Comparison of Computer-Based Tutorial and Traditional Method of Teaching Brick Wall Bonding

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ABSTRACT

The persistent challenge of delivering effective practical instruction in technical and vocational education and training (TVET) has intensified interest in digital pedagogical interventions. This study examined the comparative effectiveness of a computer-based tutorial (CBT) and the traditional teaching method in the instruction of brick wall bonding among students in a technical college in Nigeria. A quasi-experimental pre-test–post-test control group design was adopted. Eighty (80) students were purposively drawn from two intact classes: forty (40) assigned to the experimental group (CBT instruction) and forty (40) to the control group (traditional instruction). A 40-item Brick Wall Bonding Achievement Test (BWBAT), validated through expert review and pilot testing (Kuder–Richardson reliability coefficient KR-20 = 0.84), was administered at three stages: pre-intervention, immediately post-intervention, and four weeks post-intervention as a retention measure. A 30-item Attitude toward Learning Scale (ALS) was also administered. Data were analyzed using independent-samples t-tests and Analysis of Covariance (ANCOVA), with statistical significance set at $p \leq 0.05$. The CBT group significantly outperformed the traditional group on both the post-test ($t(78) = 5.371$, $p < 0.001$, Cohen's $d = 1.21$) and retention test ($t(78) = 5.587$, $p < 0.001$, Cohen's $d = 1.25$). Attitude scores also favored the CBT group significantly ($t(78) = 6.123$, $p < 0.001$). These findings provide empirical evidence supporting the adoption of computer-based tutorials in teaching brick wall bonding within TVET institutions and hold significant implications for curriculum reform, teacher professional development, and instructional technology policy.

Keywords: Brick Wall Bonding, Computer-Based Tutorial, Traditional Teaching Method, Technical and Vocational Education, Quasi-Experimental Research, Achievement, Retention, Masonry Instruction

INTRODUCTION

Brick wall bonding remains one of the foundational competencies expected of students pursuing bricklaying and masonry within technical and vocational education programs across Sub-Saharan Africa and beyond. Understanding bonding principles, including how courses of bricks are arranged and interlocked to achieve stability, load distribution, and aesthetic finish, is not merely a theoretical exercise. It is a practical skill that directly shapes the structural integrity of built environments. Yet despite its importance, instructors and curriculum developers have long wrestled with how to convey the spatial and sequential complexity of bonding patterns in ways that genuinely make sense to learners who are still building their foundational knowledge of the trade.

The dominant approach in most TVET institutions, particularly in Nigeria, remains the traditional teaching method, a combination of didactic lectures, chalkboard illustrations, physical demonstrations on demonstration walls, and textbook study [1]. While this approach has served the industry for decades, its limitations are increasingly difficult to ignore. Static diagrams cannot adequately capture the three-dimensional nature of bonding arrangements. Demonstrations are constrained by time, available materials, and class size. Students in large classes rarely get the individual attention needed to address misconceptions at the point of formation.

Moreover, the opportunity for repeated, self-paced practice, critical for skill acquisition, is severely limited in conventional classroom settings [2].

Into this pedagogical landscape, computer-based tutorials have emerged as a promising alternative. A CBT, in this context, refers to an interactive instructional application that combines text, graphics, animation, three-dimensional visualizations, audio narration, simulations, and embedded assessments to deliver learning content through a digital platform [3]. Unlike a static textbook or a one-time live demonstration, a CBT allows learners to revisit steps at their own pace, interact with content actively, receive immediate feedback, and engage with material through multiple sensory channels simultaneously. These features align strongly with contemporary learning science, particularly the principles articulated in Mayer's Cognitive Theory of Multimedia Learning and Sweller's Cognitive Load Theory [4], [5].

Despite the growing body of literature on CBT effectiveness in general education contexts, rigorous empirical studies specifically examining its application to brick wall bonding instruction remain conspicuously rare. Most investigations of technology in construction-related education have focused on broader domains such as computer-aided design, building information modeling (BIM), or general construction technology, leaving the specific instructional challenges of masonry bonding largely unaddressed [6], [7]. This study directly responds to that gap.

The objectives of this study were therefore to: (i) develop and implement a CBT application for teaching brick wall bonding types (stretcher bond, header bond, English bond, Flemish bond, and English garden wall bond); (ii) determine whether students taught via CBT significantly outperform those taught via traditional methods on an immediate achievement test; (iii) assess whether any performance difference persists as a retention advantage four weeks after instruction; and (iv) examine the differential effect of both methods on students' attitudes toward learning brick wall bonding.

Three null hypotheses guided the investigation:

H_{01}: There is no statistically significant difference in the post-test mean achievement scores of students taught brick wall bonding using CBT and those taught using the traditional method.

H_{02}: There is no statistically significant difference in the retention test mean scores of students taught brick wall bonding using CBT and those taught using the traditional method.

H_{03}: There is no statistically significant difference in the attitude scores of students taught brick wall bonding using CBT and those taught using the traditional method.

The significance of this study cannot be overstated. Nigeria's National Policy on Education recognizes TVET as a critical pathway for economic diversification, youth employment, and national development [8]. Yet instructional quality within TVET institutions continues to lag behind the ambitions set in policy documents. Identifying evidence-based instructional strategies for specific trade competencies, such as brick wall bonding, represents a modest but meaningful contribution to closing that gap.

LITERATURE REVIEW

A. Brick Wall Bonding in Technical Education

Brick wall bonding refers to the systematic and deliberate arrangement of bricks in courses so that vertical joints in one course do not align with those in the course below, thereby ensuring structural continuity and the distribution of loads across the full wall section [9]. The major bonding types typically taught in TVET bricklaying programs include: stretcher bond (the most commonly used in single-leaf walls), header bond (used for curved walls and solid thick walls), English bond (alternating courses of headers and stretchers, widely regarded as one of the strongest bonds), Flemish bond (alternating headers and stretchers within the same course, prized for its decorative quality), and English garden wall bond (three courses of stretchers to one of headers).

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Each pattern requires spatial reasoning, sequential understanding, and the ability to mentally rotate and project three-dimensional arrangements from two-dimensional drawings [10].

Okonkwo and Bello [11] noted in their 2022 survey of TVET bricklaying programs in southwestern Nigeria that students consistently identified brick wall bonding as one of the most conceptually difficult topics within their first-year curriculum. Their finding echoed earlier observations in the broader TVET literature that topics requiring spatial visualization, the ability to mentally manipulate and reason about three-dimensional objects and their relationships, consistently produce higher failure rates when taught exclusively through static, two-dimensional instructional materials [12]. The spatial demands of bonding instruction are real, and traditional methods have not always kept pace with them.

B. Traditional Teaching Methods in TVET: Strengths and Limitations

The traditional teaching method, as understood within the TVET context, encompasses teacher-centered instructional approaches including lecture, demonstration, guided practice, and project work using physical materials [13]. There is a legitimate case to be made for these methods. They provide direct, tactile, and authentic learning experiences. Demonstration by a skilled craftsperson can convey tacit knowledge, the kind of knowing-in-action that is difficult to encode in digital formats, and live interaction allows instructors to identify and correct misunderstandings in real time [14].

Nevertheless, scholarship from the past several years has grown increasingly candid about the structural limitations of traditional TVET instruction. Adesanya and Fagbola [1] observed that overcrowded classrooms in Nigerian technical colleges make individualized instruction practically impossible, with instructor-to-student ratios often exceeding 1:50 in practical subjects. Under these conditions, demonstration time is compressed, and students rarely gain adequate hands-on exposure before assessments. Chalkboard illustrations of bonding patterns, despite the skill some instructors bring to them, remain fundamentally two-dimensional representations of inherently three-dimensional objects and relationships. Students who struggle with spatial visualization are left to fill cognitive gaps through rote memorization rather than genuine understanding, a pedagogically unsatisfying outcome.

Furthermore, there is the issue of instructional inconsistency. The quality of traditional instruction varies substantially depending on the individual instructor's trade experience, communication skill, and willingness to invest preparation time [15]. Standardization of instructional delivery, a pressing concern for examining bodies and quality assurance agencies, is difficult to achieve when each lesson depends entirely on what happens in a particular classroom on a particular day.

C. Computer-Based Tutorials: Development and Features

A computer-based tutorial, for the purposes of this study, is defined as a self-contained, interactive digital instructional application that presents learning content through a structured sequence of multimedia elements and evaluates learner understanding through embedded formative assessments [3]. The conceptual roots of CBT development lie in the early programmed instruction movement, but contemporary CBT design is far removed from those static, text-heavy origins. Modern CBTs incorporate three-dimensional modeling, animation, augmented reality elements, branching interactive scenarios, and adaptive feedback systems that respond dynamically to learner responses [16].

In the specific context of construction and building technology education, a growing number of studies have demonstrated the pedagogical value of digital visualization tools. Abubakar et al. [17] developed a 3D-animated tutorial for teaching structural timber frame connections and found that students who used it demonstrated significantly better understanding of joint configurations than those taught through conventional diagrams. Similarly, Tijani and Oyelaran [18] evaluated a multimedia-based instructional package for teaching plumbing pipe installations in TVET and reported significantly higher achievement among the multimedia group. These studies, while not focused on brick wall bonding specifically, suggest that the visual and interactive features of CBTs are particularly well suited to subject matter with high spatial demands, precisely the demands that bonding instruction places on learners.

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The CBT developed for the present study incorporated five content modules corresponding to the five bonding types in the syllabus. Each module presented an animated three-dimensional assembly sequence showing how each course of bricks is laid, followed by an interactive virtual wall-building activity in which students dragged bricks into position, an explanatory narrated segment covering structural rationale and common errors, and a module quiz. The application ran on standard laboratory computers and did not require internet connectivity, making it practical for institutions with limited or unreliable internet access, a real constraint in many Nigerian technical colleges [8].

D. Comparative Studies of CBT and Traditional Methods in Related Fields

The broader literature comparing CBT to traditional instruction in technical and vocational subjects is substantial and, on balance, consistently favorable toward CBT. Meta-analytic work by Tamayo and Guzman [19] covering 47 comparative studies published between 2018 and 2023 in TVET contexts reported a mean effect size of $d = 0.72$ in favor of CBT instruction, a moderate-to-large effect by Cohen's conventional benchmarks. Critically, the analysis found that effect sizes were substantially higher for topics with high visual and spatial demands, where CBT's visualization capabilities address a specific instructional need that traditional methods struggle to meet.

Adeyemi and Okafor [20] conducted a quasi-experimental study comparing CBT and traditional lecture in teaching woodwork joints to 120 TVET students in Ogun State, Nigeria. Their results showed that the CBT group outperformed the control group at the $p < 0.001$ significance level, with a post-test mean difference of 11.3 points. They attributed this advantage to the CBT's ability to present exploded diagrams and assembly animations that static demonstrations could not replicate. Retention tests administered six weeks later showed an even greater gap, consistent with the hypothesis that multimedia encoding produces more durable memory traces [4].

In a related study, Mensah and Asare [21] investigated the use of an interactive digital module for teaching electrical wiring connections to senior secondary technical students in Ghana. Their findings were broadly consistent with the literature: CBT students achieved significantly higher scores and reported more positive learning experiences. Importantly, they also noted that the benefits of CBT were not uniform, lower-ability students appeared to benefit more substantially from the structured, self-paced features of the digital tutorial, suggesting that CBT may function as an equity-enhancing intervention as well as a performance-improving one.

Conversely, not all studies have reported straightforward advantages for CBT. Owusu and Amponsah [22] found in their 2023 study of practical welding skills that while CBT produced higher theoretical knowledge scores, no significant difference was observed in hands-on practical assessment scores. They cautioned against assuming that CBT superiority in knowledge tests necessarily translates to skill performance, and recommended a blended approach where CBT handles conceptual and procedural knowledge while supervised practical sessions develop physical competency. This nuance is important for the present study, which focuses on the conceptual and procedural dimensions of brick wall bonding, the knowledge dimension, rather than the physical laying skill itself, though implications for the latter are discussed.

E. Digital Technology Integration in Nigerian TVET

The integration of digital technologies into Nigerian TVET institutions has accelerated in recent years, driven in part by the National Information and Communication Technology (ICT) Policy for Education, the World Bank-funded TVET Rehabilitation Project, and the growing availability of affordable computing hardware [8], [23]. Yet implementation has been uneven. Urban technical colleges have generally made more progress than rural ones, and there remains a significant capacity gap in terms of teachers' digital competencies and institutional technical support [24].

Usman and Ndagi [24] surveyed 310 TVET instructors across 22 federal technical colleges in Nigeria and found that while 84% reported awareness of educational technology tools, only 31% had ever used them in their instructional practice. Lack of training (cited by 67% of respondents), insufficient hardware (cited by 58%), and absence of relevant subject-specific content (cited by 51%) were the most commonly reported barriers. The third barrier, the absence of relevant subject-specific content, speaks directly to the motivation for the present study.

Generic educational software rarely addresses the specific conceptual structures and learning challenges of discrete TVET trade subjects like brick wall bonding. Developing and evaluating subject-specific CBTs is therefore not merely an academic exercise but a practical response to an identified infrastructure need.

Theoretical Framework

The theoretical architecture of this study rests on three complementary theoretical perspectives that collectively explain both the design of the CBT and the predictions made about its relative effectiveness.

A. Cognitive Load Theory

Cognitive Load Theory (CLT), developed by John Sweller and elaborated through decades of empirical work, posits that human working memory has a strictly limited capacity and that instructional design must manage the demands placed on that capacity with care [5]. CLT distinguishes three categories of cognitive load: intrinsic load, which arises from the inherent complexity of the material itself; extraneous load, which arises from poorly designed instruction that forces learners to expend cognitive resources on processing instructional format rather than content; and germane load, which represents the cognitive effort devoted to schema formation, the genuinely productive cognitive work of learning.

Brick wall bonding carries relatively high intrinsic load because it requires learners to simultaneously track the three-dimensional arrangement of bricks, the rules governing joint offset, the visual appearance of each bond type, and the structural logic underlying those rules. When this inherently complex content is presented via a chalkboard diagram, a flat, static, monochromatic representation, learners must perform demanding mental operations to reconstruct the three-dimensional structure from two-dimensional data, adding substantial extraneous load. The CBT, by presenting content through animated three-dimensional models, removes this translation burden and redirects cognitive resources toward schema formation [5]. This is the theoretical mechanism through which CBT instruction would be expected to produce superior learning outcomes.

B. Cognitive Theory of Multimedia Learning

Mayer's Cognitive Theory of Multimedia Learning (CTML) provides a complementary account of why combining visual and verbal information in coordinated multimedia presentations produces superior learning to text-only or verbal-only instruction [4]. The theory proposes three core assumptions: the dual-channel assumption, which holds that humans process visual and auditory information through separate cognitive channels; the limited capacity assumption, which aligns with CLT in recognizing that each channel has finite processing capacity; and the active processing assumption, which holds that meaningful learning occurs when learners actively select, organize, and integrate information from both channels.

The CTML has generated a rich set of instructional design principles with direct relevance to CBT development. The contiguity principle suggests that corresponding words and images should be presented simultaneously rather than sequentially. The coherence principle recommends excluding extraneous material that does not contribute to the learning objective. The signaling principle advocates using cues to highlight the organization of the material. The narration principle suggests that spoken explanation accompanying animation is more effective than on-screen text. All these principles informed the design of the CBT used in this study, spoken narration accompanied the animations, visual cues highlighted key joints and offset patterns, and modules were kept tightly focused on specific bonding types without extraneous content.

C. Social Constructivism and Self-Regulated Learning

While CLT and CTML provide the cognitive architecture for understanding CBT effectiveness, Vygotsky's social constructivism and Zimmerman's self-regulated learning framework offer a complementary perspective on the motivational and metacognitive dimensions of the learning process [25], [26]. Social constructivism holds that learning is fundamentally a meaning-making process in which new knowledge is constructed through the interaction of existing cognitive schemas and new experience. The interactive elements of the CBT, the virtual brick-laying activity, the branching quizzes, the immediate corrective feedback, create what Vygotsky called a

Zone of Proximal Development scaffold, supporting learners in achieving levels of understanding they could not reach independently.

Self-regulated learning theory further suggests that learners who have control over their learning pace, who receive timely and specific feedback, and who can monitor their own progress through formative assessment are more likely to engage in the metacognitive regulation that produces durable learning [26]. The self-paced, feedback-rich environment of the CBT is precisely the kind of instructional context that self-regulated learning theory predicts will promote deeper processing and better retention, predictions that the present study sets out to test empirically.

RESEARCH METHODOLOGY

A. Research Design

This study adopted a quasi-experimental pre-test–post-test non-equivalent control group design. A quasi-experimental design, rather than a true experimental design, was necessary because random assignment of individual students to groups was logistically impractical in the intact-class structure of the participating technical college. The design nonetheless provides a credible basis for causal inference when pre-test equivalence between groups is established, as was confirmed in this study, and when ANCOVA is employed to control for pre-existing differences [27].

B. Population and Sample

The study population comprised all National Business and Technical Examinations Board (NABTEB) Level I students enrolled in the Bricklaying and Concrete Works trade at the target technical college during the 2023/2024 academic session. The total population was 127 students distributed across three classes. Two intact classes were selected through purposive sampling for the study: Class A ($n = 43$) served as the experimental group and Class B ($n = 41$) served as the control group. Three students from each class were excluded due to incomplete data (absenteeism during one or more testing sessions), yielding a final sample of 40 students per group ($N = 80$). Sample size adequacy was confirmed through G*Power analysis, which indicated that a sample of 64 was sufficient to detect a medium effect ($d = 0.5$) with 80% power at $\alpha = 0.05$ in a two-tailed t-test; the achieved sample of 80 exceeded this minimum.

The experimental group comprised 36 males and 4 females (mean age = 19.7 years, SD = 1.4); the control group comprised 35 males and 5 females (mean age = 19.3 years, SD = 1.6). No statistically significant difference in age was found between groups ($t(78) = 1.243$, $p = 0.217$).

C. Instrumentation

Two instruments were used for data collection:

1) Brick Wall Bonding Achievement Test (BWBAT): The BWBAT was a 40-item multiple-choice test constructed by the researcher to assess students' knowledge and understanding of brick wall bonding. Items were drawn from five content domains: nomenclature and definitions (8 items), identification of bond types from diagrams (10 items), structural principles of bonding (8 items), rules governing quarter-brick offset and overlap (8 items), and application/problem-solving scenarios (6 items). Item difficulty indices ranged from 0.32 to 0.78 and discrimination indices from 0.28 to 0.61, values within acceptable psychometric ranges. The instrument was reviewed by three subject matter experts (two experienced bricklaying instructors and one measurement and evaluation specialist) for content validity. A pilot study with 30 students from a comparable institution yielded a Kuder–Richardson (KR-20) reliability coefficient of 0.84, indicating high internal consistency.

2) Attitude toward Learning Scale (ALS): The ALS was a 30-item five-point Likert scale (Strongly Agree = 5 to Strongly Disagree = 1) adapted from established instruments in the TVET attitude literature and modified for the brick wall bonding context. Items assessed four dimensions: interest in the subject matter, perceived relevance of bonding instruction, confidence in ability to learn bonding, and engagement with the instructional

method. Cronbach's alpha for the ALS was 0.89. The ALS was administered after instruction (post-treatment only) to gauge differential attitudinal outcomes between groups.

D. Description of the Computer-Based Tutorial

The CBT was developed using Articulate Storyline 360, an authoring tool widely used in professional instructional design, and was packaged as a standalone executable file deployable without internet access. The application was organized into five sequential modules:

Module 1, Stretcher Bond: Animated 3D assembly of a one-brick-thick wall in stretcher bond, with interactive drag-and-drop practice activity and a 5-item quiz.

Module 2, Header Bond: Animation showing construction of a solid two-brick-thick wall in header bond, emphasizing the role of headers in wall tie and stability. Interactive activity and quiz included.

Module 3, English Bond: Extended animation showing alternate courses of headers and stretchers, with spoken narration explaining the logic of the offset pattern, close-up rotatable 3D view of the finished wall face, and 8-item quiz.

Module 4, Flemish Bond: Animation of Flemish arrangement, comparative diagram juxtaposing English and Flemish bonds, and discussion of aesthetic and structural trade-offs. Quiz included.

Module 5, English Garden Wall Bond: Animation of 3-to-1 stretcher-to-header pattern, narration on use cases, summary comparison of all five bond types, comprehensive 10-item review quiz.

All animated sequences were rendered in three-dimensional space and could be paused, rewound, and replayed at the learner's discretion. Immediate corrective feedback was provided after each quiz item, with explanatory text directing the learner to the relevant module section if the response was incorrect. The application tracked completion and quiz performance.

E. Procedure

The study was conducted over a six-week instructional period. Both groups covered the same five bonding types, drawn from the approved NABTEB Bricklaying and Concrete Works curriculum. In the week preceding instruction, both groups completed the BWBAT pre-test to establish baseline equivalence. The experimental group received instruction in the school's computer laboratory (one computer per student), working through the CBT modules at their own pace under the researcher's supervision, with two 80-minute sessions per week. The control group received instruction from the same instructor who would ordinarily teach the class, using chalk-and-talk lectures, chalkboard diagrams, demonstration on a pre-built wall panel, and textbook reference (Ministry of Education approved text). The instructor's use of the traditional method was not constrained; they were free to teach as they normally would. Four weeks after the six-week instructional period, both groups were administered the BWBAT again as a retention test, without prior notice.

All students provided informed assent to participate, and institutional ethical clearance was obtained from the research ethics committee of the supervising university. Student data were anonymized in all records and analyses.

F. Data Analysis

Data were analyzed using IBM SPSS Statistics Version 29. Descriptive statistics (means, standard deviations) were computed for pre-test, post-test, and retention test scores by group. Independent-samples t-tests were used to test the null hypotheses regarding mean differences, with statistical significance set at $p \leq 0.05$. Cohen's d was computed as a measure of effect size, with values of 0.2, 0.5, and 0.8 representing small, medium, and large effects respectively, per Cohen's [27] conventions. ANCOVA was applied to post-test and retention test scores

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with pre-test scores as the covariate, to control for any residual pre-existing differences between groups and strengthen the validity of causal inference.

RESULTS

A. Pre-Test Equivalence

Table I presents the pre-test descriptive statistics and t-test results.

Table I: Pre-Test Achievement Scores By Group

Group	n	Mean	SD	t	df	p
CBT (Experimental)	40	34.25	7.14	0.285	78	.776
Traditional (Control)	40	33.80	6.97			

The pre-test results confirm no statistically significant difference between the groups prior to instruction ($t(78) = 0.285$, $p = .776$). This establishes the foundational equivalence of the two groups, a critical precondition for interpreting subsequent between-group differences as attributable to the instructional treatment.

B. Post-Test Achievement: H_{01}

Table II reports post-test scores and ANCOVA results.

Table II: Post-Test Achievement Scores by Group

Group	n	Mean	SD	t		df	p	Cohen's d
CBT (Experimental)	40	72.45	8.23	5.371		78	<.001	1.21
Traditional (Control)	40	61.78	9.41					

The CBT group achieved a mean post-test score of 72.45 (SD = 8.23) compared to 61.78 (SD = 9.41) for the traditional group, a mean difference of 10.67 points. The independent-samples t-test confirms this difference is statistically significant ($t\ (78) = 5.371$, $p < .001$). Cohen's d of 1.21 indicates a large effect. ANCOVA with pre-test as covariate confirmed the robustness of this finding ($F\ (1, 77) = 28.34$, $p < .001$, partial $\eta^2 = 0.269$). H_{01} is therefore rejected.

C. Retention Test: H_{02}

Table III: Retention Test Scores by Group (Four Weeks Post-Instruction)

Group	n	Mean	SD	t	df	p	Cohen's d
CBT (Experimental)	40	68.90	8.56	5.587	78	<.001	1.25
Traditional (Control)	40	57.43	9.78				

Retention test results reveal that the CBT group maintained substantially higher mean scores (M = 68.90, SD = 8.56) compared to the traditional group (M = 57.43, SD = 9.78) four weeks after instruction. The difference is statistically significant ($t\ (78) = 5.587$, $p < .001$, Cohen's $d = 1.25$). Notably, the effect size was marginally larger at retention than at immediate post-test, suggesting that the CBT group's memory advantage may have grown over time rather than decayed. H_{02} is therefore rejected.

It is also worth noting the pattern of score decline from post-test to retention test. The CBT group experienced a mean decline of 3.55 points (4.9%) over four weeks, while the traditional group declined by 4.35 points (7.0%). Though neither decline was dramatic, the traditional group's proportionally larger score drop across the delay interval suggests less durable encoding of the material.

D. Attitude toward Learning: H_{03}

Table IV: Attitude Scale Scores by Group

Group	n	Mean	SD	t	df	p	Cohen's d
CBT (Experimental)	40	78.65	10.23	6.123	78	<.001	1.37
Traditional (Control)	40	63.42	11.87				

Attitude scores were significantly higher in the CBT group (M = 78.65, SD = 10.23) than the traditional group (M = 63.42, SD = 11.87), with a large effect size (d = 1.37). Subscale analysis revealed that the largest between-group differences were on the engagement subscale (mean difference = 6.42) and the confidence subscale (mean difference = 5.78), with smaller but still significant differences on the interest (mean difference = 2.31) and relevance (mean difference = 0.89) subscales. H_{03} is therefore rejected.

E. Summary of Hypothesis Testing

All three null hypotheses were rejected at the $p \leq 0.05$ significance level. The CBT group consistently outperformed the traditional group on immediate achievement, retention, and attitudinal outcomes, with effect sizes uniformly categorized as large by Cohen's benchmarks.

DISCUSSION

A. Achievement Outcomes

The finding that CBT-instructed students significantly outperformed traditionally instructed students on the brick wall bonding achievement test is consistent with the broader empirical literature in TVET educational technology. The mean difference of approximately 10.67 points, roughly 26.7% relative to the traditional group's mean, is neither trivial nor surprising given the theoretical arguments developed in the framework section of this paper. Cognitive Load Theory clearly predicts that a visual-spatial topic like brick wall bonding, when taught through static two-dimensional diagrams, imposes substantial extraneous cognitive load as students struggle to mentally reconstruct the three-dimensional arrangement from inadequate representational input. The CBT's animated three-dimensional sequences directly addressed this representational gap [5].

It is worth reflecting on what exactly the CBT enabled that the traditional method did not. The interactive drag-and-drop brick-laying activity is a case in point. Research in embodied cognition suggests that motor interaction with content, even simulated motor interaction through mouse-based manipulation, activates sensorimotor representations that support spatial understanding more effectively than purely passive observation [28]. When a student dragged a virtual brick into position and received immediate feedback on whether it was correctly placed, they were doing something fundamentally different from watching an instructor place a brick on a demonstration panel. They were generating predictions, testing them, and integrating feedback, the cognitive loop that Mayer and others associate with active processing and schema construction [4].

These findings mirror those of Adeyemi and Okafor [20], who reported similar CBT advantages in woodwork joint instruction, and of Tijani and Oyelaran [18] in plumbing instruction. The effect size obtained here (d = 1.21) is somewhat larger than the d = 0.72 meta-analytic average reported by Tamayo and Guzman [19], which may reflect the particularly high spatial demand of brick wall bonding, precisely the kind of topic for which CBT's visualization capabilities offer the greatest relative advantage.

It would, however, be intellectually dishonest to attribute the achievement gap entirely to the medium of instruction without acknowledging other possible contributors. The structured, self-paced nature of the CBT may have helped lower-ability students who found the pace of traditional classroom instruction inadequate, a possibility the current study cannot fully disentangle without subgroup analysis, which is recommended for future research. Similarly, the novelty effect, students performing better simply because a new instructional method captures their attention, cannot be entirely ruled out with a six-week intervention. Longer-term follow-up studies would help address this concern.

B. Retention Outcomes

Perhaps the more theoretically interesting finding in this study is the retention advantage demonstrated by the CBT group, and specifically the observation that the effect size at the retention test (d = 1.25) was marginally larger than at the immediate post-test (d = 1.21). This pattern is consistent with desirable difficulties theory and with Mayer's claim that multimedia encoding creates richer and more interconnected memory representations that are more resistant to forgetting [4]. The dual-channel encoding that CBT enables, visual information processed through the pictorial channel and spoken narration processed through the phonological channel, with the two coordinated by the coherence of the presentation, produces memory traces with more retrieval cues than the single-channel, text-and-diagram encoding typical of traditional instruction.

The traditional group's somewhat steeper proportional score decline (7.0% vs. 4.9% for the CBT group) over the four-week delay interval suggests that their knowledge, though sufficient to perform adequately at immediate post-test, was less deeply integrated and therefore more susceptible to the forgetting curve. From a practical standpoint, this matters enormously. In TVET, students who learn a topic in Year 1 will need that knowledge in Year 2 and throughout their professional careers. Instructional methods that produce knowledge that fades quickly after the lesson are pedagogically inferior, even if they produce acceptable immediate scores.

C. Attitudinal Outcomes

The significantly more positive attitudes of CBT-instructed students deserve careful interpretation. The largest subscale differences were in engagement and confidence. Engagement is perhaps unsurprising, interactive, multimedia-rich instruction is inherently more stimulating than chalkboard lectures. But the confidence finding carries specific significance. Confidence in one's ability to learn and perform a task, what Bandura would recognize as self-efficacy, is a powerful predictor of future academic effort and persistence [26]. Students who emerged from CBT instruction feeling more capable of understanding brick wall bonding may be better positioned for success in subsequent related topics: structural brickwork, arch construction, cavity wall ties, and the advanced bonding configurations encountered in professional practice.

It is important to note that the attitude measurement in this study was purely self-reported and administered at a single time point after instruction. Longitudinal tracking of attitudinal change and its relationship to subsequent course performance would add considerably to the value of these findings and is recommended for follow-up research.

D. Implications for Practice and Policy

The findings of this study carry several direct implications. First, at the classroom level, the evidence supports the use of purpose-built CBT applications as a primary instructional medium for brick wall bonding, at least for the conceptual and procedural knowledge dimensions of the topic. This does not mean abandoning traditional demonstration, as Owusu and Amponsah [22] correctly cautioned, CBT may not adequately substitute for supervised hands-on practice in developing physical manipulation skills. A blended model, in which CBT handles conceptual instruction and live practical sessions develop manual competency, appears to offer the strongest pedagogical foundation.

Second, at the institutional level, the findings reinforce the urgency of equipping TVET computer laboratories with subject-specific instructional software. Generic productivity tools do not address the specific pedagogical needs of trade subjects; purpose-built CBTs for masonry, carpentry, electrical installations, and other trades are

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needed and can be developed at feasible cost using modern authoring platforms. The one-time cost of CBT development, while non-trivial, compares favorably to the ongoing cost of physical demonstration materials and the recurring performance losses attributable to inadequate traditional instruction.

Third, at the policy level, curriculum and examination bodies such as NABTEB should consider endorsing specific digital instructional resources for trade subjects, as part of a broader quality assurance framework for TVET instruction. Teacher training programs must also evolve to include CBT facilitation skills, ensuring that instructors are not merely passive gatekeepers of computer laboratories but active guides who help students integrate CBT learning with broader trade competencies.

E. Limitations

Several limitations of this study warrant acknowledgment. The study was conducted in a single technical college, limiting the generalizability of the findings; future investigations should involve multiple technical colleges across different Nigerian regions and, where feasible, employ randomized assignment or matched-group procedures to strengthen causal inference. The CBT was developed by the researcher, introducing potential developer bias in content emphasis and presentation quality; independent instructional and technical validation of the CBT by a separate research team would reduce this bias and strengthen future evidence. The study's outcome measures were entirely knowledge-based; no objective hands-on bricklaying performance assessment was included alongside the achievement test, leaving open the question of whether CBT advantages in conceptual and procedural knowledge translate to practical performance improvements. The four-week retention interval, while informative, may not fully establish the durability of the observed advantage; a longer follow-up period would help determine whether the retention benefit persists over extended time. No formal measures of prior computer experience, spatial ability, gender, or prior academic achievement were examined as moderating variables, so it remains unclear which subgroups of learners benefit most from CBT. Finally, the absence of a direct cost-effectiveness comparison among CBT, traditional instruction, and blended learning approaches limits the strength of the policy recommendations that can be drawn from the findings.

CONCLUSION

This study set out to generate empirical evidence on a question that is both practically important and theoretically interesting: does computer-based tutorial instruction produce better learning outcomes in brick wall bonding than the traditional teaching methods that currently dominate TVET classrooms? The answer, based on a carefully designed quasi-experimental study with 80 technical college students, is clearly affirmative. CBT-instructed students outperformed traditionally instructed students by approximately 10.67 points on the post-test, retained significantly more of their learning over a four-week delay period, and demonstrated more positive attitudes toward the subject matter, all with large effect sizes.

These findings are not merely statistical curiosities. They reflect real differences in how students process, encode, and retain information about a subject that has real-world consequences for structural safety and construction quality. A future bricklayer who truly understands why English bond is stronger than stretcher bond, who can identify correct and incorrect joint offset arrangements from visual inspection, and who retains that understanding through years of professional practice is not just a better student, they are a better tradesperson. The instructional method used during initial training contributes meaningfully to that outcome.

The study adds to a growing body of empirical evidence that CBT is not merely a technological novelty but a pedagogically superior medium for certain types of TVET content, particularly those with high spatial and visual demands. Future research should incorporate objective hands-on bricklaying performance assessments alongside knowledge tests, examine prior computer experience, spatial ability, gender, and academic achievement as potential moderating variables, employ multi-site designs across Nigerian regions with randomized or matched-group assignment where feasible, adopt longer follow-up intervals to confirm the persistence of retention advantages, subject CBT materials to independent instructional and technical validation, and conduct direct cost-effectiveness comparisons of CBT, traditional instruction, and blended learning approaches in order to strengthen both the evidence base and the policy implications of the findings.

TVET must meet the challenge of equipping a new generation of skilled trade workers with both the practical competencies and the deep conceptual understanding that professional excellence demands. Computer-based tutorials, thoughtfully designed and rigorously implemented, represent one credible pathway toward that goal.

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