-enhanced instruction leading to stronger retention outcomes than traditional methods.

Notably, the adjusted post-test means for Control Group 2 (C2) dropped to 49.61 from an unadjusted 55.61 after controlling for prior knowledge. This suggests that pre-existing knowledge may have slightly inflated raw scores in the control group, and when corrected, the impact of traditional instruction on content retention appeared even weaker. In contrast, the adjusted scores for experimental groups remained consistently higher, reaffirming AR's effectiveness in enhancing trainees' ability to retain intricate engineering concepts. These findings are in line with prior research demonstrating that immersive and interactive tools like AR help solidify understanding and long-term recall of complex subject matter (AlGerafi et al., 2024).

The ANCOVA results complement earlier statistical tests, including t-tests, ANOVA, and Bonferroni post hoc analysis, all of which reinforce the conclusion that AR-based learning significantly improves content retention. This confirms that the AR approach not only boosts short-term comprehension but also supports the long-term consolidation of knowledge key to mastering technical subjects in Building and Civil Engineering. Similar outcomes have been reported in studies by Kim et al. (2022), Wang and Xie (2023), and Sakr and Abdullah (2024), who found that AR facilitates sustained engagement and deeper learning in technical education contexts.

Furthermore, the lower variability and higher adjusted mean scores among AR-exposed groups indicate that trainees benefitted from a more structured, engaging, and cognitively supportive learning process. This consistency supports Alnajim's (2023) findings on the value of AR in ensuring equitable learning outcomes. Overall, these results provide robust empirical backing for the integration of AR into TVET programmes as a strategic instructional tool that enhances the retention of complex technical content, ultimately strengthening trainee competency and preparedness in real-world engineering applications (Chen & Chan, 2024).

4.6.3 Qualitative Analysis on trainees' retention of complex

To complement the quantitative findings, a thematic analysis was conducted on trainees' responses to the open-ended question: *"In what ways has AR influenced your approach to taking charge of your own learning?"* The goal was to explore how AR contributes to trainees' understanding and long-term retention of complex concepts in Building and Civil Engineering courses within TVET institutions.

Four key themes emerged: visualization of abstract concepts, improved recall through interaction, increased curiosity and independent exploration, and personalized learning pace.

Many trainees indicated that AR helped them grasp difficult engineering topics by allowing them to visualize abstract content. One trainee shared, *"Seeing 3D structures made it easier to understand what we were learning. I don't forget it easily."* Another remarked, *"Instead of imagining how things work, I could see and rotate them in AR."* These insights align with research by Wang et al. (2025) and Takrouri et al. (2022), who found that immersive visualization through AR significantly enhances concept retention in STEM education.

Trainees frequently noted that interactive engagement with AR materials strengthened their ability to remember technical content. One stated, *"I can remember topics better when I interact with them in AR than just listening in class."* Another explained, *"The movement and touch made the ideas stick in my head longer."* This supports the work of Stanney et al. (2022) and Teplá et al. (2022), who emphasized that sensory involvement in AR enhances memory encoding, especially for complex technical concepts.

Several trainees described how AR made them more curious and motivated to explore learning materials beyond class time. For instance, one wrote, *"After using AR in class, I wanted to go back and try things on my own to understand them more."* Another said, *"It made me interested in finding out how things work, even outside the lessons."* This finding resonates with Rotsios et al. (2022) and Sharmila (2024), who argue that AR can stimulate self-initiated learning by sparking interest and encouraging knowledge-seeking behavior.

Many trainees valued the ability to learn at their own pace using AR applications. One mentioned, *"I can revisit the simulations as many times as I want until I get it."* Another said, *"With AR, I don't have to rush I learn when I'm ready."* This theme reflects the benefits of personalized pacing, as discussed by Ryan et al. (2022) and Siricharoen (2023), who suggest that AR allows trainees to tailor their learning speed, which is particularly important for mastering technical details.

The qualitative findings demonstrate that AR significantly contributes to content retention by enhancing visualization, promoting active learning, stimulating trainee curiosity, and supporting personalized study routines. Trainees reported improved memory of complex concepts, greater engagement, and increased motivation to revisit and review materials independently.

These outcomes are supported by studies such as Sakr and Abdullah (2024), Rezai et al. (2025), and Silva et al. (2024), which collectively highlight the capacity of AR to not only improve conceptual understanding but also strengthen long-term retention through immersive, trainee-centered strategies.

4.6.4 Trainers' Interview on trainees' retention of complex

To analyze how AR supports the retention of complex engineering concepts among Building and Civil Engineering trainees, interviews were conducted with 10 construction technology instructors each representing a participating TVET institution in Nairobi County. The trainers, who were directly involved in teaching the research unit, shared their experiences with AR integration in lessons requiring high cognitive demand and conceptual depth. A thematic analysis of their responses revealed clear trends in the improved retention of technical content, particularly due to AR's visualization, repetition, and interactivity features.

All interviewed trainers reported that AR significantly helped trainees grasp and retain difficult engineering concepts more effectively than traditional methods. Respondent 6 explained, *"With AR, trainees don't just listen they see and interact. That makes them remember better, especially when we revisit the content later."* Respondent 5 echoed, *"Trainees can recall even small details of a structure they interacted with weeks ago, something that rarely happens with chalk-and-talk lessons."* These findings align with Sweller's (1988) Cognitive Load Theory, which posits that visual aids reduce extraneous cognitive load, and with Garzón and Acevedo (2022), who emphasized that immersive tools facilitate deeper processing and memory retention.

Several trainers also highlighted specific content areas where AR had the most pronounced impact on retention. Respondent 1 noted, *"AR works best for abstract and spatial topics like load paths, reinforcement patterns, and plumbing layouts. Once they see it in 3D, it sticks."* Respondent 10 added, *"Trainees often struggle with structural behavior, but the AR animations help them visualize forces and deformations. That understanding lasts beyond exams."* This observation is supported by Zhang et al. (2023) and Rezai et al. (2025), who found that spatially demanding content is best retained when trainees engage with it through interactive 3D simulations.

Trainers also emphasized the role of AR visualizations in supporting long-term memory formation. Respondent 4 explained, *"AR allows them to walk through a system or structure in a way that's similar to being on-site. That level of immersion reinforces memory."* Respondent 8 described AR as a "mental blueprint," stating, *"Even in later lessons, trainees recall the AR simulations and apply what they saw earlier. It's like building memory with pictures and motion."* This aligns with Scavarelli et al. (2021) and Yilmaz (2021), who asserted that AR enhances recall by linking content with spatial-temporal experiences.

Despite these advantages, a few trainers noted the importance of pairing AR with reflective activities to deepen learning. Respondent 10 mentioned, *"AR shows them the concept, but we also ask them to explain or draw what they saw. That combination really boosts retention."* This approach resonates with the recommendations of

Rotsios et al. (2022), who argue that AR's benefits are maximized when integrated with active learning strategies such as reflection, discussion, and hands-on practice.

In conclusion, trainers confirmed that AR plays a valuable role in enhancing the retention of complex technical content. By making abstract topics visible and interactive, AR helps trainees form strong mental representations that endure over time. However, the effectiveness of AR in supporting long-term memory is most evident when it is used deliberately for challenging content areas and reinforced through complementary instructional techniques. These findings underscore the potential of AR to transform technical education by supporting sustained learning, as emphasized by Stanney et al. (2022), Ryan et al. (2022), and Takrouri et al. (2022).

4.7 Impact of augmented reality and self-directed learning among trainees.

This section presents findings on the influence of Augmented Reality on the development of effective self-directed learning among trainees in Building and Civil Engineering diploma programmes within TVET institutions. AR technology promotes autonomy by enabling trainees to explore content interactively, revisit complex concepts at their own pace, and engage with materials beyond the constraints of traditional classroom instruction. Developing self-directed learning is particularly vital in technical education, where ongoing practice and independent inquiry are essential for mastery.

The findings are organized into the following sub-sections: Descriptive Analysis provides statistical summaries from trainee questionnaires that capture perceptions of how AR impacted their ability to set learning goals, seek out additional resources, and take responsibility for their learning process. Qualitative Analysis that includes open-ended responses analyzes trainees' written reflections on how the use of AR supported independent learning, critical thinking, and personal motivation to engage with technical content beyond classroom requirements and interview findings that summarizes instructors' views gathered from interviews, focusing on observed changes in trainees' learning behaviours, initiative, and capacity to manage their own learning through AR-enhanced instructional environments.

Together, these analyses offer a well-rounded assessment of how AR contributes to fostering effective self-directed learning skills among trainees, a crucial competency for success in dynamic and evolving technical fields.

4.7.1 Descriptive analysis on self-directed learning among trainees

This section presents findings related to the third specific objective, which aimed to determine how AR influences the development of self-directed learning (SDL) among trainees in Building and Civil Engineering diploma programmes within TVET institutions. Self-directed learning is a vital component of academic success, especially in technical fields that require autonomous problem-solving, time management, and consistent engagement with learning resources. It involves trainees taking the initiative in planning, monitoring, and evaluating their learning processes.

AR is believed to encourage SDL by providing engaging, interactive, and trainee-controlled content that supports independent exploration and flexible study pacing. The integration of AR into instructional practices is expected to promote behaviors such as goal setting, self-monitoring, and motivation to learn beyond classroom settings.

To assess this relationship, the following hypothesis was tested:

Null Hypothesis (H_{04}): Augmented reality has no significant effect on the development of effective self-directed learning among trainees.

Descriptive statistics, correlation analysis, and multiple regression analysis were employed to examine whether AR-based learning influences study autonomy, planning, and confidence in independent learning. Five statements were used to measure trainees' perceptions of AR's role in promoting SDL. Responses were rated on a five-point Likert scale from 1 (Strongly Disagree) to 5 (Strongly Agree), as shown in Table 4.19.

Table 4.19: Augmented Reality and Self-Directed Learning

No.	Statement	S Dis (1)	Dis (2)	N (3)	A (4)	SA (5)	M	SD	I
1.	I use AR tools on my own outside of class.	10	30	50	47	36	3.37	1.44	Not Sure
2.	I feel confident using AR without help.	4	12	26	82	49	3.90	1.07	Agree
3.	I plan my own studies using AR.	5	10	27	80	50	3.90	1.13	Agree
4.	AR helps me learn at my own pace.	2	8	15	65	83	4.20	1.01	Strongly Agree
5.	I explore AR content to understand better.	12	26	58	42	33	3.20	1.39	Not Sure

Note. Key: S Dis= Strongly Disagree, Dis = Disagree, N = Neither Agree nor Disagree, A = Agree, SA = Strongly Agree, M = Mean, SD = Standard Deviation, I= Interpretation.
Mean Interpretation: 1-1.79 = Strongly Disagree, 1.8-2.59 = Disagree, 2.6-3.39 = Neither Agree nor Disagree, 3.4-4.19 = Agree, 4.2-5.0 = Strongly Agree.

The results indicate varied trainee perceptions of AR's role in fostering self-directed learning. The highest-rated item, *"AR helps me learn at my own pace"* (M = 4.20, SD = 1.01), suggests that AR supports autonomy by allowing trainees to control the speed and sequence of learning an essential trait in SDL. Similarly, the statements *"I feel confident using AR without help"* and *"I plan my own studies using AR"* both scored M = 3.90, indicating that AR contributes to trainees' confidence and planning skills.

However, the statements *"I use AR tools on my own outside of class"* (M = 3.37, SD = 1.44) and *"I explore AR content to understand better"* (M = 3.20, SD = 1.39) fell within the "Not Sure" category. These results reflect uncertainty about the degree to which AR is used independently beyond the classroom and whether it encourages deeper self-motivated exploration of learning materials.

These findings align with the work of Sabri et al. (2024) and Suhail et al. (2024), who emphasize that AR can foster self-directed learning when appropriately integrated into curriculum and supported by scaffolding. AR offers a trainee-centered environment where trainees can take initiative and reflect on their learning, which is particularly beneficial in technical fields that demand continuous knowledge application. As Tan et al. (2024) and Rezai et al. (2025) have noted, AR's interactive features can

strengthen SDL by encouraging active engagement and persistence with challenging tasks.

However, the neutral responses regarding independent AR use and content exploration suggest that while trainees may appreciate AR for structured classroom learning, its potential for independent learning has not been fully realized. This could be due to limitations in access, digital literacy, or lack of clear guidance on using AR tools autonomously points similarly raised by Stanney et al. (2022) and Seyman Guray and Kismet (2023), who stress that trainees need digital confidence and institutional support to fully benefit from AR-based SDL environments.

In conclusion, the findings show that AR contributes positively to aspects of self-directed learning such as pacing, confidence, and planning, but its impact on independent learning outside structured environments remains limited. To maximize its effectiveness, TVET institutions must support AR integration not only during instruction but also in trainee autonomy strategies through increased access, orientation sessions, and personalized learning paths.

4.7.2 Qualitative Analysis on self-directed learning among trainees

A thematic analysis was conducted on trainees' responses to the open-ended question: *"In what ways did AR help you understand and retain complex engineering concepts better than traditional teaching methods?"* This analysis aimed to uncover how AR supports the development of self-directed learning behaviours among Building and Civil Engineering trainees in TVET institutions. Four primary themes emerged: enhanced trainee autonomy, individualized pacing, active experimentation, and motivation to explore.

Trainees consistently reported that AR made them more independent in their learning process. One participant shared, *"With AR, I didn't wait for the teacher to explain everything. I would try out the app first, then ask questions later."* Another commented, *"It encouraged me to take charge of my learning and find answers on my own."* These observations reflect the findings of Simonsmeier et al. (2022) and Takrouri et al. (2022), who noted that AR environments encourage trainees to initiate their own learning paths and explore materials proactively.

Many respondents expressed appreciation for the ability to study at a self-chosen pace. One noted, *"AR let me go over the parts I didn't understand again and again until I got it."* Another said, *"Unlike in class where the teacher moves on, AR gave me time to catch up at my own speed."* This echoes studies by Teplá et al. (2022) and Sakr and Abdullah (2024), which suggest that the self-paced nature of AR supports deep learning, particularly for trainees with varied academic backgrounds.

Trainees emphasized how AR allowed them to experiment and test engineering concepts outside the classroom. One said, *"I was able to practise on my own using AR without needing machines or a lab."* Another mentioned, *"The simulations helped me try things out without fear of making mistakes."* These reflections align with Xie et al. (2022) and Ruhama et al. (2025), who highlight AR's capacity to simulate technical processes and encourage experiential learning, a key driver of self-directed mastery.

Several trainees reported that AR sparked their curiosity and made them more engaged with the subject matter. One shared, *"I wanted to learn more after using AR because it made the topic more exciting."* Another added, *"It was more interesting than just notes or lectures, and that made me read more even outside class."* This corresponds with findings by Siricharoen (2023) and Rotsios et al. (2022), who observed that AR enhances intrinsic motivation, which is vital for sustaining self-directed learning habits.

Trainees perceived AR as a tool that significantly supports self-directed learning by enhancing autonomy, enabling self-paced study, encouraging active practice, and boosting motivation. These qualitative insights suggest that AR fosters habits of independent learning and engagement that traditional teaching methods may not consistently promote.

These findings align with the works of Sweller (1988), Shaghaghian et al. (2022), and Ryan et al. (2022), who stress that AR's interactive and trainee-controlled features help cultivate essential self-regulation skills necessary for success in complex technical education.

4.7.3 Trainers' Interview on self-directed learning among trainees

To explore how AR influences the development of self-directed learning among Building and Civil Engineering trainees, interviews were conducted with 10 construction technology instructors one from each TVET institution participating in the study. These instructors were selected based on their active engagement with the AR-based instructional interventions and their direct role in guiding trainee learning. Thematic analysis of their responses revealed that AR fosters trainee autonomy, curiosity, and independent study habits, although some challenges related to digital readiness were also identified.

Most trainers observed a noticeable shift in trainees' learning behaviors after the introduction of AR. Respondent 6 remarked, *"Since we introduced AR, trainees don't wait for the teacher to explain everything they take initiative, pause, explore, and repeat simulations on their own."* Respondent 3 added, *"You can tell they're more in control of how they learn. Some even come to class with questions based on what they've tried at home."* This aligns with findings by Simonsmeier et al. (2022) and Sharmila (2024), who highlight that interactive learning environments, like AR, promote trainee agency by supporting independent knowledge construction.

Trainers also noted that AR motivated trainees to explore content beyond scheduled lessons. Respondent 2 explained, *"We've seen more trainees using AR apps outside class hours, especially those who want to go deeper into technical concepts or catch up at their own pace."* Respondent 9 observed, *"Some trainees review simulations on their own before practical lessons it shows they're planning and managing their learning, which wasn't common before."* These findings echo Vairamani (2024) and Siricharoen (2023), who reported that AR enhances trainee motivation and encourages study beyond the classroom through interactive exploration.

However, a few trainers expressed concerns about varying levels of digital independence among trainees. Respondent 8 noted, *"While some trainees thrive with AR, others need a lot of guidance. Without that, they get distracted or frustrated."* Respondent 5 cautioned, *"AR can be overwhelming if trainees are not digitally literate or don't understand how to navigate the content effectively."* This is consistent with findings by Takrouri et al. (2022) and Vaithianathan et al. (2024), who emphasized

the importance of structured onboarding and scaffolding to support self-regulated learning with AR tools.

Several trainers emphasized that AR's flexible, trainee-controlled features supported individualized learning paths. Respondent 7 shared, *"Trainees use it differently some focus on repeating tasks, others on visualizing difficult structures. It allows them to tailor their study according to their needs."* This is in line with Tobias et al. (2024) and Riniati et al. (2024), who argue that AR aligns well with personalized learning strategies by enabling trainees to pace, revisit, and organize content independently.

In conclusion, the interviews indicated that AR-based instruction positively contributes to the development of self-directed learning among trainees. It induces trainee engagement, encourages initiative, and supports time management and independent exploration. However, to optimize these benefits, trainers highlighted the need for digital support structures that address trainee variability in autonomy and technical proficiency. These findings reinforce the role of AR in building modern learning competencies essential for success in technical education environments.

4.8 Multiple Regression

Multiple regression analysis was conducted to explore the extent to which AR–based instructional dimensions predict the overall academic achievement of trainees in Building and Civil Engineering diploma programmes in Nairobi's TVET institutions. This analysis directly supports the sixth objective of the study, which is to assess the overall impact of AR on academic achievement. The independent variables used in the regression model include AR-induced trainee engagement, AR-influenced instructional strategies, AR-facilitated retention of complex technical content, and AR-supported self-directed learning. Trainees' prior knowledge (Objective 5), which serves as a moderating factor, is also considered in an extended regression model for further analysis.

The multiple regression model follows the equation:

Equation 4.3: Multiple regression model equation

$$Y = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \beta_3 X_3 + \beta_4 X_4 + \varepsilon$$

Where;

$$Y = Academic\ Achievement$$

$$X_1 = Trainees\ Engament$$

$$X_2 = Instructional\ Strategies$$

$$X_3 = Self - directed\ learning$$

$$X_4 = Retention\ of\ Complex\ Content$$

$$\beta_0 = Intercept$$

$$\beta_1, \beta_2, \beta_3, \beta_4 = Regression\ Coefficients$$

$$\varepsilon = Error\ term$$

To interpret the model, three key outputs were generated: the model summary, the ANOVA table, and the regression coefficients table. The model summary reports the R-squared (R^2) and adjusted R^2 values, indicating the proportion of variance in academic achievement that can be explained by the selected AR-based predictors. The ANOVA table tests the overall significance of the regression model, confirming whether the set of predictors reliably forecasts academic outcomes. Lastly, the regression coefficients table displays both unstandardized (B) and standardized (β) coefficients, along with their associated p-values, to assess the strength and statistical significance of each variable's contribution to academic performance.

This regression analysis provides critical insights into which AR-enhanced instructional elements are most impactful in improving academic outcomes. It strengthens the argument for integrating AR technologies in technical education by empirically demonstrating their predictive relationship with academic achievement,

thereby reinforcing the value of AR in pedagogical strategies across TVET institutions. This is presented in the Table 4.20.

Table 4.20: Model Summary of Multiple regression analysis

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.746[a]	.557	.538	.673

a. Predictors: (Constant), trainees' engagement, instructional strategies, retention of complex technical content, and self-directed learning

Table 4.20 presents the results of the multiple regression analysis conducted to evaluate the overall predictive power of AR-related instructional components on trainees' academic achievement in Building and Civil Engineering diploma programmes. The model includes four key independent variables AR-induced trainee engagement, AR-based instructional strategies, AR-enhanced self-directed learning, and AR-supported retention of complex technical content reflecting the core dimensions articulated in the revised study objectives.

The model yielded a multiple correlation coefficient (R) of 0.746, indicating a strong positive relationship between the selected AR-related instructional strategies and academic achievement. The R Square value of 0.557 implies that approximately 55.7% of the variance in trainee academic achievement can be explained by the collective influence of the four AR constructs. This finding supports Objective 6, which sought to assess the overall impact of AR on academic performance, and aligns with research by Williams et al. (2025) and Ryan et al. (2022), who reported similarly strong predictive relationships between immersive technologies and learning outcomes in technical education.

The Adjusted R Square of 0.538 which accounts for the number of predictors in the model further affirms the model's reliability by showing that 53.8% of the variance in academic performance remains stable after adjusting for possible overfitting. This aligns with the findings of Scavarelli et al. (2021) and Sabri et al. (2024), who emphasized that AR-based environments provide robust scaffolding that improves not only trainee engagement but also performance consistency across diverse learning contexts.

The Standard Error of the Estimate (0.673) reflects the average deviation of the predicted academic achievement scores from the actual scores. A relatively low value here supports the model's goodness-of-fit and predictive validity, reinforcing the position of Sweller (1988) and Stanney et al. (2022) that AR technologies, when designed to reduce cognitive overload and enhance visualization, improve the precision and reliability of learning outcomes.

Taken together, these results strongly support the hypothesis that AR, as implemented across the four domains in this study, has a significant and positive impact on academic achievement among Building and Civil Engineering trainees. They also underscore the importance of a multidimensional integration of AR one that goes beyond content delivery to actively promote trainee autonomy, instructional innovation, and knowledge retention, echoing insights from Rezai et al. (2025), Yilmaz (2021), and Tan et al. (2022). The results presented in Table 4.21.

Table 4.21: AVOVA table

Model		Sum of Squares	Df	Mean Square	F	Sig.
1	Regression	95.772	4	23.943	52.854	.000[b]
	Residual	76.170	168	0.453		
	Total	171.942	172			

a. Dependent Variable: Trainee Academic achievement

b. Predictors: (Constant), trainees' engagement, instructional strategies, retention of complex technical content, and self-directed learning

The ANOVA provide compelling evidence that the multiple regression model significantly predicts academic achievement among trainees in Building and Civil Engineering diploma programmes within TVET institutions. The model yielded an F-value of 52.854 with a significance level (p-value) of .000, indicating that the combined effect of the independent variables AR-induced trainee engagement, AR-based instructional strategies, AR-enhanced retention of complex content, and AR-facilitated self-directed learning explains a statistically significant proportion of the variance in academic achievement. This strongly supports the study's sixth objective, which aimed to assess the overall impact of augmented reality on academic achievement.

The strength of this relationship is further substantiated by the sum of squares for regression (95.772), which shows how much variation in the dependent variable (trainee academic achievement) is explained by the model. The residual sum of squares (76.170) reflects the unexplained variance, and when combined, they form the total variance (171.942) accounted for in the model. The mean square value of 23.943 (regression) compared to 0.453 (residual) further affirms the model's predictive power. These results align with the Model Summary presented earlier, which showed an R^2 of .557, indicating that over 55% of the variance in academic achievement is explained by the predictors included in the model.

These findings are in line with existing research that highlights the transformative potential of AR in education. For instance, Sakr and Abdullah (2024) and Williams et al. (2025) found that AR-based instruction enhances trainee motivation and academic outcomes by offering interactive and immersive learning experiences. Similarly, Ruhama et al. (2025) emphasized that AR-supported environments promote self-directed learning and deeper understanding of technical concepts factors that are crucial for academic success in engineering fields. Therefore, the significant results of this ANOVA analysis not only affirm the effectiveness of AR in influencing academic performance but also reinforce the theoretical and practical relevance of integrating AR into instructional strategies within TVET institutions.

The regression coefficient results is presented in Table 4.22.

Table 4.22: Coefficients Table

Model	Unstandardized Coefficients (B)	Std. Error	Standardized Coefficients (Beta)	T	Sig.
(Constant)	3.139	0.494	—	6.354	< .001
Trainee Engagement	0.507	0.080	0.501	6.338	< .001
Instructional Strategies	0.692	0.071	0.685	9.746	< .001
Self-Directed Learning	0.460	0.075	0.459	6.133	< .001
Retention of Complex Content	0.817	0.076	0.811	10.750	< .001

Dependent Variable: Trainee Academic Achievement
Note: All predictors are statistically significant at the 0.05 level.

The regression coefficient results presented in Table 4.22 indicate that all four independent variables trainee engagement, instructional strategies, self-directed learning, and retention of complex content are statistically significant predictors of academic achievement among trainees in Building and Civil Engineering diploma programmes within TVET institutions.

The unstandardized coefficients (B) represent the amount of change in academic achievement for each one-unit change in the respective predictor, holding other variables constant. Among the predictors, *retention of complex content* has the highest unstandardized coefficient (B = 0.817, $p < .001$), suggesting that improvements in trainees' ability to retain complex technical concepts through AR have the strongest positive effect on their academic performance. This finding aligns with studies by Wang et al. (2025) and Ruhama et al. (2025), which highlighted that AR significantly enhances memory retention through immersive and interactive experiences.

Instructional strategies influenced by AR also showed a strong contribution to academic achievement (B = 0.692, $p < .001$), indicating that the effectiveness of AR-supported pedagogical approaches such as visualization of technical concepts and real-time feedback significantly improves learning outcomes. This is consistent with the findings of Tan et al. (2022) and Suhail et al. (2024), who emphasized the critical role of adaptive instructional strategies in maximizing AR's educational benefits.

Trainee engagement (B = 0.507, $p < .001$) was also a significant predictor. This underscores that AR-enhanced learning environments boost active participation, attention, and motivation, which are key drivers of academic success. These findings are supported by Scavarelli et al. (2021) and Seyman Guray and Kismet (2023), who found that immersive AR applications foster high levels of trainee engagement and focus.

Self-directed learning (B = 0.460, $p < .001$) also emerged as a statistically significant predictor, affirming that AR not only promotes engagement during instruction but also empowers trainees to explore, revise, and internalize concepts independently. This finding resonates with the arguments by Riniati et al. (2024) and Rezai et al. (2025), who assert that AR stimulates curiosity and autonomy in learning, which are essential for long-term academic growth.

Overall, the high t-values and low significance levels indicate that each of the four AR-related dimensions significantly contributes to explaining variations in trainees' academic achievement. This supports the theoretical frameworks underpinning the study, such as Constructivist Learning Theory (Piaget, 1950; Vygotsky, 1978), which emphasizes active, contextualized learning, and Cognitive Load Theory (Sweller, 1988), which advocates for visualization tools like AR to ease cognitive processing. Thus, the regression analysis confirms that AR is a robust instructional innovation with multifaceted effects on learning outcomes in technical education.

The final equation is presented as:

$$Y = 3.139 + 0.507X_1 + 0.692X_2 + 0.460X_3 + 0.817X_4 + \epsilon$$

Since all predictors were statistically significant ($p<.05$), the results confirm that Augmented Reality based learning strategies significantly improve trainee academic achievement in Building and Civil Engineering diploma courses within TVET institutions.

4.9 Impact of trainees' prior knowledge on the relationship between Augmented Reality and academic achievement.

This section presents findings on the moderating role of trainees' prior knowledge in shaping the relationship between AR and academic achievement among Building and Civil Engineering diploma trainees in TVET institutions. Prior knowledge is considered a critical cognitive factor that influences how trainees interact with and benefit from instructional innovations such as AR. Investigating this moderating effect provides insights into whether the benefits of AR-based instruction vary depending on the trainees' initial understanding of technical content.

To comprehensively address this objective, the analysis is structured under the following subheadings: Descriptive Analysis summarizes the trainees' prior knowledge levels and corresponding academic performance, offering an overview of patterns that may suggest moderation effects. Hierarchical Regression Analysis explores the statistical interaction between AR use and prior knowledge in predicting academic achievement, assessing whether prior knowledge significantly alters the strength or direction of AR's impact. Qualitative Analysis that presents insights from

trainee responses to open-ended questions and instructor interviews, highlighting how prior knowledge influenced learning experiences and outcomes in AR-enhanced environments.

This multi-method analysis helps determine whether prior knowledge strengthens or weakens the effectiveness of AR instruction, ultimately contributing to differentiated instructional planning in technical education.

4.9.1 Descriptive analysis on prior knowledge

This section addresses the fifth specific objective, which sought to examine the role of trainees' prior knowledge as a moderating variable in the relationship between various AR instructional factors and academic achievement in Building and Civil Engineering diploma programmes within TVET institutions. Prior knowledge such as hands-on experience with engineering tools, familiarity with AR technologies, preferred learning styles, and access to AR-compatible devices can significantly shape how trainees engage with, interpret, and benefit from AR-based instructional methods.

To assess this relationship, the following hypothesis was tested:

Null Hypothesis (H_{05}): Trainees' prior knowledge has no significant impact on the relationship between Augmented Reality and trainee academic achievement in Building and Civil Engineering diploma courses within TVET institutions in Kenya.

The analysis began with descriptive statistics to evaluate trainees' perceptions of how their previous technical exposure and learning readiness influenced their interaction with AR. Subsequently, a moderated regression analysis (MRA) was conducted to determine whether prior knowledge significantly altered the strength or direction of the relationship between AR and academic outcomes.

The descriptive statistics on trainee prior knowledge is presented in Table 4.23.

Table 4.23: Descriptive Statistics on Trainee Prior Knowledge

S No.	Statement	S Dis (1)	Dis (2)	N (3)	A (4)	SA (5)	M	SD	I
1.	Before using AR, I was confident using engineering tools.	3	10	22	75	63	3.9	1.06	Agree
2.	My previous skills helped me learn AR faster.	1	4	14	58	94	4.2	0.94	Strongly Agree
3.	I was comfortable using AR before this course.	26	70	40	20	16	2.4	1.02	Disagree
4.	My learning style (hands-on, visual, etc.) affects how I use AR.	12	24	66	40	30	3.1	1.31	Not Sure
5.	I have a phone or device to access AR learning materials.	6	15	29	70	52	3.6	1.24	Agree

Note. Key: S Dis= Strongly Disagree, Dis = Disagree, N = Neither Agree nor Disagree, A = Agree, SA = Strongly Agree, M = Mean, SD = Standard Deviation, I= Interpretation.
Mean Interpretation: 1-1.79 = Strongly Disagree, 1.8-2.59 = Disagree, 2.6-3.39 = Neither Agree nor Disagree, 3.4-4.19 = Agree, 4.2-5.0 = Strongly Agree.

The descriptive findings show that trainees generally agreed that they had sufficient prior exposure to engineering tools before engaging with AR (M = 3.9, SD = 1.06), and that their previous technical skills helped them adapt more quickly to AR-based learning environments (M = 4.2, SD = 0.94). This indicates that trainees with hands-on or foundational knowledge were more comfortable integrating AR into their learning, which is consistent with Yilmaz (2021) and Vaithianathan et al. (2024), who emphasized that previous skills significantly influence trainees' adaptability to digital innovations in technical training.

However, familiarity with AR before the course was low, as reflected in the statement *"I was comfortable using AR before this course"* (M = 2.4, SD = 1.02, Disagree), suggesting that most trainees had limited prior exposure to AR technology. This aligns with the findings of Tahir and Abdullah (2023) and Riniati et al. (2024), who noted that although AR tools are increasingly available in education, their classroom integration remains recent, and many trainees encounter them for the first time during formal training.

Regarding learning preferences, trainees were unsure whether their preferred learning style (e.g., hands-on or visual) influenced their AR experience (M = 3.1, SD = 1.31), suggesting a lack of awareness of how personal learning preferences affect the use of immersive technologies. Studies by Sweller (1988) and Sakr and Abdullah (2024) suggest that while visual and kinesthetic trainees often benefit more from AR, not all trainees recognize how their style interacts with the learning medium without explicit instructional scaffolding.

In terms of accessibility, trainees agreed that they had a device capable of supporting AR applications (M = 3.6, SD = 1.24), though the relatively moderate mean implies that device access was not universal, possibly constraining the full potential of AR-based instruction for some trainees. This is in line with Stanney et al. (2022) and Yao (2023), who argued that while digital access has improved, disparities in device compatibility and availability continue to affect digital equity in education.

These descriptive insights set the foundation for the moderated regression analysis, which investigates whether prior knowledge significantly changes the relationship between AR dimensions such as engagement, instructional strategies, self-directed learning, and content retention and academic achievement.

In conclusion, while prior knowledge appears to support AR integration through improved adaptability and confidence, limited prior exposure to AR and inconsistent device access may weaken or vary its effectiveness across trainee groups. The findings suggest that for AR to fully realize its pedagogical potential, targeted orientation and equitable access strategies should be implemented, especially in resource-constrained TVET environments.

4.9.2 Hierarchical Regression

A hierarchical regression analysis was conducted to determine whether Trainee Prior Knowledge moderate the relationship between AR factors and Trainee Academic achievement. A moderating effect occurs when the influence of an independent variable (IV) on the dependent variable (DV) varies depending on the presence of a third variable (moderator). In this study, prior knowledge, technical experience, and access to AR-compatible devices may enhance or weaken the impact of AR-based learning on academic achievement.

The regression model is expressed as:

Equation 4.4: Hierarchical regression equation

$$Y = \beta_0 + \beta_1 X + \beta_2 M + \beta_3 (X \times M) + \epsilon$$

Where;

$$Y = Academic\ Achievement$$

$$X = AR\ Factors(IVs: Trainees' Engagement, Instructional\ Strategies, Retention\ of\ complex\ content, \quad Self-directed\ learning,)$$

$$M = Prior\ Knowledge$$

$$X\ and\ M = Interaction\ Term\ (Moderating\ Effect)$$

$$\beta_0 = Intercept$$

$$\beta_1, \beta_2, \beta_3 = Regression\ Coefficients$$

$$\epsilon = Error\ term$$

The results in Table 4.24 present a hierarchical regression analysis aimed at assessing the overall impact of AR on trainees' academic achievement in Building and Civil Engineering diploma programmes in Nairobi's TVET institutions, while also examining the moderating effect of trainees' prior knowledge.

Table 4.24: Model Summary for the Moderating Variable

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate	Change Statistics				
					R Square Change	F Change	df1	df2	Sig. F Change
1	.746[a]	.557	.538	.673	.571	52.854	4	168	.000
2	.798[b]	.636	.629	.620	.079	17.042	4	164	<.001

a. Predictors: (Constant), Trainees' engagement, instructional strategies, retention of complex technical content, and self-directed learning.
b. Predictors: (Constant), Trainees' engagement, instructional strategies, retention of complex technical content, and self-directed learning, Interaction_Engagement, Interaction_Instruction_Strategies, Interaction_Retention, Interaction_ Self-directed learning

The results in Table 4.24 present a hierarchical regression analysis aimed at assessing the overall impact of AR on trainees' academic achievement. The analysis was conducted in two steps: Model 1 included the direct predictors, and Model 2 introduced interaction terms to evaluate moderation effects.

In Model 1, the predictors Trainees' Engagement, Instructional Strategies, Retention of Complex Technical Content, and Self-Directed Learning jointly explained 55.7% of the variance in academic achievement ($R^2 = 0.557$, Adjusted $R^2 = 0.538$), with a statistically significant model ($F(4,168) = 52.854$, $p < .001$). This indicates that AR-driven pedagogical elements significantly contribute to explaining differences in academic outcomes. The findings align with Teplá et al. (2022) and Sabri et al. (2024), who emphasized that trainee-centered and technology-integrated strategies enhance performance in technical education.

In Model 2, the addition of interaction terms involving trainees' prior knowledge significantly improved the model fit, increasing R^2 to 0.636 and Adjusted R^2 to 0.629, indicating that 63.6% of the variance in academic achievement is now explained. The R^2 change of 0.079 was statistically significant (F change = 17.042, $p < .001$), suggesting that prior knowledge significantly moderates the relationship between AR-based instructional components and academic performance. This supports findings by

Simonsmeier et al. (2022) and Yilmaz (2021), who observed that trainees' pre-existing cognitive structures influence how effectively they benefit from immersive digital tools like AR.

The reduction in the standard error of the estimate from 0.673 in Model 1 to 0.620 in Model 2 indicates improved predictive accuracy upon inclusion of the interaction terms. This improvement demonstrates that understanding the role of trainees' prior knowledge can sharpen instructional design decisions involving AR, echoing insights by Sweller (1988) on cognitive load and by Rezai et al. (2025) regarding adaptive instructional strategies in AR environments.

In conclusion, the regression analysis demonstrates that AR-based instructional approaches when aligned with trainee engagement, clear strategies, support for self-directed learning, and reinforcement of complex content retention can significantly enhance academic achievement. Moreover, the effectiveness of these strategies is influenced by the trainees' prior knowledge, making it a critical factor in the successful integration of AR in technical and vocational education. These findings support the use of constructivist theory and cognitive load theory as theoretical underpinnings for AR integration in education (Ravichandran & Mahapatra, 2023; Sweller, 1988; Scavarelli et al., 2021).

Table 4.25 presents the results of an ANOVA (Analysis of Variance) conducted during a hierarchical regression analysis to test the predictive power of AR-based instructional variables and the moderating role of trainees' prior knowledge on academic achievement in Building and Civil Engineering diploma programmes within TVET institutions in Nairobi County.

Table 4.25: ANOVA table for the Moderating Variable

Model		Sum of Squares	Df	Mean Square	F	Sig.
1	Regression	95.772	4	23.943	52.854	.000[b]
	Residual	76.170	168	.453		
	Total	171.942	172			
2	Regression	109.355	8	13.667	35.812	.000[c]
	Residual	62.587	164	.382		
	Total	171.942	172			

a. Dependent Variable: Trainee Academic achievement

b. Predictors: (Constant), Trainee Prior Knowledge, Trainees' engagement, instructional strategies, retention of complex technical content, and self-directed learning

c. Predictors: (Constant), Trainee Prior Knowledge, Trainees' engagement, instructional strategies, retention of complex technical content, and self-directed learning, Interaction Engagement, Interaction Instruction Strategies, Interaction Retention, Interaction Self-directed learning.

In Model 1, the regression equation included the main effects of the key AR-based instructional factors Trainees' Engagement, Instructional Strategies, Retention of Complex Technical Content, Self-Directed Learning, and Prior Knowledge. The model produced a highly significant F-statistic of 52.854 ($df = 4, 168$, $p < .001$), indicating that the model significantly predicts trainees' academic achievement. This supports the view that AR-enhanced instructional approaches meaningfully impact performance, in line with the findings of Tan et al. (2024) and Yilmaz (2021), who documented the effectiveness of digital tools in improving technical learning outcomes.

In Model 2, interaction terms between prior knowledge and the four AR-related predictors were added to test for moderation effects. This model also showed a statistically significant improvement, with an F-statistic of 35.812 ($df = 8, 164$, $p < .001$). The increase in the explained variance from Model 1 to Model 2 confirms that trainees' prior knowledge significantly moderates the relationship between AR-based instructional strategies and academic achievement. These findings resonate with the theoretical insights of Sweller (1988) on cognitive load and the empirical evidence from Simonsmeier et al. (2022) and Rezai et al. (2025), who emphasized the

importance of prior knowledge in determining the effectiveness of innovative instructional technologies like AR.

Moreover, this result aligns with Constructivist Learning Theory as cited in Ravichandran and Mahapatra (2023), which asserts that meaningful learning is built upon pre-existing knowledge structures. When AR instruction is tailored to trainees' existing cognitive frameworks, it becomes more effective at promoting retention, engagement, and self-directed learning all of which were directly assessed in your study's objectives.

Thus, the ANOVA results confirm that AR-based instructional design, particularly when adjusted for trainees' prior knowledge, significantly enhances academic achievement. This reinforces your sixth objective and validates the integration of adaptive AR pedagogy into technical education curricula in TVET institutions.

The coefficients for the moderating variable are presented in the Table 4.26.

Table 4.26: Coefficients Table for the Moderating Variable

Model		Unstandardized Coefficients		Standardized Coefficients	T	Sig.
		B	Std. Error	Beta		
1	(Constant)	3.139	.494		6.354	<.001
	Trainees' Engagement	.507	.080	.501	6.338	.031
	Instructional Strategies	.692	.071	.685	9.746	.007
	Self-directed learning	.460	.075	.459	6.133	.012
	Retention of Complex Concepts	.817	.076	.811	10.75	.002
2	(Constant)	3.269	1.449		2.257	.025
	Trainees' Engagement	.504	2.244	.502	1.131	.260
	Instructional Strategies	.690	1.778	.687	1.227	.221
	Self-directed learning	.461	1.831	.458	.844	.400
	Retention of Complex Concepts	.817	1.692	.817	1.382	.169
	Interaction_trainees' Engagement	.546	.072	.541	7.583	.000
	Interaction_Instruction_Strategies	.613	.072	.612	8.513	.000
	Interaction_Self-Directed Learning	.466	.075	.461	6.213	.000
	Interaction_Retention of Complex content	.820	.074	.813	11.081	.000

a. Dependent Variable: Trainee Academic achievement

Table 4.26 presents the regression coefficients for two hierarchical models assessing the impact of AR-based instructional variables on academic achievement, as well as the moderating role of trainees' prior knowledge through interaction terms.

In Model 1, without interaction effects, all four AR-based predictors Trainees' Engagement (B = 0.507, p = .031), Instructional Strategies (B = 0.692, p = .007), Self-Directed Learning (B = 0.460, p = .012), and Retention of Complex Concepts (B = 0.817, p = .002) were statistically significant contributors to academic achievement. These findings underscore that AR, when used to promote engagement, instructional clarity, autonomous learning, and understanding of complex content, positively influences performance outcomes in Building and Civil Engineering diploma programmes. This supports Objective 1 through Objective 4 of the study and aligns with evidence from Teplá et al. (2022), Ryan et al. (2022), and Zhang et al. (2023) who emphasized that immersive tools like AR boost active learning and comprehension in technical disciplines.

In Model 2, the inclusion of interaction terms between trainees' prior knowledge and each AR-based instructional component revealed that all interaction variables significantly predicted academic achievement. Notably, Interaction_Trainees' Engagement (B = 0.546, p < .001), Interaction_Instructional Strategies (B = 0.613, p < .001), Interaction_Self-Directed Learning (B = 0.466, p < .001), and Interaction_Retention of Complex Content (B = 0.820, p < .001) were all statistically significant. These results confirm that prior knowledge moderates the relationship between AR instructional strategies and learning outcomes, thereby validating Objective 5 of the study. The significant positive coefficients imply that trainees with higher prior knowledge benefit more from AR tools, an effect consistent with the principles of Cognitive Load Theory (Sweller, 1988) and supported by Simonsmeier et al. (2022), Yao (2023), and Riniati et al. (2024).

Together, these findings reinforce the sixth objective to assess the overall impact of AR on academic achievement as the moderated model yields stronger predictive power. This demonstrates that adaptive, AR-based pedagogy, when aligned with trainees' cognitive readiness, enhances academic performance, especially in complex technical domains. The study's results thus contribute meaningful insights into how instructional innovation through AR can be optimized for trainee diversity in TVET institutions, echoing recommendations by Wang et al. (2025) and Stanney et al. (2022) for context-sensitive educational technologies.

4.9.3 Qualitative Analysis on prior knowledge

A thematic analysis was conducted to explore how trainees past experiences influenced their learning with AR in Building and Civil Engineering diploma programmes within TVET institutions. Responses to the open-ended question *"How has your past experience helped you learn with AR?"* were analyzed to identify patterns illustrating how prior knowledge moderated the effectiveness of AR in promoting academic achievement.

Four major themes emerged: smoother transition to AR tools, faster conceptual understanding, confidence in technical navigation, and peer support capacity.

Trainees with prior technical exposure reported that their background made it easier to adopt AR tools. One trainee shared, *"Since I had used some engineering tools before, it was easier for me to understand the AR simulations."* Another mentioned, *"I wasn't new to the basic concepts, so AR just added more clarity."* This observation supports research by Vaithianathan et al. (2024) and Yilmaz (2021), who noted that foundational knowledge enhances trainees' ability to quickly adapt to digital instructional technologies like AR.

Several trainees noted that their previous knowledge helped them grasp new or complex content more quickly through AR. One explained, *"Because I already knew how the tools worked, it was easier to understand the animations and examples."* This aligns with Sweller's (1988) Cognitive Load Theory, which posits that existing schemas reduce the cognitive burden when encountering new information, allowing more efficient learning. Similarly, Wang et al. (2023) emphasized that trainees with background familiarity benefit more deeply from AR-enhanced instruction.

Trainees indicated that prior knowledge gave them confidence in exploring AR applications independently. One said, *"My earlier experience made me less afraid of using new technology I felt more in control."* Another added, *"I didn't need much help learning how to use the AR features."* This reflects findings by Yazdi (2024) and Ruhama et al. (2025), who emphasized that trainees with stronger technical foundations exhibit greater self-efficacy and ease in navigating immersive environments like AR.

Interestingly, some trainees noted that prior knowledge enabled them to assist others. One remarked, *"I could help classmates who were struggling to use the AR tools because I had done something similar before."* This demonstrates a spillover effect of prior knowledge, not only improving personal learning but also enhancing collaborative learning. According to Simonsmeier et al. (2022), peer scaffolding can be especially valuable in digital environments where trainee familiarity varies.

Trainees' reflections indicate that prior experience in technical subjects or tools positively influenced how they engaged with and benefited from AR-enhanced instruction. Their foundational knowledge facilitated a smoother transition to AR use, improved conceptual clarity, increased trainee confidence, and even supported peer learning. These findings reinforce the notion that prior knowledge significantly moderates the relationship between AR and academic achievement.

This supports literature by Mokmin et al. (2024), Nikimaleki and Rahimi (2022), and Sakr and Abdullah (2024), all of whom emphasize the need to consider trainees' backgrounds when integrating new technologies like AR. For maximum effectiveness, institutions should implement orientation sessions or bridging activities to ensure that all trainees, regardless of their starting point, can effectively use AR to enhance academic success.

4.9.4 Trainers' Interview on prior knowledge

To better understand how trainees' prior knowledge influences the effectiveness of AR in improving academic outcomes, interviews were conducted with 10 construction technology instructors from TVET institutions in Nairobi County. These instructors, who were directly involved in delivering AR-based lessons, shared their experiences regarding variations in trainee responses based on technical background, digital familiarity, and foundational skills. The analysis of their feedback, guided by a thematic approach, revealed how prior knowledge acts as a moderator in AR-facilitated learning environments, affecting both the pace and depth of trainee engagement and achievement.

Several instructors reported that trainees with strong technical foundations and prior exposure to digital tools engaged more confidently and productively with AR content. Respondent 4 noted, *"Trainees who already had experience with basic engineering*

concepts or digital tools adapted quickly to AR. They were able to grasp complex ideas with less explanation." Respondent 10 shared, *"They ask higher-level questions and often explore beyond what is covered in class."* These observations resonate with Yilmaz (2021) and Vaithianathan et al. (2024), who found that trainees with prior knowledge benefit more rapidly from technology-enhanced instruction due to existing cognitive frameworks.

Conversely, trainers also emphasized that AR served as a valuable support mechanism for trainees with limited prior knowledge, though it required more guided facilitation. Respondent 3 explained, *"Some trainees were completely new to the concepts and struggled at first, but the visual and interactive elements of AR helped them catch up slowly."* Another stated, *"Without AR, these trainees would have fallen further behind it gave them something concrete to hold on to while learning."* This aligns with the work of Yazdi (2024) and Sakr and Abdullah (2024), who emphasize AR's role in scaffolding novice trainees through step-by-step conceptual development.

The instructors acknowledged that prior knowledge differences influenced how they implemented AR tools in class. Respondent 2 mentioned, *"For trainees with less experience, I break the simulations down and add extra instructions. For the more advanced ones, I let them explore and reflect on their own."* Respondent 7 added, *"Sometimes I pair trainees with different levels of knowledge to help each other when using AR apps."* This adaptive approach is supported by Sweller (1988) and Rotsios et al. (2022), who argue for differentiated instruction based on trainees' prior knowledge to optimize cognitive load and instructional efficiency.

Some trainers also noted that while AR was broadly effective, device familiarity and digital access played a role in how well trainees engaged. Respondent 1 said, *"Some trainees had never used AR or similar apps before. They needed a few sessions just to learn the interface."* This aligns with Stanney et al. (2022) and Yao (2023), who highlighted that digital readiness including access to compatible devices can impact AR adoption and its instructional impact.

In summary, the interviews revealed that prior knowledge significantly moderates the effectiveness of AR in promoting academic achievement. While AR benefits all trainees, those with stronger foundations engage more deeply and independently,

while those with less experience need more structured support. The findings underscore the importance of differentiated instructional strategies and technical scaffolding to ensure that all trainees can meaningfully benefit from AR-integrated learning environments.

4.10 Impact of Augmented Reality on the academic achievement

This section presents the findings related to the overall impact of Augmented Reality on the academic achievement of trainees enrolled in Building and Civil Engineering diploma programmes within TVET institutions in Nairobi County. Academic achievement, in this context, encompasses multiple indicators namely theoretical content mastery, practical skills acquisition, problem-solving ability, summative examination performance, and retention of complex technical content. AR was introduced as an instructional innovation aimed at transforming conventional teaching by integrating interactive, immersive learning experiences designed to induce trainee engagement, conceptual understanding, and performance outcomes.

To comprehensively assess AR's impact, the findings are presented under the following subheadings: Descriptive Analysis provides a summary of trainees' performance across both experimental and control groups based on various academic indicators. Measures include mean scores in theoretical content, practical assessments, summative exams, and engagement levels with AR-based instruction. Summative Examination Performance assesses trainees' outcomes in standardized institutional assessments to determine whether AR-enhanced instruction leads to measurable improvements in high-stakes evaluations. Inferential Statistics ANOVA examines the statistical significance of observed differences between the experimental and control groups. This includes both between-group comparisons and adjusted analyses accounting for covariates such as prior knowledge. Effect Size and Post Hoc Analyses investigates the magnitude of the instructional effect using effect size calculations and post hoc tests (e.g., Bonferroni), enabling a deeper understanding of AR's impact on different trainee categories. Qualitative Analysis incorporates data to provide contextual understanding of how AR influenced trainee achievement, classroom dynamics, and perceived value of instruction and includes open-ended questionnaire responses and instructor interviews

Together, these analyses offer a multidimensional perspective on how AR contributes to improved academic performance in TVET settings. The integration of both quantitative and qualitative evidence ensures a rigorous and holistic assessment of AR's effectiveness, thereby validating its potential as a transformative pedagogical tool in Building and Civil Engineering education.

4.10.1 Descriptive analysis on the academic achievement

This section addresses the sixth specific objective, which sought to determine the overall effect of AR on the academic achievement of trainees enrolled in Building and Civil Engineering diploma programmes within Nairobi's TVET institutions. AR has been recognized as a transformative instructional tool capable of enhancing trainee engagement, improving content comprehension, increasing class participation, and building trainee confidence. This study explored how AR influences these learning dimensions and, in turn, contributes to trainees' academic performance.

To evaluate this relationship, the following hypothesis was tested:

Null Hypothesis (H_{06}): Augmented Reality has no significant effect on the academic performance of Building and Civil Engineering trainees in TVET institutions in Nairobi.

Descriptive statistics were computed to analyze trainees' perceptions of how AR impacts various facets of academic achievement, including performance in tests and exams, comprehension of complex topics, classroom participation, examination confidence, and overall course performance.

The descriptive analysis for overall impact of augmented reality on the academic achievement is presented in the Table 4.27.

Table 4.27: Descriptive analysis for overall impact of Augmented Reality on the academic achievement

No.	Statement	S Dis (1)	Dis (2)	N (3)	A (4)	SA (5)	M	SD	I
1.	AR has helped me score better in tests and exams.	1	4	12	60	95	4.3	0.85	Strongly Agree
2.	AR makes hard topics easier to understand.	1	4	14	58	94	4.2	0.94	Strongly Agree
3.	AR makes me more active in class, which helps me learn.	0	2	6	40	125	4.6	0.78	Strongly Agree
4.	AR gives me confidence in exams and practical work.	1	3	10	46	110	4.5	0.81	Strongly Agree
5.	AR has improved my overall performance in this course.	0	1	5	26	139	4.8	0.87	Strongly Agree

Note. Key: S Dis= Strongly Disagree, Dis = Disagree, N = Neither Agree nor Disagree, A = Agree, SA = Strongly Agree, M = Mean, SD = Standard Deviation, I= Interpretation.
Mean Interpretation: 1-1.79 = Strongly Disagree, 1.8-2.59 = Disagree, 2.6-3.39 = Neither Agree nor Disagree, 3.4-4.19 = Agree, 4.2-5.0 = Strongly Agree.

The findings show strong agreement across all five items, with mean scores ranging from 4.2 to 4.8. The highest-rated statement, *"AR has improved my overall performance in this course"* (M = 4.8, SD = 0.87), suggests that trainees perceive AR as a powerful enabler of academic success. Similarly, high ratings for *"AR makes me more active in class, which helps me learn"* (M = 4.6, SD = 0.78) and *"AR gives me confidence in exams and practical work"* (M = 4.5, SD = 0.81) reflect that AR not only supports understanding but also enhances trainee motivation and participation.

These findings align with existing research that highlights AR's potential to improve academic achievement through multisensory engagement, real-time feedback, and trainee-centered interactivity. For instance, studies by Seyman Guray and Kismet (2023), Sakr and Abdullah (2024), and Simonsmeier et al. (2022) emphasized that AR facilitates deeper learning by making abstract content more tangible and memorable. Moreover, the sense of control and autonomy that AR offers contributes to improved self-efficacy and academic confidence (Silva et al., 2024; Yilmaz, 2021).

In addition, research by Ruhama et al. (2025) and Scavarelli et al. (2021) supports the notion that AR-enhanced learning environments stimulate active participation and higher-order thinking attributes linked to improved academic outcomes. The current findings also echo those of Siricharoen (2023), who found that immersive AR learning supports academic achievement by enabling better comprehension and increased trainee engagement.

The consistently high ratings in this study affirm the strong perceived benefits of AR in academic settings, particularly in technical and engineering disciplines that demand both conceptual clarity and applied problem-solving skills. These outcomes suggest that AR is not only a supportive supplement but a central driver of academic excellence in modern TVET pedagogy.

The descriptive analysis indicates that trainees overwhelmingly perceive Augmented Reality as having a positive and significant influence on their academic achievement. From improved test performance to increased class participation and confidence in assessments, AR appears to be a highly effective instructional tool. These insights justify the continued integration of AR technologies into technical training and highlight the importance of institutional support to maximize its impact.

4.10.2 Summative Examination Performance Analysis

This section addresses the sixth specific objective, which sought to assess the overall impact of Augmented Reality on academic achievement among Building and Civil Engineering trainees in TVET institutions within Nairobi County. The analysis was based on summative examination results collected from multiple institutions. These assessments were administered by unit instructors at the end of the term following two semesters of instruction in the Concrete Technology unit, ensuring comprehensive curriculum coverage and accurate reflection of academic performance.

The summative results offer insights into the influence of AR on trainees' academic outcomes, including theoretical understanding, problem-solving capabilities, and applied skills. Table 4.28 displays the mean scores and standard deviations for the experimental (E1, E2) and control (C1, C2) groups.

Table 4.28: Mean and Standard Deviation for E1, C1, E2, C2 summative examination

Group	N	Mean	Standard Deviation
E1	88	68.64	6.46
C1	83	54.24	9.61
E2	84	66.58	2.46
C2	79	54.29	12.86

Trainees in the experimental groups (E1 and E2), who were taught using AR-enhanced strategies, scored higher and exhibited more consistent performance compared to those in the control groups. These results indicate that AR positively influenced academic achievement by enhancing content understanding, improving retention, and promoting better problem-solving consistent with findings by Wang et al. (2025) and Sakr and Abdullah (2024), who affirm that immersive technologies like AR strengthen both cognitive and performance outcomes in technical fields.

By contrast, the control groups (C1 and C2) showed lower average scores and wider variability, suggesting that traditional teaching methods may not adequately support consistent trainee performance. This trend supports prior observations by Simonsmeier et al. (2022) and Williams et al. (2025), who argue that non-interactive instructional approaches result in fragmented knowledge retention and performance gaps.

The ANOVA for the summative results is presented in the Table 4.29.

Table 4.29: ANOVA table for the summative results

Source	Sum of Squares	Degrees of Freedom	Mean Square	F-Statistic	P-Value
Between Groups	14,924.66	3	4,974.89	66.29	0.000
Within Groups	24,841.95	331	75.05	-	-
Total	39,766.61	334	-	-	-

The ANOVA results reveal statistically significant differences in summative performance across the four groups ($F = 66.29$, $p < 0.001$). This outcome confirms that AR integration had a measurable and substantial effect on academic outcomes, validating findings from Sakr and Abdullah (2024) and Sharmila (2024), who reported that AR significantly boosts knowledge acquisition and application in engineering education.

To further explore the specific group differences, a Bonferroni post hoc test was conducted. The Bonferroni Post Hoc Test for Trainees' Summative Examination Performance is presented in the Table 4.30.

Table 4.30: Bonferroni Post Hoc Test for Trainees' Summative Examination Performance

Group 1	Group 2	Mean Difference	p-Value	Lower CI	Upper CI	Significant?
C1	C2	0.0502	1.0000	-3.4199	3.5202	No
C1	E1	13.4134	0.0000	9.9653	16.8614	Yes
C1	E2	12.2352	0.0000	8.8185	15.6520	Yes
C2	E1	13.3632	0.0000	9.8723	16.8541	Yes
C2	E2	12.1851	0.0000	8.7251	15.6450	Yes
E1	E2	-1.1781	0.8127	-4.6160	2.2598	No

The Bonferroni test shows no significant difference between the two control groups (C1 and C2), indicating that traditional instruction yielded similar outcomes. In contrast, significant differences were observed between the experimental and control groups ($p < 0.001$), validating that AR-enhanced instruction leads to superior academic performance.

Interestingly, no significant difference emerged between E1 and E2, implying consistency in the effectiveness of AR regardless of minor instructional variations or institutional contexts. This observation supports findings by Vaithianathan et al. (2024), who noted that AR's learning benefits are robust across different delivery settings when implemented with pedagogical fidelity.

However, while the data confirms AR's effectiveness, the analysis does not account for moderating variables prior knowledge. As pointed out by Simonsmeier et al. (2022) and Yazdi (2024), this factor can interact with AR-based instruction to enhance or hinder learning outcomes.

The summative examination analysis provides strong statistical evidence to reject the null hypothesis, which stated that Augmented Reality has no significant impact on the academic performance of Building and Civil Engineering trainees in TVET institutions in Nairobi. The consistent performance of experimental groups demonstrates AR's capacity to induce engagement, comprehension, and skill development. These findings reinforce calls for broader integration of AR in TVET curricula, particularly in technical disciplines where spatial and conceptual understanding are critical (Seyman Guray & Kismet, 2023; Ruhama et al., 2025).

4.10.3 Qualitative Analysis on the academic achievement

A thematic analysis was conducted to explore trainees' reflections on how AR influenced their academic experience and performance in Building and Civil Engineering diploma programmes across TVET institutions in Nairobi. Responses to the open-ended question *"How has AR impacted your overall learning experience and academic achievement?"* were coded and categorized into four major themes: induced engagement, improved understanding of technical content, increased academic confidence, and overall performance gains.

Many trainees expressed that AR made learning more engaging and interactive. One noted, *"Learning became fun and more interesting with AR. It made me want to attend classes more."* Others shared that the immersive and visual features of AR helped them stay focused during lessons. This aligns with findings by Ryan et al. (2022) and Rotsios et al. (2022), who found that AR tools significantly enhance trainee engagement and motivation, especially in technical disciplines.

Trainees consistently mentioned that AR helped them understand and retain complex engineering content more effectively than traditional teaching methods. One trainee stated, *"I now understand things like structural designs better because I can see them clearly through AR."* Another remarked, *"The AR animations made it easier to remember how systems work."* These sentiments are supported by Sakr and Abdullah (2024) and Sweller (1988), who emphasized that AR reduces cognitive load and supports long-term retention by providing multisensory, real-time visualizations of abstract content.

Several trainees indicated that AR boosted their confidence in both classroom participation and assessments. One trainee commented, *"I feel more confident answering questions and doing practicals after using AR."* Others shared that AR made them feel more prepared for tests and assignments. This is consistent with findings by Yazdi (2024) and Ruhama et al. (2025), who found that trainees using AR technologies reported increased self-efficacy and readiness for both theoretical and practical evaluations.

Many trainees credited AR with improving their academic results. One trainee reflected, *"My grades improved after we started using AR I now perform better in both exams and projects."* Another added, *"AR helped me understand topics I used to fail."* This confirms the results of studies by Williams et al. (2025) and Zhang et al. (2023), which showed that AR positively impacts academic achievement across different educational contexts by reinforcing content mastery and skill acquisition.

Trainees' responses indicate that AR has had a profound positive impact on their academic achievement and overall learning experience. Through induced engagement, better understanding of technical content, improved confidence, and noticeable performance gains, AR emerged as a transformative instructional tool in Building and Civil Engineering training. These findings validate the broader research consensus that AR not only enriches classroom dynamics but also translates into measurable academic improvements (Silva et al., 2024; Scott & Husain, 2021; Tan et al., 2022).

For sustainable impact, institutions are encouraged to integrate AR into curriculum delivery systematically, ensuring that trainees continue to benefit from its pedagogical potential in both theoretical and practical domains.

4.10.4 Trainers' Interview on the academic achievement

To evaluate the overall impact of AR on the academic achievement of trainees in Building and Civil Engineering diploma programmes, qualitative interviews were conducted with 10 construction technology instructors each representing a different TVET institution in Nairobi County. These trainers were selected due to their direct involvement in implementing AR-based instructional methods in the research unit. Thematic analysis of their responses provided critical insights into how AR influences test performance, conceptual mastery, practical application, and the broader teaching and learning experience.

Trainers unanimously reported that AR had a positive impact on trainees' academic performance. Respondent 2 shared, *"Since we introduced AR, I've noticed a clear improvement in how well trainees perform in both class assessments and practical evaluations."* Respondent 4 noted, *"There's a difference in how quickly they grasp complex ideas and how they apply them in exams or site work."* These experiences are supported by research from Williams et al. (2025) and Tobias et al. (2024), who found that immersive technologies like AR lead to measurable gains in both theoretical understanding and practical competence.

When asked whether AR leads to measurable improvements in academic metrics such as grades and comprehension, instructors cited various indicators. Respondent 6 stated, *"Trainees using AR scored higher on average than those using traditional methods in the past year."* Respondent 9 explained, *"It's not just about higher marks trainees understand the 'why' behind engineering processes better, which reflects in their reasoning during tests."* This aligns with findings by Siricharoen (2023) and Tarigan (2024), who emphasized AR's effectiveness in promoting deep learning, critical thinking, and knowledge transfer especially in technical fields.

Trainers were also asked if they would recommend the broader adoption of AR in TVET training. All responded affirmatively, citing both pedagogical and motivational benefits. Respondent 1 respondent commented, *"Absolutely. It has transformed my classroom. Trainees are more focused, they ask better questions, and they're more confident."* Respondent 1 noted, *"Even trainees who used to struggle now show interest and participate more actively."* These remarks echo conclusions drawn by

Simonsmeier et al. (2022) and Scavarelli et al. (2021), who advocate for integrating AR as a core element in technical education due to its ability to engage diverse trainees and enhance instructional delivery.

However, a few trainers emphasized the need for proper implementation and support. Respondent 6 advised, *"For AR to be effective, institutions must invest in training both staff and trainees. It's not just about having the tools it's about knowing how to use them well."* This is consistent with research by Ziden et al. (2022), which stresses that professional development and infrastructure are critical for maximizing the benefits of AR in education.

In conclusion, the trainers agreed that AR significantly enhances academic achievement by improving comprehension, practical skills, and trainee motivation. They supported its broader integration across technical subjects, provided that adequate training and resource support are in place. These findings reinforce the role of AR as a transformative pedagogical tool within TVET institutions.

4.11 Hypothesis Testing Results

The findings of this study confirm that AR plays a significant role in enhancing learning outcomes in Building and Civil Engineering diploma courses within TVET institutions in Nairobi County. The hypotheses tested in this research reveal the substantial impact of AR on achievement in theoretical content, problem-solving skills, achievement in practical skills, Summative Examination Performance and the moderating role of prior knowledge in AR-based learning environments.

The hypothesis testing results is presented in the Table 4.31.

Table 4.31: Hypothesis Testing Results

Objective	Result	Findings
1. Trainee Engagement: To assess the extent to which AR induces trainee engagement.	Accepted	The study confirmed a significant positive relationship between AR and trainee engagement ($r = .723$, $p < .01$; $M = 4.36$). The high engagement score indicates that AR's interactive and immersive capabilities stimulate attention, motivation, and active participation among trainees. These findings are supported by Gong et al. (2024) and Affandi et al. (2024).
2. Instructional Strategies: To examine how AR influences instructional strategies.	Accepted	AR significantly influenced instructional strategies ($r = .691$, $p < .01$; $M = 3.71$). Trainers reported improved visualization of technical processes and better content delivery efficiency. However, moderate ratings suggest some variability depending on instructor expertise and AR resource availability. This aligns with Sabri et al. (2024) and Rotsios et al. (2022).
3. Retention of Complex Technical Content: To analyze the role of AR in enhancing retention of complex content.	Accepted	A strong correlation ($r = .758$, $p < .01$; $M = 4.34$) indicates that AR significantly aids in retaining complex engineering concepts. Trainees retained content better due to the 3D visualization and contextual interaction AR offers. This supports Seyman Guray and Kismet (2023) and Stanney et al. (2022).
4. Self-Directed Learning: To determine the effect of AR on the development of effective self-directed learning.	Accepted	The findings reveal that AR fosters self-directed learning ($r = .744$, $p < .01$; $M = 4.40$), allowing trainees to independently navigate virtual content at their own pace. AR's flexibility encourages reflective and autonomous learning behavior, consistent with the views of Tahir and Abdullah (2023) and Vaithianathan et al. (2024).
5. Moderating Role of Prior Knowledge: To assess the moderating effect of trainees' prior	Accepted	Hierarchical regression confirmed a significant moderating effect of trainees' prior knowledge on the relationship between AR variables and academic achievement (β interaction terms all $p < .001$). Those with higher prior knowledge

Objective	Result	Findings
knowledge on the AR–achievement relationship.		benefitted more from AR, confirming findings by Simonsmeier et al. (2022) and Yao (2023).
6. Overall Academic Achievement: To assess the overall impact of AR on academic achievement.	Accepted	Overall academic achievement was significantly influenced by AR ($r = .742$, $p < .01$; $M = 4.46$). The multiple regression model ($R^2 = .557$) and the ANOVA ($F = 52.854$, $p < .001$) confirmed that AR-based engagement, strategies, self-direction, and retention collectively predict academic outcomes. These results reinforce conclusions from Wang et al. (2025) and Izah et al. (2023).

4.12 Chapter Summary

This chapter presented a comprehensive analysis of the data collected to examine the impact of Augmented Reality (AR) on the academic achievement of trainees in Building and Civil Engineering diploma programmes within TVET institutions in Nairobi County. The analysis addressed each of the study's objectives through quantitative and qualitative approaches.

Descriptive statistics provided insights into trainee demographics and general trends in learning outcomes. Inferential statistics, including multiple regression and correlation analyses, were used to test the hypotheses related to the extent to which AR enhances trainee engagement, improves instructional strategies, supports retention of complex technical content, and promotes self-directed learning. The results showed statistically significant improvements in all domains among trainees exposed to AR-based instruction compared to those taught using conventional methods.

Additionally, the chapter explored the moderating role of prior knowledge in the relationship between AR instruction and academic outcomes. Hierarchical regression analysis revealed that prior knowledge significantly influenced the strength of this relationship, particularly in enhancing content retention, learner engagement, and academic performance.

CHAPTER FIVE

SUMMARY, CONCLUSION AND RECOMMENDATIONS

5.1 Summary of Results

This section presents a synthesized summary of the key findings of the study, which explored the impact of AR on academic achievement among trainees enrolled in Building and Civil Engineering diploma programmes within TVET institutions in Nairobi County. The study was guided by six core objectives, each addressing a unique aspect of how AR influences teaching and learning in technical education.

Using a combination of quantitative and qualitative methods, the research evaluated the extent to which AR induces trainee engagement, shapes instructional strategies, improves retention of complex technical content, fosters self-directed learning, and ultimately contributes to overall academic achievement. Additionally, the study examined the moderating effect of trainees' prior knowledge on the relationship between AR-based instruction and academic outcomes.

Findings from questionnaire, pre- and post-tests, summative examination results, and interview data revealed that AR significantly enhances both the learning process and its outcomes. The results consistently showed that AR fosters a more engaging, autonomous, and effective learning environment, particularly in delivering complex technical content that is foundational to Building and Civil Engineering training.

5.1.1 Impact of augmented reality and trainee engagement

The quantitative results showed that trainees perceived AR as highly effective in enhancing their engagement during learning. Descriptive statistics indicated high mean scores across statements related to trainee participation, enjoyment, task completion, confidence, and content recall. These outcomes point to AR's ability to foster sustained attention, motivation, and emotional investment critical elements of trainee engagement. The data supported the conclusion that AR fosters an immersive learning experience, increasing both interest and active participation among trainees.

Qualitative data from open-ended trainee responses and trainer interviews reinforced these findings. Trainees expressed that AR made lessons more exciting, interactive, and easier to follow, which in turn encouraged them to participate more actively.

Trainers observed that trainees appeared more motivated, attentive, and eager to explore learning content when AR tools were used. The majority emphasized that AR helped capture trainee interest and reduce classroom distraction, particularly for complex technical topics.

Together, the mixed-methods evidence confirms that AR positively induces trainee engagement. This positions AR as a pedagogical tool capable of transforming passive learning into an active and trainee-centered experience within technical training environments.

5.1.2 Impact of augmented reality and instructional strategies.

Quantitative findings indicated that AR positively influenced instructional strategies in Building and Civil Engineering programmes. Trainees reported that AR-based instruction improved the clarity of technical demonstrations, enabled more interactive learning environments, and helped instructors break down complex concepts into manageable components. High mean scores on relevant indicators reflected trainees' agreement that AR enhanced the teaching process by making abstract or complicated content more accessible and understandable.

Qualitative insights from trainer interviews further supported this outcome. Trainers noted that AR shifted their teaching from conventional lecture-based delivery to more trainee-centered, visual, and activity-driven methods. Many instructors emphasized that AR empowered them to adapt lessons to varied trainee needs and offer differentiated instruction. It also encouraged trainers to integrate technology creatively in curriculum delivery and to move beyond traditional chalk-and-board practices.

The combination of quantitative and qualitative results demonstrates that AR serves as a catalyst for pedagogical innovation in technical education. It promotes the adoption of more dynamic and visually enriched instructional strategies, making teaching more effective and aligned with the learning needs of 21st-century trainees.

5.1.3 Impact of augmented reality and retention of complex technical content.

Quantitative results revealed that AR had a strong positive influence on trainees' retention of complex technical content in Building and Civil Engineering programmes. High mean scores and statistically significant regression coefficients indicated that

trainees who used AR-based tools demonstrated improved long-term understanding and memory of abstract and intricate engineering concepts. This was attributed to AR's ability to present content in interactive, visual, and three-dimensional formats that facilitated cognitive processing and knowledge retention.

The qualitative data gathered from trainer interviews reinforced these findings. Trainers observed that AR enabled trainees to repeatedly explore difficult content at their own pace and visualize procedures that were previously difficult to comprehend. Many trainers noted improved trainee recall during assessments and practical applications, suggesting deeper and more sustained understanding. They also pointed out that the visualization and simulation capabilities of AR helped reduce cognitive overload and increased trainees' ability to relate theoretical knowledge to real-world scenarios.

In conclusion, both quantitative and qualitative evidence confirmed that AR significantly enhances trainees' ability to retain and apply complex technical content. It improves cognitive engagement and supports meaningful learning by turning difficult concepts into interactive and easily memorable experiences.

5.1.4 Impact of augmented reality and self-directed learning among trainees.

The study found that AR plays a significant role in promoting self-directed learning among trainees in Building and Civil Engineering diploma programmes. Quantitative results showed consistently high mean scores for items related to trainees' ability to take initiative, manage their learning pace, and seek further exploration of concepts using AR tools. Regression analysis revealed a statistically significant relationship between AR-based instruction and self-directed learning, indicating that trainees became more autonomous and motivated when AR was integrated into the instructional process.

Qualitative insights from trainer interviews supported these findings. Trainers reported that AR encouraged trainees to explore engineering concepts independently beyond class hours, revisit difficult content multiple times, and take responsibility for completing interactive tasks without prompting. They also observed that trainees exhibited greater curiosity, initiative, and perseverance when using AR applications, especially during problem-solving and technical simulations.

Overall, the findings demonstrated that AR-based instruction cultivates essential self-directed learning behaviors by providing trainees with control over their learning journey, access to real-time feedback, and interactive experiences that sustain motivation and ownership. This suggests that integrating AR into TVET instruction can significantly enhance trainees' independence and lifelong learning capabilities.

5.1.5 Impact of trainees' prior knowledge on the relationship between Augmented Reality and academic achievement

The study established that trainees' prior knowledge significantly moderates the relationship between AR and academic achievement in Building and Civil Engineering diploma programmes. Quantitative analysis through hierarchical multiple regression revealed that when interaction terms between AR variables and prior knowledge were introduced, there was a notable increase in the model's explanatory power. This indicates that the influence of AR-based instruction on academic outcomes was stronger among trainees with higher levels of prior knowledge.

Further statistical tests confirmed that prior knowledge enhances the effectiveness of AR in facilitating content comprehension, practical skill application, and examination performance. Trainees with a solid foundational understanding were better able to navigate AR environments, interpret technical simulations, and apply theoretical knowledge more effectively.

Qualitative data from trainer interviews supported these findings. Trainers noted that trainees with pre-existing subject familiarity adapted more quickly to AR tools, showed higher confidence during interactive tasks, and engaged more deeply with the content. Conversely, trainees with limited prior knowledge sometimes required additional guidance to fully benefit from AR experiences.

Overall, the results suggest that prior knowledge is a critical factor in maximizing the pedagogical benefits of AR. It enables trainees to leverage AR features more effectively, leading to improved academic performance. This highlights the need to tailor AR integration strategies to the trainees' baseline knowledge and provide differentiated support to ensure equitable learning outcomes.

5.1.6 Overall impact of Augmented Reality and academic achievement of trainees

The study found that AR has a significant and positive overall impact on the academic achievement of trainees enrolled in Building and Civil Engineering diploma programmes in Nairobi's TVET institutions. Multiple regression analysis demonstrated that AR-based factors such as trainee engagement, instructional strategies, retention of complex content, and self-directed learning collectively explained a substantial proportion of the variance in academic performance. AR integration consistently predicted higher achievement scores across theoretical understanding, practical skills, and summative assessments.

Descriptive statistics showed that trainees rated the overall impact of AR highly, reflecting strong perceptions of its effectiveness in supporting their academic success. Correlation results confirmed strong associations between AR use and improved learning outcomes, while inferential tests validated the statistical significance of these relationships.

Qualitative insights from trainer interviews further reinforced the quantitative findings. Trainers reported noticeable improvements in trainee motivation, concept mastery, and independent problem-solving when AR was incorporated into instruction. Many attributed this to the immersive, visual, and interactive nature of AR, which made abstract or technical content more accessible and engaging.

In conclusion, the research confirms that AR is an effective pedagogical tool that enhances academic achievement by supporting a wide range of cognitive and experiential learning processes. Its successful implementation in TVET institutions contributes meaningfully to improving educational outcomes in technical and engineering disciplines.

5.2 Conclusion

5.2.1 Impact of augmented reality and trainee engagement

The findings of the study affirm that AR significantly enhances trainee engagement among Building and Civil Engineering trainees in TVET institutions. AR was found to stimulate active participation, increase motivation, and promote emotional involvement in learning tasks. Trainees expressed greater enthusiasm and attentiveness during AR-integrated lessons, with a majority reporting that they

completed tasks more consistently and retained information more effectively. These outcomes suggest that the interactive and immersive features of AR technologies foster a more stimulating and meaningful learning experience, which is critical for technical subjects that demand both conceptual understanding and practical application.

The integration of AR into technical training environments creates a dynamic and trainee-centered instructional atmosphere. It empowers trainees to engage deeply with content, facilitates exploration beyond the classroom, and builds confidence in mastering complex engineering concepts. Therefore, AR is not just a supplementary tool but a transformative pedagogical approach that strengthens engagement and lays a solid foundation for improved academic outcomes in technical education.

5.2.2 Impact of augmented reality and instructional strategies.

The study concluded that AR positively transforms instructional strategies employed in teaching technical concepts within Building and Civil Engineering programs in TVET institutions. AR facilitated the shift from teacher-centered approaches to more interactive, trainee-centered methodologies. Trainers were able to visualize complex structures, demonstrate technical processes in real-time, and simplify abstract engineering content through immersive 3D simulations. This not only improved the clarity of instruction but also encouraged greater trainee participation and collaboration during lessons.

Furthermore, AR allowed for differentiated instruction, enabling trainers to cater to diverse trainee needs and varying levels of prior knowledge. Despite some limitations such as initial unfamiliarity and limited infrastructure, trainers adapted their strategies to integrate AR tools effectively into both theory and practical sessions.

AR has proven to be an effective instructional enhancer that enriches teaching methodologies by making complex technical concepts more accessible, engaging, and easier to grasp. Its integration supports more dynamic and flexible pedagogical practices, contributing to better comprehension and skill development among trainees in technical education.

5.2.3 Impact of augmented reality and retention of complex technical content.

The study concluded that AR significantly enhances trainees' retention of complex technical content in Building and Civil Engineering diploma programmes within TVET institutions. The immersive and interactive nature of AR enabled trainees to visualize abstract and difficult concepts in a more concrete and memorable manner. This multimodal learning experience supported better cognitive processing, making technical knowledge easier to recall and apply in both theoretical and practical contexts.

Trainees reported improved understanding and long-term retention of engineering concepts when AR was used as a learning aid, particularly in areas that traditionally pose challenges in conventional instruction. The ability to repeatedly interact with virtual models and simulations also contributed to reinforcement of knowledge and reduction of cognitive overload.

In summary, AR effectively supports the retention of complex content by presenting information in visually engaging, intuitive formats that align with trainees' needs. Its integration into instructional practice improves knowledge recall and strengthens conceptual mastery among trainees in technical education.

5.2.4 Impact of augmented reality and self-directed learning among trainees.

The study concluded that AR significantly fosters the development of effective self-directed learning among Building and Civil Engineering trainees in TVET institutions. The integration of AR into instructional activities empowered trainees to take greater ownership of their learning by promoting curiosity, exploration, and independent engagement with complex content.

Trainees were motivated to revisit AR learning materials beyond class time, complete tasks independently, and seek deeper understanding of technical concepts. The flexibility and interactivity provided by AR technologies created a trainee-centered environment where individuals could progress at their own pace, revisit difficult concepts, and reinforce learning according to their unique needs.

Overall, the findings demonstrated that AR plays a critical role in promoting self-regulated learning behaviors. It equips trainees with the confidence, autonomy, and

initiative necessary for success in technical fields, thereby supporting the broader goals of competency-based training and lifelong learning in TVET education.

5.2.5 Impact of trainees' prior knowledge on the relationship between Augmented Reality and academic achievement

The study concluded that trainees' prior knowledge significantly moderates the relationship between AR and academic achievement in Building and Civil Engineering programmes. Trainees who entered the learning environment with stronger foundational knowledge or prior exposure to AR technologies demonstrated higher adaptability, deeper engagement, and better academic outcomes compared to their peers with limited prior knowledge.

The findings revealed that prior knowledge enhances the effectiveness of AR-based instruction by enabling trainees to connect new information with existing cognitive frameworks. As a result, trainees were better able to comprehend complex technical concepts, engage meaningfully with AR content, and perform more confidently in assessments.

Therefore, the study emphasizes the importance of considering trainees' background knowledge when implementing AR in technical education. Tailored onboarding strategies and differentiated instructional support may be necessary to ensure that all trainees benefit equally from AR-enhanced learning experiences.

5.2.6 Overall impact of Augmented Reality and academic achievement of trainees

The study concluded that AR has a substantial and positive overall impact on the academic achievement of trainees in Building and Civil Engineering diploma programmes. AR-based instruction significantly enhanced trainees' understanding of theoretical content, acquisition of practical skills, and performance in summative examinations. Its interactive and immersive nature promoted higher levels of engagement, deeper conceptual comprehension, and long-term retention of complex technical information.

Quantitative findings demonstrated that AR-based learning environments yielded higher academic scores compared to traditional instructional methods, while qualitative feedback from trainees and trainers confirmed AR's role in improving

motivation, confidence, and academic performance. These results validate AR as an effective instructional innovation capable of addressing learning challenges in technical education.

In summary, the integration of AR in TVET institutions in Nairobi County is shown to enrich instructional delivery and substantially improve trainee academic achievement across multiple learning domains.

5.3 Recommendations for TVET Institutions, Policymakers, and Educators

Based on the study findings, several recommendations are proposed to enhance the integration and effectiveness of AR in teaching and learning within Building and Civil Engineering diploma programmes in TVET institutions.

For TVET institutions, it is essential to embed AR technology into the curriculum to complement both theoretical instruction and practical training. AR should be strategically aligned with competency-based education frameworks to ensure relevance and coherence with industry demands. Institutions are encouraged to invest in appropriate AR infrastructure, including compatible hardware and software, and to establish AR-enabled smart classrooms or laboratories that support immersive and interactive learning experiences. Furthermore, building the capacity of trainers through continuous professional development is critical. Educators must be equipped with the necessary digital and pedagogical skills to effectively deliver AR-based content. TVET institutions are also advised to pilot AR-based instruction in selected subject areas and establish internal research and innovation units to monitor its impact and share best practices across departments.

For policymakers, there is a need to develop clear guidelines and policies that support the systematic integration of AR in TVET. These guidelines should define standards for AR use, learning outcomes, and instructional design. Policymakers should also prioritize funding to support the acquisition and implementation of AR technologies in TVET institutions, particularly in under-resourced areas. Providing financial support through grants, subsidies, or national innovation funds can accelerate adoption and ensure sustainability. Additionally, it is recommended that incentive structures be established to reward institutions and educators who demonstrate innovation and improvement in trainee outcomes through the use of AR. Equity-focused initiatives

should also be implemented to bridge the digital divide, ensuring that trainees in rural and marginalized institutions have equal access to AR learning tools and digital infrastructure.

For educators and trainers, it is recommended that they adopt trainee-centered AR instructional strategies that foster active engagement, collaboration, and self-directed learning. Trainers should tailor AR content to accommodate diverse learning needs and prior knowledge levels, thereby maximizing its effectiveness. By using AR to visualize complex concepts and promote exploration, trainers can enhance comprehension and long-term retention. It is also important for educators to regularly assess the effectiveness of AR tools and make evidence-based adjustments to their teaching approaches. Encouraging group-based projects and peer interactions through AR can further stimulate critical thinking and problem-solving skills, which are essential in engineering education.

In summary, successful implementation of AR in TVET institutions requires coordinated efforts from institutional leaders, policymakers, and educators. These recommendations aim to create an enabling environment that leverages AR to improve academic outcomes, boost trainee engagement, and strengthen the quality of training in technical disciplines.

5.4 Recommendations for Further Studies

While this study has provided valuable insights into the impact of AR on academic achievement among Building and Civil Engineering trainees in TVET institutions, it also opens up several avenues for further investigation. Future studies should consider expanding the scope to include a broader range of technical disciplines beyond Building and Civil Engineering to determine whether the positive effects of AR are consistent across different vocational training areas. Additionally, longitudinal studies are recommended to assess the long-term impact of AR on knowledge retention, skills development, and job-readiness among TVET graduates. This would help establish whether the benefits observed in short-term interventions are sustained over time.

Researchers are also encouraged to examine the cost-effectiveness of implementing AR in TVET institutions, especially in resource-constrained environments. Understanding the economic implications can guide policymakers and institutional

leaders in making informed investment decisions. Moreover, future research could explore the integration of AR with other emerging technologies, such as Virtual Reality (VR), Artificial Intelligence (AI), and Learning Analytics, to determine how combined approaches could further enhance teaching and learning outcomes.

Another critical area for further study is the exploration of gender, socioeconomic status, and geographic location as moderating variables. Investigating how these factors influence trainees' access to and experiences with AR could help in designing more inclusive and equitable digital learning environments. Lastly, qualitative studies involving in-depth interviews and case studies across diverse TVET settings can provide richer contextual insights into the challenges and opportunities associated with AR-based instruction. These studies will be vital in developing comprehensive strategies for the effective and sustainable adoption of AR in technical and vocational education.

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APPENDICIES

Appendix 1: Introductory Letter

Felix Quentin Biketi
Reg No: TE500/5560/2021
Box 144
Ngara Nairobi

Dear Sir/Madam,

RE: REQUEST FOR PERMISSION TO CONDUCT RESEARCH AT YOUR INSTITUTION

I am a postgraduate student at Murang'a University of Technology, pursuing a Doctorate degree in Education Technology. As part of the requirements for the award of this degree, I am conducting a research study titled: **"Impact of Augmented Reality on Academic Achievement in Building and Civil Engineering Diploma Programmes within TVET Institutions in Nairobi County."**The purpose of this study is to investigate how Augmented Reality (AR) influences trainees' academic outcomes in various learning domains. Specifically, the study seeks to:

1. To assess the extent to which augmented reality induces trainee engagement among building and civil engineering trainees in TVET institutions.
2. To examine how augmented reality influences instructional strategies used in teaching technical concepts in building and civil engineering.
3. To analyze the role of augmented reality in enhancing trainees' retention of complex technical content.
4. To determine the effect of augmented reality on the development of effective self-directed learning among trainees.
5. To assess the moderating effect of trainees' prior knowledge on the relationship between Augmented Reality and academic achievement.
6. To assess the overall impact of augmented reality on the academic achievement of trainees in building and civil engineering programmes in Nairobi's TVET institutions.

To collect relevant data, I kindly request permission to conduct a pre-test and post-test, administer questionnaires, with trainees enrolled in the Building and Civil Engineering diploma programmes at your institution and conduct interviews to trainers. The information gathered will be used solely for academic purposes and will be treated with the utmost confidentiality. The findings will also be shared with your institution upon request.

Thank you for considering my request. I look forward to your positive response.

Yours sincerely,



Felix Quentin Biketi
Reg No: TE500/5560/2021

Appendix 2: Questionnaire For Trainees

SECTION A: BIOGRAPHICAL DATA

Instructions: Kindly respond to the questions below by ticking (✓) the appropriate box. The information provided will be used strictly for research purposes and will be treated with the utmost confidentiality.

1.What is your age group?

☐ Below 19 years

☐ 19 – 22 years

☐ 22 – 30 years

☐ 30 years and above

2.What is your gender?

☐ Male

☐ Female

3.What was your previous academic qualification?

☐ Kenya Certificate of Secondary Education (KCSE)

☐ Relevant Craft Certificate

4.Which programme are you enrolled in?

☐ Diploma in Building

☐ Diploma in Civil Engineering

SECTION B: AUGMENTED REALITY ENHANCED ENGAGEMENT

For the following statements, please tick against the answer which closely reflects your opinion on the extent to which augmented reality enhances trainees' engagement among building and civil engineering trainees in TVET institutions. on a Likert scale of 1 to 5,

Where: *5= strongly agree 4= Agree 3= Disagree 2= Strongly Disagree 1=Disagree*

NO	Augmented Reality Induced Engagement	1	2	3	4	5
1.	I take part in AR learning activities in class.					
2.	I enjoy using AR and like exploring it beyond class.					
3.	I always finish AR learning tasks.					
4.	AR makes me feel more confident about engineering topics.					
5.	I remember lessons better when I use AR.					

What do you like most about AR learning, and how has it helped you?

_____

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SECTION C: AUGMENTED REALITY INFLUENCE ON INSTRUCTIONAL STRATEGY

For the following statements, please tick against the answer which closely reflects your opinion on how augmented reality influences instructional strategies used in teaching technical concepts in building and civil engineering on a Likert scale of 1 to 5,

Where: *5= strongly agree 4= Agree 3= Disagree 2= Strongly Disagree 1= Neither agree nor Disagree*

NO	Augmented Reality as an instructional strategy	1	2	3	4	5
1.	AR tools match well with what I am learning.					
2.	AR makes learning more interesting.					
3.	My teacher knows how to use AR well.					
4.	We use AR enough times in class to understand topics better.					
5.	AR helps me understand lessons better than normal teaching.					

How can we improve the use of AR in teaching?

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SECTION D: AUGMENTED REALITY ENHANCING TRAINEES' RETENTION OF COMPLEX CONCEPTS

For the following statements, please tick against the answer which closely reflects your opinion on impact of augmented reality in enhancing trainees' retention of complex technical content on a Likert scale of 1 to 5.

Where: *5= strongly agree 4= Agree 3= Disagree 2= Strongly Disagree 1= Neither agree nor Disagree*

NO	**Augmented Reality in improving trainee understanding and retention of complex concepts**	**1**	**2**	**3**	**4**	**5**
1.	AR helps me understand difficult engineering topics.					
2.	I remember things better when I use AR.					
3.	AR helps me solve engineering problems better.					
4.	AR lessons make me think more deeply about topics.					
5.	AR makes learning more fun and engaging.					

In what ways did AR help you understand and retain complex engineering concepts better than traditional teaching methods?

_____

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SECTION E: AUGMENTED REALITY ON THE DEVELOPMENT OF EFFECTIVE SELF-DIRECTED LEARNING AMONG TRAINEES

For the following statements, please tick against the answer which closely reflects your opinion on the impact of augmented reality on the development of effective self-directed learning among trainees on a Likert scale of 1 to 5.

Where: *5= strongly agree 4= Agree 3= Disagree 2= Strongly Disagree 1= Neither agree nor Disagree*

NO	Augmented Reality self-directed learning	1	2	3	4	5
1.	I use AR tools on my own outside of class.					
2.	I feel confident using AR without help.					
3.	I plan my own studies using AR.					
4.	AR helps me learn at my own pace.					
5.	I explore AR content to understand better.					

In what ways has AR influenced your approach to taking charge of your own learning?

_____

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SECTION F: STUDENT PRIOR KNOWLEDGE

For the following statements, please tick against the answer which closely reflects your opinion the moderating impact of trainees' prior knowledge on the relationship between Augmented Reality and academic achievement on a Likert scale of 1 to 5,

Where: *5= strongly agree 4= Agree 3= Disagree 2= Strongly Disagree 1= Neither agree nor Disagree*

NO	Student Prior Knowledge	1	2	3	4	5
1.	Before using AR, I was confident using engineering tools.					
2.	My previous skills helped me learn AR faster.					
3.	I was comfortable using AR before this course.					
4.	My learning style (hands-on, visual, etc.) affects how I use AR.					
5.	I have a phone or device to access AR learning materials.					

How has your past experience helped you learn with AR?

_____

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SECTION G: OVERALL TRAINEE ACADEMIC ACHIEVEMENT

For the following statements, please tick against the answer which closely reflects your opinion the overall impact of augmented reality on the academic achievement of trainees in building and civil engineering programmes in Nairobi's TVET institutions on a Likert scale of 1 to 5,

Where: *5= strongly agree 4= Agree 3= Disagree 2= Strongly Disagree 1= Neither agree nor Disagree*

NO	Trainee Academic achievement	1	2	3	4	5
1.	AR has helped me score better in tests and exams.					
2.	AR makes hard topics easier to understand.					
3.	AR makes me more active in class, which helps me learn.					
4.	AR gives me confidence in exams and practical work.					
5.	AR has improved my overall performance in this course.					

How has AR impacted your overall learning experience and academic achievement?

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Appendix 3: Interview Guide for Trainers

Title: To investigate the impact of augmented reality on the academic performance of building and civil engineering trainees in TVET institutions in Nairobi, Kenya.

Objective: To understand trainers' experiences with Augmented Reality (AR) in Building and Civil Engineering diploma programmes within TVET institutions.

Section 1: Background Information

1. How long have you been teaching?

☐ Below 4 years ☐ 5 – 9 years ☐ 10 – 14 years ☐ 15 years and above

2.What is your gender?

☐ Male ☐ Female

3.What is your highest level of education??

☐ Doctoral Degree ☐ Masters ☐ Undergraduate ☐ Higher Diploma ☐ Diploma

☐ Others

4. Have you used Augmented Reality (AR) in your teaching before?

☐ Yes ☐ No

Section 2: To assess the extent to which Augmented Reality enhances trainee engagement

1. In your experience, how does AR affect trainees' attention and participation during lessons?
2. Have you observed increased enthusiasm or interest from trainees when AR is used in class?
3. Are there specific features of AR that you feel are particularly effective in capturing and sustaining trainee engagement?

Section 3: To examine how Augmented Reality influences instructional strategies

1. How has the integration of AR changed your approach to teaching technical content?
2. Do you find AR-based strategies more effective than traditional approaches in promoting understanding of engineering concepts?
3. What challenges or benefits have you encountered while using AR as an instructional tool?

Section 4: To analyze the role of Augmented Reality in enhancing retention of complex content

1. How has AR helped trainees understand and remember difficult engineering concepts over time?
2. Are there certain topics where AR appears to improve retention more significantly?
3. In what ways do AR visualizations or simulations contribute to long-term memory of technical material?

Section 5: To determine the effect of Augmented Reality on the development of effective self-directed learning among trainees

1. Have you noticed trainees taking more initiative in their learning when using AR-based resources?
2. Does AR encourage trainees to explore topics outside of regular class hours or assignments?
3. How do you think AR supports or challenges trainees in managing their own learning process?

Section 6: To assess the moderating effect of trainees' prior knowledge on the relationship between AR and academic achievement

1. Do trainees with more technical background or familiarity with digital tools respond differently to AR-based instruction?
2. How do differences in prior knowledge influence the effectiveness of AR in improving learning outcomes?

3. Have you had to adjust your use of AR tools depending on trainees' starting levels of understanding or experience?

Section 7: To assess the overall impact of Augmented Reality on the academic achievement of trainees

1. How would you describe impact of AR on trainees' academic performance in your subject area?
2. In your view, does AR lead to measurable improvements in grades, understanding, or application of knowledge?
3. Would you recommend the broader adoption of AR in technical training, and why?

Appendix 4: Examination Paper Trainees Tested

PRE-TEST EXAMINATION

TIME: 30 MINUTES

Instructions: Answer all questions. For multiple-choice questions, circle the correct answer. For short-answer questions, provide concise responses. Complete the bio-data section accurately before proceeding with the academic questions.

SECTION A: Bio-Data (For Research Purposes Only)

Please tick (✓) or fill in the appropriate responses.

1. **Age Group**:
   ☐ Below 19 years
   ☐ 19 – 22 years
   ☐ 22 – 30 years
   ☐ 30 and above
2. **Gender**:
   ☐ Male
   ☐ Female
3. **Previous Academic Qualification**:
   ☐ KCSE Certificate
   ☐ Relevant Craft Certificate
4. **Current Programme Enrolled**:
   ☐ Building Technicians Diploma
   ☐ Civil Engineering Diploma

SECTION B: Multiple-Choice Questions (1 mark each)

1. Which of the following materials is not a primary ingredient in concrete?
   a) Cement b) Sand c) Gravel d) Bitumen

2. The main purpose of air-entraining agents in concrete is to:
   a) Increase strength b) Improve durability in freeze-thaw conditions
   c) Reduce workability d) Increase density
3. Which of the following factors affects the workability of concrete the most?
   a) Aggregate size and shape b) Curing temperature
   c) Compressive strength d) Concrete age
4. What is the primary function of reinforcement in reinforced concrete?
   a) To prevent concrete from cracking b) To improve concrete durability
   c) To provide tensile strength d) To reduce shrinkage
5. The compressive strength of concrete is usually measured after:
   a) 1 day b) 3 days c) 7 days d) 28 days
6. A slump test is used to measure:
   a) Compressive strength b) Workability c) Density d) Durability
7. What is the minimum cement content recommended for durable concrete?
   a) 100 kg/m³ b) 150 kg/m³ c) 200 kg/m³ d) 300 kg/m³
8. Which of the following aggregates is best suited for high-strength concrete?
   a) Rounded aggregates b) Angular aggregates
   c) Elongated aggregates d) Flat aggregates
9. What is the main cause of segregation in concrete?
   a) Excess water in the mix b) Insufficient curing
   c) Use of admixtures d) Improper compaction
10. Which curing method is most effective in preventing moisture loss in fresh concrete?
   a) Air drying b) Sprinkling water
   c) Covering with plastic sheets d) Placing in direct sunlight

SECTION C: Short Answer Questions (2 marks each)

11. Define concrete and list its primary components.
12. Explain two common defects in concrete and their causes.
13. What is segregation and how can it be prevented in concrete?
14. Differentiate between bleeding and segregation in fresh concrete.
15. Why is proper curing important in concrete construction?

MARKING SCHEME

SECTION A: Multiple-Choice Questions (1 mark each)

1 d) Bitumen

2 b) Improve durability in freeze-thaw conditions

3 a) Aggregate size and shape

4 c) To provide tensile strength

5 d) 28 days

6 b) Workability

7 d) 300 kg/m³

8 b) Angular aggregates

9 a) Excess water in the mix

10 c) Covering with plastic sheets

Total for Section A: 10 Marks

SECTION B: Short Answer Questions (2 marks each)

11. Define concrete and list its primary components.

- ✓ Concrete is a composite material made of cement, aggregates (sand and gravel), water, and sometimes admixtures. *(1 mark)*
- ✓ Primary components: Cement, sand, coarse aggregates, water. *(1 mark)*

12. Explain two common defects in concrete and their causes.

- ✓ Cracking: Due to shrinkage, excessive loading, or poor curing. *(1 mark)*
- ✓ Honeycombing: Caused by improper compaction or insufficient cement paste. *(1 mark)*

13. What is segregation and how can it be prevented in concrete?

- ✓ Definition: Segregation is the separation of coarse aggregates from the cement paste and finer materials in a concrete mix. *(1 mark)*
- ✓ Prevention: Use proper water content, mix design, and adequate compaction. *(1 mark)*

14. Differentiate between bleeding and segregation in fresh concrete.

- ✓ Bleeding: Water rising to the surface of concrete due to settling of heavier particles. *(1 mark)*
- ✓ Segregation: Separation of coarse aggregates from the mix due to poor consistency or over-vibration. *(1 mark)*

15. **Why is proper curing important in concrete construction?**

- ✓ Ensures hydration continues, improving strength and durability. *(1 mark)*
- ✓ Prevents cracking and shrinkage by maintaining moisture levels. *(1 mark)*

Total for Section B: 10 Marks

Appendix 5: Post-Test Concrete Technology Examination

HYDRATION PROCESS IN CONCRETE TECHNOLOGY

TIME: 30 MIN

Instructions: Answer all questions. For multiple-choice questions, circle the correct answer. For short-answer questions, provide concise responses.

SECTION A: Multiple Choice Questions (10 marks)

Questions: (1 mark each)

What is the primary function of water in the hydration process of cement?

a) Acts as a filler material.

b) Provides workability to the mix.

c) Reacts chemically with cement compounds.

d) Reduces the heat of hydration.

Which cement compound reacts most rapidly with water?

a) C_2S

b) C_4AF

c) C_3S

d) C_3A

What is the typical relative humidity required for proper cement hydration to occur?

a) Below 40%

b) Above 80%

c) Around 50%

d) It is independent of humidity.

What is meant by the "degree of hydration"?

a) The temperature of the concrete during curing.

b) The amount of water added to the cement.

c) The percentage of cement that has reacted with water.

d) The size of the aggregate used in the concrete mix.

How does the presence of chlorides generally affect the hydration process?

a) Slows down the hydration process.

b) Accelerates the hydration process.

c) Has no effect on the hydration process.

d) Improves the final strength of concrete.

Which of the following is NOT a product of cement hydration?

a) Calcium Silicate Hydrate (C-S-H)

b) Ettringite

c) Alumina

d) Calcium Hydroxide (CH)

Why is proper curing important for concrete hydration?

a) To reduce the cost of the concrete mix.

b) To prevent moisture loss and ensure complete hydration.

c) To improve the aesthetic appearance of the concrete.

d) To increase the workability of fresh concrete.

What is the effect of increased temperature on the rate of cement hydration (up to a certain point)?

a) Decreases the rate.

b) Increases the rate.

c) Has no effect.

d) Stabilizes the rate.

What is the role of "pozzolans" in concrete related to hydration?

a) They directly hydrate and increase early strength.

b) They react with calcium hydroxide to form additional C-S-H.

c) They reduce the heat of hydration by replacing cement.

d) They act as water reducers.

What is 'self-desiccation' in concrete?

a) External water curing of concrete

b) Drying of the concrete due to excessive heat

c) Internal drying due to chemical reaction consuming water

d) Addition of desiccant during mixing

SECTION B: Short Answer Questions (20 marks)

Questions: (2 marks each)

1. Define hydration in the context of concrete technology.
2. List and explain two ways in which heat of hydration can be controlled in concrete structures.
3. Explain the reason why is gypsum added to cement during manufacturing?
4. How does fineness of cement affect the hydration process and strength development?
5. Explain why high temperatures accelerate hydration but may reduce long-term strength.

MARKING SCHEME

SECTION A: Multiple Choice Questions (10 marks)

Questions: (1 mark each)

1. c) Reacts chemically with cement compounds.
2. a) C_2S
3. c) Around 50%
4. c) The percentage of cement that has reacted with water
5. a) Slows down the hydration process.
6. c) Alumina
7. b) To prevent moisture loss and ensure complete hydration
8. b) Increases the rate
9. b) They react with calcium hydroxide to form additional C-S-H.
10. c) Internal drying due to chemical reaction consuming water

SECTION B: Short Answer Questions (20 marks)

Questions: (2 marks each)

11. Hydration is the chemical reaction between cement and water that results in the formation of hydration products, primarily calcium silicate hydrate (C-S-H) and calcium hydroxide (CH), which provide strength and durability to concrete.
12.
    i. Use of low-heat cement: Using cement with a lower proportion of tricalcium aluminate (C_3A) reduces the amount of heat generated.
    ii. Cooling techniques: Methods such as using chilled water, ice, or cooling pipes can help dissipate heat in large concrete masses, preventing thermal cracking.
13. Gypsum is added to control the setting time of cement by preventing flash setting caused by the rapid hydration of tricalcium aluminate (C_3A). This allows sufficient time for mixing, placing, and finishing the concrete.

14. Finer cement particles have a larger surface area, leading to faster hydration and early strength gain. However, extremely fine cement may increase heat of hydration, which can cause thermal cracking in mass concrete structures.
15. High temperatures speed up the hydration reaction, leading to faster strength gain initially. However, this rapid reaction causes the formation of non-uniform hydration products, increasing porosity and reducing long-term strength and durability due to improper crystalline structure formation.

Appendix 6: Control Group 1 Results

C1		PRETEST		POST-TEST		EXAM
S No.	Name	Marks (out of 30)	Marks (out of 100)	Marks (out of 30)	Marks (out of 100)	Marks (out of 100)
1.	B.M	9	30	17	56	45
2.	J.M	10	33	20	67	60
3.	M.W.M	9	30	17	56	50
4.	J. K	10	33	8	27	62
5.	P. N	9	30	15	49	55
6.	G.M	10	33	15	51	42
7.	J. M	11	37	13	42	58
8.	E. W	9	30	17	58	65
9.	D. M	10	33	20	68	39
10.	P. K	9	30	20	68	47
11.	D. G	10	33	13	43	63
12.	E. T.	11	37	8	25	55
13.	J. K.	9	30	21	71	49
14.	C. N. M.	10	33	19	63	66
15.	M. V. O.	9	30	8	26	53
16.	S. K. W.	10	33	20	67	68
17.	W. N. K.	11	37	20	65	44
18.	K. D. M.	9	30	14	46	57
19.	G. M. J.	10	33	15	50	36
20.	K. J. N.	9	30	12	40	
21.	M. B. M.	10	33	7	22	54
22.	K. M. M.	11	37	11	37	52
23.	A. M.	9	30	18	61	48
24.	C. W.	10	33	6	20	69
25.	K. W. M.	9	30	11	37	50
26.	M. W.	10	33	12	40	
27.	S. K.	11	37	14	47	70
28.	H. K.	9	30	20	67	55
29.	W. J. O.	10	33	11	38	41
30.	E. W. I.	9	30	11	38	60
31.	W. T.	10	33	17	58	66
32.	I. P. W.	11	37	13	43	53
33.	K. A.	9	30	9	31	58
34.	S. L.	10	33	13	43	39
35.	K. S. K.	9	30	8	27	62
36.	M. M. M.	10	33	9	29	57
37.	W. M.	11	37	14	45	47
38.	B. W.	9	30	12	41	72
39.	G. M. K.	10	33	20	67	51
40.	T. M.	9	30	11	38	45
41.	W. C.	10	33	15	50	54
42.	N. M. N.	11	37	16	52	49
43.	G. K. J.	9	30	6	20	64
44.	M. N. A.	10	33	16	54	38
45.	K. M.	9	30	9	29	46
46.	K. K.	10	33	21	69	71

47.	J. L.	11	37	8	27	59
48.	B. K. K.	9	30	12	41	52
49.	P. K. R.	10	33	7	24	56
50.	D. K.	9	30	21	71	43
51.	B. K.	10	33	14	46	
52.	K. K. D.	11	37	15	50	48
53.	K. G.	9	30	7	23	65
54.	G. K. S.	10	33	17	58	40
55.	K. M. D.	9	30	9	30	43
56.	W. M. I.	10	33	20	66	62
57.	K. K. F.	11	37	9	30	35
58.	M. M. B.	9	30	9	29	57
59.	K. G. N.	10	33	6	21	
60.	M. W. H.	9	30	13	44	61
61.	M. G. K.	10	33	15	49	63
62.	E. K.	11	37	7	23	55
63.	N. M. L.	9	30	18	60	46
64.	K. M. B.	10	33	13	43	68
65.	I. M. W.	9	30	14	47	61
66.	J. W. N.	10	33	13	42	59
67.	J. W. M.	11	37	12	40	64
68.	I. W. N.	9	30	15	49	48
69.	P. W. W.	10	33	8	28	42
70.	M. W. N.	9	30	9	29	73
71.	E. G.	10	33	19	64	50
72.	C. M.	11	37	21	69	37
73.	E. G.	9	30	12	39	56
74.	A. K.	10	33	10	34	47
75.	P. G.	9	30	16	53	51
76.	E. M.	10	33	12	41	60
77.	D. O.	11	37	6	21	55
78.	E. O.	9	30	8	28	58
79.	B. M.	10	33	17	57	46
80.	K. K. M.	9	30	16	54	70
81.	M. M.	10	33	6	21	
82.	A. M.	11	37	9	31	54
83.	N. S. M.	9	30	10	32	62
84.	M. I.	10	33	16	54	67
85.	D. W.	9	30	6	21	49
86.	O. O. M.	10	33	8	25	50
87.	W. O. M.	11	37	18	61	66
88.	P. O.	9	30	9	29	39

Appendix 7: Experimental Group 1 Results

E1		PRETEST		POST-TEST		EXAM
S No.	Name	Marks (out of 30)	Marks (out of 100)	Marks (out of 30)	Marks (out of 100)	Marks (out of 100)
1.	O.K.	10	33	24	81	71
2.	B.K.	12	41	22	75	68
3.	T.M.	10	33	23	76	72
4.	P.M.K.	11	37	21	71	78
5.	J.N.K.	11	37	23	76	67
6.	E.T.	10	33	22	74	67
7.	P.G.	11	37	23	78	78
8.	V.T.	10	33	21	71	
9.	P.M.	12	40	24	79	66
10.	S.M.	10	33	25	84	72
11.	M.N.	11	37	22	75	66
12.	A.N.	13	43	23	78	66
13.	J.W.	10	33	24	80	70
14.	J.M.	11	37	22	74	57
15.	P.K.	10	33	23	77	58
16.	R.K.	12	40	23	76	65
17.	K.A.K.	10	33	23	77	62
18.	K.C.K.	11	37	22	72	70
19.	K.I.K.	13	43	23	76	63
20.	E.K.	10	33	24	79	60
21.	B.K.	11	37	25	84	77
22.	D.K.	10	33	24	81	67
23.	K.K.F.	11	37	26	88	69
24.	C.K.S.	9	30	22	72	60
25.	W.W.N.	11	37	24	81	65
26.	N.M.J.	13	43	23	77	69
27.	M.M.J.	10	33	26	88	61
28.	S.K.	12	40	22	72	71
29.	N.E.W.	10	33	21	71	65
30.	P.M.	13	43	22	73	67
31.	S.N.	10	33	19	64	
32.	E.B.K.	11	37	22	73	79
33.	W.S.W.	9	30	22	72	68
34.	J.K.N.	13	43	23	77	62
35.	S.M.G.	11	37	23	78	73
36.	N.P.M.	12	40	26	86	61
37.	K.P.M.	13	43	24	81	70
38.	J.O.C.K.	10	33	22	73	57
39.	B.N.	11	37	21	71	60
40.	N.J.K.	9	30	24	79	70
41.	W.W.	13	43	21	69	73
42.	E.G.	11	37	26	86	69
43.	K.T.K.	12	40	25	82	68
44.	T.K.	13	43	22	73	67
45.	B.C.	10	33	20	67	59
46.	L.F.K.	12	40	25	83	64

47.	L.M.K.	10	33	22	75	66
48.	N.N.	9	30	25	83	75
49.	W.P.A.	12	40	20	67	70
50.	H.K.	11	37	22	73	58
51.	G.K.	13	43	23	76	70
52.	C.O.	9	30	23	76	66
53.	C.K.	11	37	22	74	64
54.	D.K.K.	10	33	24	79	72
55.	T.K.K.	13	43	21	70	75
56.	F.K.R.	10	33	22	75	74
57.	P.S.	12	40	23	77	63
58.	B.O.I.	9	30	24	79	67
59.	K.W.H.	11	37	24	80	70
60.	I.T.B.	13	43	21	70	74
61.	N.K.K.	10	33	20	68	65
62.	D.K.	10	33	25	83	67
63.	P.K.K.	12	40	23	78	62
64.	M.K.	9	30	22	72	61
65.	S.M.	11	37	25	84	73
66.	B.N.	13	43	23	77	77
67.	E.K.	10	33	25	82	68
68.	B.M.	11	37	23	76	74
69.	P.K.	11	37	26	87	71
70.	R.W.	11	37	26	86	64
71.	K.K.	10	33	22	75	71
72.	M.M.	11	37	24	81	78
73.	S.M.	10	33	24	80	68
74.	J.W.	12	40	25	83	78
75.	D.M.	11	37	21	71	53
76.	A.W.	11	37	24	80	73
77.	E.J.	11	37	25	82	69
78.	S.D.G.	11	37	20	66	67
79.	M.M.	10	33	21	70	69
80.	M.O.R.	10	33	20	65	56
81.	N.J.	11	37	22	75	67
82.	N.P.	11	37	24	80	82
83.	M.W.L.	11	37	25	84	81
84.	M.K.P.	11	37	23	76	79
85.	N.K.C.	10	33	26	85	80
86.	N.P.N.	10	33	20	68	78
87.	J.W.	11	37	20	67	81
88.	M.K.	11	37	23	76	79

Appendix 8: Control Group 2 Results

C2		PRETEST		EXAM
Serial No.	**Name**	**Marks (out of 30)**	**Marks (out of 100)**	**Marks (out of 100)**
1.	S.M.	16	53	
2.	D.W.	10	32	63
3.	D.W.	8	25	52
4.	D.M.	10	32	66
5.	S.W.	17	57	49
6.	M.W.I.	19	64	37
7.	L.M.N.	19	63	60
8.	M.M.C.	12	40	71
9.	L.N.M.	16	54	45
10.	E.M.	9	30	53
11.	M.J.W.	10	35	
12.	E.M.	20	66	57
13.	L.W.N.	6	20	42
14.	G.M.W.	7	24	74
15.	S.E.	9	30	55
16.	E.N.	6	21	78
17.	L.W.W.	9	29	41
18.	W.N.A.	15	50	
19.	S.K.	12	41	35
20.	M.D.M.	20	66	64
21.	M.M.R.	19	62	50
22.	J.T.M.	11	37	48
23.	I.S.	10	33	
24.	D.W.	12	39	75
25.	B.W.	15	50	51
26.	F.M.	10	33	39
27.	J.M.K.	16	52	76
28.	N.N.E.	12	41	54
29.	K.M.M.	14	48	38
30.	S.J.O.	13	42	62
31.	K.O.O.	10	35	69
32.	F.M.	21	69	47
33.	Z.O.	18	59	61
34.	A.O.	8	27	36
35.	M.K.	20	65	65
36.	W.A.	14	45	58
37.	C.O.	20	66	46
38.	O.G.O.	18	61	80
39.	O.V.O.	13	42	49
40.	M.K.J.	6	21	42
41.	P.W.	10	33	52
42.	Y.N.	14	48	45
43.	F.M.	16	52	70
44.	J.W.	10	33	33
45.	J.M.	8	27	43
46.	R.W.	19	63	77

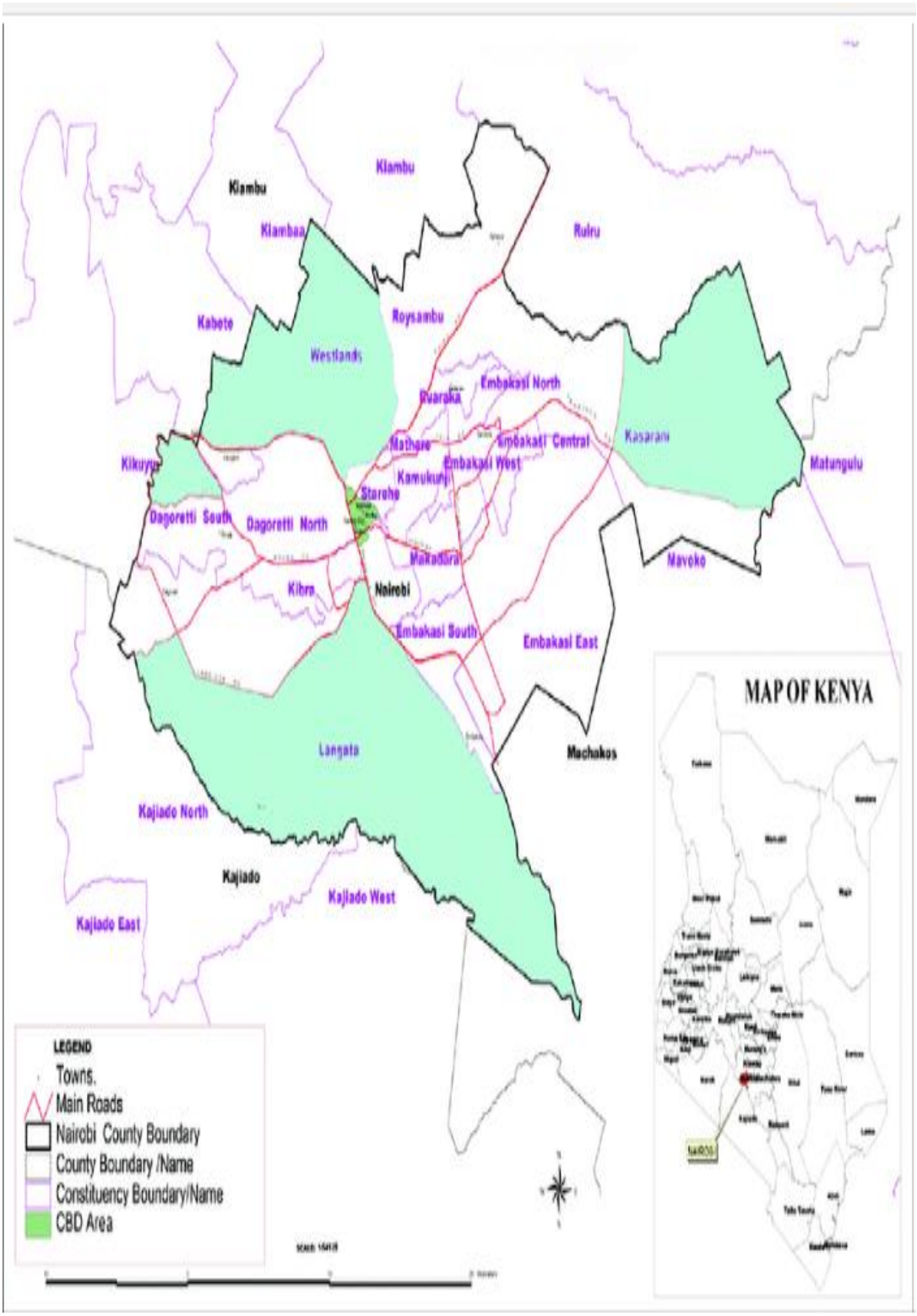
47.	D.K.	21	71	60
48.	E.N.	14	47	47
49.	H.M.	8	28	55
50.	E.M.	10	34	39
51.	R.N.	6	20	72
52.	P.C.	20	67	44
53.	A.C.	8	26	67
54.	S.V.O.	15	49	35
55.	W.B.E.	10	34	48
56.	T.L.M.	14	48	64
57.	N.T.N.	16	53	30
58.	J.W.K.	19	63	
59.	M.G.V.	9	30	51
60.	K.F.E.	6	20	45
61.	M.N.K.	8	27	66
62.	W.S.M.	20	66	53
63.	C.H.	20	65	43
64.	S.M.	15	51	73
65.	K.M.M.	15	51	60
66.	G.K.P.	16	54	40
67.	N.P.	9	29	69
68.	G.A.	20	67	47
69.	M.A.N.	12	41	39
70.	N.J.M.	12	39	79
71.	L.O.	14	46	48
72.	O.H.	7	22	32
73.	N.M.	8	28	57
74.	O.E.M.	17	58	46
75.	M.M.K.	7	24	71
76.	K.K.C.	15	51	64
77.	J.M.	10	32	68
78.	F.O.	12	40	44
79.	C.O.	10	35	41
80.	D.S.	11	38	
81.	O.T.O.	17	57	59
82.	O.O.D.	10	35	53
83.	O.S.	15	49	58
84.	S.O.	13	44	56
85.	O.M.	16	54	62
86.	R.B.	20	68	54
87.	G.N.K.	17	58	59
88.	N.A.	9	31	41
89.	J.W.	6	21	53

Appendix 9: Experimental Group 2 Results

E2		PRETEST		EXAM
Serial No.	**Name**	**Marks (out of 30)**	**Marks (out of 100)**	**Marks (out of 100)**
1.	S.W.N.	23	78	67
2.	K.M.E.	22	75	69
3.	N.W.S.	19	64	64
4.	W.M.	22	75	71
5.	W.D.U.	20	68	66
6.	L.M.N.	24	79	65
7.	K.H.K.	23	77	
8.	J.M.W.	21	70	68
9.	K.P.S.	22	73	66
10.	O.T.R.	21	70	65
11.	O.E.O.	22	75	68
12.	M.E.M.	24	81	67
13.	M.S.M.	21	70	62
14.	M.C.N.	23	78	70
15.	M.M.D.	22	72	66
16.	K.M.K.	21	71	72
17.	M.E.R.	22	75	64
18.	N.O.I.	21	70	67
19.	W.O.M.	22	72	63
20.	M.N.M.	21	69	70
21.	E.R.	26	86	66
22.	E.O.T.	23	76	67
23.	O.N.E.	22	72	68
24.	A.E.O.	23	77	61
25.	O.B.	22	75	65
26.	S.J.W.	22	74	64
27.	W.L.O.	24	79	70
28.	W.B.S.	24	80	66
29.	O.B.K.	22	72	66
30.	A.C.	22	72	68
31.	O.M.D.	22	74	69
32.	T.O.	19	63	65
33.	A.S.	20	67	67
34.	P.W.	25	83	63
35.	D.K.	25	84	69
36.	G.W.M.	22	74	67
37.	W.W.K.	24	79	66
38.	K.B.W.	23	77	71
39.	M.I.	28	92	65
40.	G.J.	25	82	64
41.	L.O.	22	75	66
42.	J.A.	21	70	66
43.	D.W.	20	67	68
44.	D.O.	23	77	63
45.	F.O.	21	71	64
46.	V.M.	20	68	

47.	L.O.	22	72	68
48.	M.O.J.	21	69	65
49.	O.O.B.	26	85	67
50.	Y.D.C.	24	80	64
51.	C.L.K.	22	75	71
52.	J.K.K.	25	84	66
53.	M.B.	23	76	69
54.	S.G.	21	71	63
55.	N.N.	25	84	65
56.	F.N.	23	78	68
57.	B.W.	21	70	62
58.	S.O.	22	74	67
59.	M.E.	21	71	66
60.	D.K.	20	68	65
61.	S.M.	24	81	69
62.	D.N.	26	86	
63.	M.M.	20	68	64
64.	S.J.T.	24	79	70
65.	S.N.K.	22	72	68
66.	J.W.G.	22	73	67
67.	M.S.W.	22	72	69
68.	W.N.W.	21	71	65
69.	K.K.L.	23	76	64
70.	A.K.	21	71	72
71.	K.E.K.	23	77	66
72.	D.M.	22	75	63
73.	M.E.K.	22	74	
74.	M.R.M.	21	70	65
75.	G.C.G.	22	72	69
76.	B.O.	24	80	68
77.	K.M.I.	23	78	66
78.	D.W.M.	21	70	67
79.	I.B.L.	23	76	
80.	M.M.E.	24	80	70
81.	J.M.M.	20	66	63
82.	E.M.	23	78	66
83.	M.S.	22	72	68
84.	M.E.M.	24	79	67
85.	R.W.W.L.K.	21	71	70
86.	D.S.	20	65	66
87.	D.M.	20	66	70
88.	D.N.	23	76	67
89.	P.G.	23	77	64

Appendix 10: Nairobi County Map



Appendix 11: Approval Letter for Research from Institution

MURANG'A UNIVERSITY OF TECHNOLOGY
Office of the Director, Postgraduate Studies
E-mail: bps@mut.ac.ke
Website: www.mut.ac.ke
P.O. Box 75-10200
Murang'a, Kenya

Ref: MUT/ARP/PGS/19/2020 /VOL.1 **Date:** 2nd September, 2024

Mr. Felix Biketi-TE500/5560/2021,
School of Education,
Murang'a University of Technology,
P.O. Box 75-10200
Murang'a.

Dear Mr. Biketi,

RE: APPROVAL OF RESEARCH PROPOSAL AND SUPERVISORS.

I am pleased to inform you that the Directorate of Postgraduate Studies on 29th August 2024 considered and approved your Doctoral research proposal entitled ***"To Investigate the Impact of Augmented Reality on Students' Performance in Building and Civil Engineering with TVET Insitutions in Nairobi County, Kenya."*** and appointed the following as supervisors:

1.Dr. Chrispinus Waswa Wamalwa - Masinde Muliro University of Science and Technology

2.Dr. Peter Mwangi - Murang'a University of Technology

You may now proceed with your data collection subject to obtaining research permit from NACOSTI, if required. You should also begin consulting your supervisors and submit through them quarterly progress reports to the Director Postgraduate Studies through your CoD and School Dean. Progress Reports forms can be accessed in the Student Portal.

It is the policy and regulations of the University that you observe deadlines. The guidelines on Postgraduate supervision can be accessed in the post graduate Handbook.

Your responsibilities as a student will include, among others;

i. Maintain regular consultation with your supervisor(s), at least once a month
ii. Submit quarterly reports on time, through your supervisors, CoD, Dean and to the Director of Postgraduate Studies;

iii. Ensure quality work all through;
iv. Present your research findings at 2-3 seminars/conferences prior to thesis examination.
v. Publish two articles from your research findings in a refereed journal prior to thesis examination.

For any further clarification please contact the undersigned.

Yours Sincerely,

Prof. Geoffrey Muchiri, PhD
Director, Postgraduate Studies

GM/MMK

DIRECTORATE OF POSTGRADUATE STUDIES
MURANG'A UNIVERSITY OF TECHNOLOGY
02 SEP 2021
P. O. Box 75 - 10200, MURANG'A
Tel: 0771463515, Email: info@mut.ac.ke

Copy to:
1. Registrar, Academics, Research and Students Affairs
2. Dean, School of Education

Appendix 12: NACOSTI Permit

REPUBLIC OF KENYA

NATIONAL COMMISSION FOR SCIENCE,TECHNOLOGY & INNOVATION

Ref No: 368557

Date of Issue: 08/August/2024

RESEARCH LICENSE



This is to Certify that Mr.. Felix Quentin Biketi of Jomo Kenyatta University of Agriculture and Technology, has been licensed to conduct research as per the provision of the Science, Technology and Innovation Act, 2013 (Rev.2014) in Nairobi on the topic: THE IMPACT OF AUGMENTED REALITY ON STUDENTS' PERFORMANCE IN BUILDING AND CIVIL ENGINEERING WITHIN TVET INSTITUTIONS IN NAIROBI COUNTY, KENYA for the period ending : 08/August/2025.

License No: NACOSTI/P/24/38967

368557

Applicant Identification Number

Director General
NATIONAL COMMISSION FOR SCIENCE,TECHNOLOGY & INNOVATION

Verification QR Code

NOTE: This is a computer generated License. To verify the authenticity of this document, Scan the QR Code using QR scanner application.

See overleaf for conditions

Appendix 13: Publications

This thesis has produced the following publications;

Biketi, F. Q., Mukoche, W. C., & Mwangi, P. (2025). Augmented Reality as A Tool for Practical Skills Development in Building and Civil Engineering Programmes. *International Journal of Advance Research and Innovative Ideas in Education*, 11(3), 2139-2147.

Biketi, F. Q., Mukoche, W. C., & Mwangi, P. (2025). Enhancing Theoretical Learning in Engineering Education Through Augmented Reality. *International Journal of Advance Research and Innovative Ideas in Education*, 11(3), 3061-3070.