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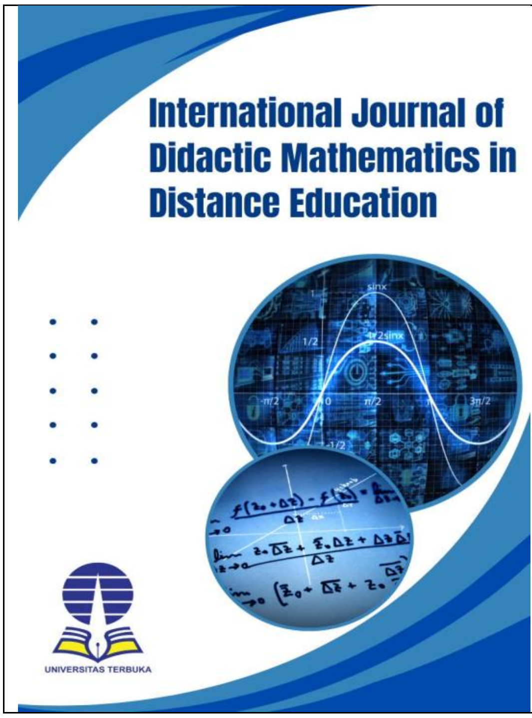

Bridging the integer gap: Computer-assisted instruction's effects on student achievement, gender equity, and learning perceptions

Saviour Dogbe[1], Clement Ayarebilla Ali[2]

[1]College for Distance and e-Learning, University of Education, Winneba, Ghana, sdogbe@gmail.com

[2]School of Education and Lifelong Learning, University of Education, Winneba, Ghana, aliclement83@gmail.com

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Bridging the integer gap: Computer-assisted instruction's effects on student achievement, gender equity, and learning perceptions

Saviour Dogbe[1*], Clement Ayarebilla Ali[2]
[1]College for Distance and e-Learning, University of Education, Winneba, Ghana, sdogbe@gmail.com
[2]School of Education and Lifelong Learning, University of Education, Winneba, Ghana, aliclement83@gmail.com

*Correspondence: sdogbe@gmail.com

Abstract
Despite extensive research on Computer-Assisted Instruction (CAI) in mathematics education, few studies have specifically examined its effectiveness for teaching integer operations—a foundational yet persistently challenging topic for students. This study addressed this gap by examining the effects of CAI on students' achievement in integer operations and exploring potential gender differences in learning outcomes. A quasi-experimental pretest-posttest nonequivalent groups design was employed with 44 Year 2 students (22 experimental, 22 control) over four weeks. The experimental group received CAI-based instruction using interactive software with visual representations and immediate feedback, while the control group was taught using traditional methods. Data were collected using a Mathematics Achievement Test and a perception questionnaire, then analyzed using independent sample t-tests at $p < 0.05$. Results revealed that the experimental group achieved significantly higher post-test scores ($M = 13.19$, $SD = 4.19$) compared to the control group ($M = 10.71$, $SD = 3.70$), with $t = 2.03$, $p = 0.049$. Retention tests confirmed sustained learning gains four weeks post-intervention. No significant gender-based differences were found ($p = 0.96$), indicating CAI benefited male and female students equally. Student perceptions were overwhelmingly positive ($M > 3.73$), with participants appreciating CAI's interactive features, self-paced learning, and enhanced conceptual understanding. The study recommends integrating CAI into mathematics instruction to improve student engagement, understanding, and achievement in integer operations, particularly given its equitable benefits across gender groups.

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1. Introduction

The mastery of integer operations constitutes a cornerstone of mathematical literacy, serving as an indispensable foundation upon which more sophisticated mathematical reasoning is built (Agwagah et al., 2019). Far from being merely an isolated computational skill, proficiency in integer operations underpins students' ability to engage meaningfully with algebraic manipulation, geometric transformations, calculus concepts, and statistical analysis at advanced educational levels (Mayasari et al., 2021). Beyond the classroom, integer operations permeate everyday decision-making processes, from calculating financial gains and losses to interpreting temperature fluctuations and navigating directional movements (Asare, 2022). Yet despite its fundamental importance, the learning of integers consistently presents formidable challenges to students worldwide. The abstract nature of negative numbers, the counterintuitive rules governing their operations, and the cognitive leap required to conceptualize quantities "less than nothing" create persistent barriers to understanding (WAEC, 2021; Adarkwah et al., 2024). When students fail to develop robust mental models of integer operations, the consequences extend far beyond computational errors; they experience cumulative difficulties in subsequent mathematical topics, develop mathematics anxiety, and often disengage from the subject altogether (Adarkwah et al., 2024; Ayiwah, 2019). Research has consistently demonstrated that poor understanding of integer operations not only affects immediate mathematical performance but also creates cascading effects that hinder students' progress in more advanced mathematical domains (Agwagah et al., 2019; WAEC, 2021). This makes the question of how to effectively teach integer operations not merely a pedagogical concern but an urgent educational priority with long-term implications for students' academic trajectories and quantitative reasoning capabilities (Asare, 2022; Ibrahim et al., 2025).

The gravity of this instructional challenge is starkly illustrated in recent assessment data from the West African Examinations Council. The Chief Examiner's reports (WAEC, 2021) reveal a deeply troubling pattern of persistent underachievement in mathematics, with integer operations emerging as one of the domains where students demonstrate the most pronounced difficulties. The reports document widespread struggles with translating word problems into mathematical statements involving integers, manipulating algebraic expressions with negative coefficients, and solving distance-time problems that require understanding of directional movement (WAEC, 2021). These documented deficiencies point directly to systemic failures in current instructional approaches. The Traditional Instructional Method (TIM) that continues to dominate mathematics classrooms operates through a rigid pedagogical sequence: review of previous homework, teacher-centered exposition of new content through verbal explanation, and assessment through memorization and recitation (Agwagah et al., 2019). This approach positions the teacher as the sole authority and knowledge transmitter while relegating students to passive recipients of information, thereby failing to develop learners' critical thinking skills (Asare, 2022). In the context of integer operations, this manifests as teachers presenting abstract rules, "two negatives make a positive" or "subtracting a negative means adding", without grounding these principles in concrete experiences or visual representations that students can manipulate and explore. The WAEC (2021) reports specifically note that lessons are delivered through unfamiliar symbols and abstract explanations disconnected from students' lived experiences, rendering the learning process confusing and frustrating, particularly for those who require concrete or visual pathways to understanding. The fundamental flaw in TIM lies not only in its pedagogical approach but in its underlying assumptions about learners. By presuming homogeneity among students, TIM ignores critical individual differences in prior knowledge, cognitive processing speeds, learning preferences, and developmental readiness (Adarkwah et al., 2024). This one-size-fits-all model inevitably produces disengagement among struggling learners who cannot keep pace, boredom among advanced students who are not challenged, and missed opportunities for differentiated instruction that could address diverse learning needs (Asare, 2022). The resulting educational landscape is characterized by widespread student disengagement, poor retention of mathematical concepts, and persistently unsatisfactory academic performance that reflects not students' inherent abilities but rather the limitations of the instructional methods employed, compounded by poor pedagogy, inadequate resources, limited teaching experience, and insufficient motivation (Adarkwah et al., 2024).

Recognizing these profound limitations, educational researchers have increasingly turned their attention to Computer-Assisted Instruction as a promising alternative paradigm for mathematics teaching (Ayiwah, 2019). The accumulated evidence base demonstrates CAI's potential to fundamentally transform the learning experience. Asare (2022) documented that students receiving CAI-based instruction achieved significantly higher test scores compared to peers taught through traditional methods, while Agwagah et al. (2019) established that CAI produced statistically significant improvements in mathematics achievement across diverse student populations. The mechanisms through which CAI generates these outcomes are multifaceted and theoretically grounded. Unlike traditional instruction's linear, teacher-paced delivery, CAI enables genuine personalization of content delivery, allowing students to navigate material at individualized paces, receive immediate corrective feedback, and experience learning pathways adapted to their demonstrated mastery levels (Ibrahim et al., 2025; Agwagah et al., 2019). This individualized approach aligns closely with Mastery Learning principles, ensuring students develop solid understanding of foundational concepts before progressing to more complex material, thereby preventing the accumulation of knowledge gaps that plague traditional instruction (Christopoulos et al., 2024). Furthermore, CAI addresses the abstraction problem that particularly afflicts integer instruction by providing rich visual representations and interactive manipulatives through various formats such as practice exercises, tutorials, and simulations (Agwagah et al., 2019). Applications such as GeoGebra enable students to visualize integer operations on number lines, manipulate representations of positive and negative quantities in two- and three-dimensional spaces, and experiment dynamically with mathematical relationships, including geometric transformations and algebraic operations (Asamoah, 2023; Mayasari et al., 2021). Microsoft Mathematics complements these capabilities by simplifying complex problem-solving processes, generating instant visual representations of mathematical graphs, and enhancing both calculation accuracy and processing speed (Rabi et al.,2023; Rawa et al., 2020). Ayiwah (2019) demonstrated that such technology-enhanced instruction produced significant cognitive gains in chemistry education, while Doku and Adherr (2019) established that CAI not only improved immediate performance but also enhanced long-term knowledge retention. Similarly, Qayumi et al. (2004) found meaningful differences in academic performance between students exposed to CAI and those taught through traditional methods. Perhaps equally important, research indicates that students respond favorably to CAI environments, demonstrating positive attitudes toward computer-based learning and increased motivation to engage with mathematical content (Asare, 2022; Rizki & Widyastuti, 2019). These affective dimensions should not be underestimated; by transforming mathematics from a source of anxiety into an engaging, manageable challenge, CAI may help break the cycle of negative emotions that often accompanies mathematical learning (Baiden & Agbene, 2022).

However, despite this encouraging body of evidence, significant gaps remain in our understanding of CAI's effectiveness for specific mathematical domains and student populations. While studies have demonstrated CAI's general efficacy in mathematics instruction, relatively few have focused specifically on integer operations, a domain where students' conceptual difficulties are particularly acute and where visual, interactive representations may offer unique advantages (WAEC, 2021). Notably, Asamoah (2023) studied 212 participants in experimental and control groups and found no significant difference between the groups in learning quadratic equations, suggesting that CAI's effectiveness may vary depending on the specific mathematical content and implementation context. Moreover, questions about potential gender differences in response to CAI remain unresolved, with some studies suggesting male students demonstrate greater confidence with technology and perform better when exposed to CAI (Cai et al., 2017; Mchiri, 2018) while others find no gender-based performance differences, arguing that computer programs lack specific gender attributes and are unlikely to produce differential responses between male and female learners (Olanrewaju et al., 2016). Still other recent studies document female students' superior mastery of specific CAI tools, with Asamoah (2023) finding that female respondents demonstrated greater mastery of Microsoft Math Solver in learning quadratic equations, thereby rejecting the assumption that males are inherently better at using technology for mathematics learning. These contradictory findings underscore the need for continued investigation into how gender may mediate CAI's effects. Additionally, while we know students generally hold positive attitudes toward CAI (Pilli, 2013), we have limited understanding of students' specific perceptions regarding CAI's utility for learning integer operations—whether they find technological representations helpful for understanding negative numbers, whether interactive features support or distract from learning, and whether they perceive CAI as superior to traditional instruction for this particular content domain (Asare, 2022). These gaps in the research literature create an imperative for targeted investigation.

This study addresses these gaps by systematically examining the effectiveness of Computer-Assisted Instruction specifically for teaching integer operations, a critical yet challenging domain in mathematics education. By implementing CAI with its capacity for visual representation, interactive manipulation, immediate feedback, and individualized pacing, this research tests whether technology-enhanced instruction can overcome the documented failures of traditional approaches in helping students develop robust understanding of integer concepts and operations (Ibrahim et al., 2025). The study adopts a comprehensive approach by examining not only overall achievement effects but also potential differential

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impacts based on gender and students' subjective experiences with the instructional method, recognizing that CAI's ability to provide learner-controlled instruction, prompt feedback, self-pacing, and adaptability may benefit different student groups in varying ways (Agwagah et al., 2019; Keenan et al., 2020). Specifically, this research investigates three critical questions:

(1) what is the effect of CAI on students' performance in integer operations, as measured by standardized achievement assessments?
(2) does CAI produce differential effects based on gender, either ameliorating or exacerbating existing performance gaps between male and female students?
(3) what are students' perceptions of CAI as a learning tool for integer operations, including their views on its effectiveness, usability, and value compared to traditional instruction?

1.2 Theoretical Framework of the Study

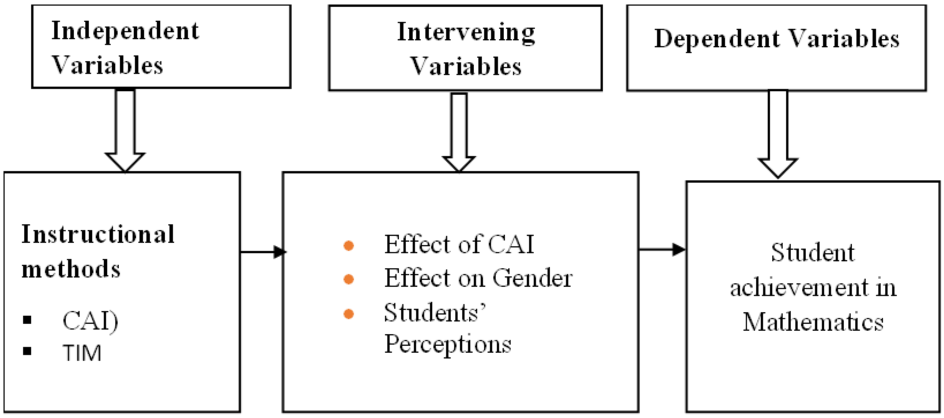
The theoretical framework was grounded in Vygotsky's Social Constructivist Theory of Learning and Davis's (1989) Technology Acceptance Model (TAM), which serve as the pillar of constructivism in active learning, social interaction, and collaborations. These theorists proposed that learning is a socially mediated activity, and interactions with peers, teachers, and technology play a critical role in a learner's cognitive development.

Vygotsky's theory revolves around social interaction, the More Knowledgeable Other (MKO), and the Zone of Proximal Development (ZPD). Social interaction allows learners to exchange ideas, challenge each other's thoughts, and deepen their understanding. The MKO refers to more experienced or knowledgeable teachers, experienced peers, or even well-designed educational programmes to guide learners. The ZPD represents the gap between what a learner can achieve on their own and what they can accomplish with support. In this framework, CAI acts as an MKO to guide students through integer operations and provide personalized feedback, and ZPD allows students to explore and learn beyond what they typically achieve alone. Moreover, Vygotsky believed that tools, whether they are physical, cognitive, or technological, expand students' capabilities, and this calls for the support of TAM, so that CAI acts as a technology tool, providing scaffolding and supporting independent thinking, problem-solving, and creativity to make learning more engaging and effective experiences. In this case, CAI transforms students, teachers, and technology interaction in the learning process. So, the students not only absorb information, but they also actively construct knowledge with the help of their peers, teachers, and technology to extend deeper understanding, motivation, and collaboration.

1.3 Conceptual Framework

On Figure 1, the independent variables are the CAI and TIM methods, which represent the interventions or treatments. The intervening variables are the Effect of CAI, the Effect on Gender, and Students' Perceptions. Teachers undertake training, teaching experience, and personal disposition on the approaches. The training teachers have received in implementing the CAI and TIM methods is dependent on the teaching experience variables and the students' disposition. Students' variables are mainly personal attitudes, beliefs, motivations, and perceptions of the instructional methods. The gender recognizes the biological, social, and sociocultural roles in learning CAI and TIM methods. The dependent variable is the student performance, and demonstrable in the outcome of the integer operation before and after treatments.

Figure 1
Conceptual Framework of CAI and TIM (Adopted from Asare, 2022)



1.3.1 The Concept of Integer Operations

Integers form a special group of numbers that includes both positive whole numbers and their opposite counterparts—negative counterparts, so they always carry either a plus or a minus sign. Zero is described as an integer because it is a whole number, holds a unique place, and serves as its opposite (Kwakye & Aggrey, 2022). One common model of negative numbers is through an ordinal or order-based perspective, where they are seen as part of a larger ordered number system (Bishop et al., 2018). In this view, negative numbers are simply an extension of the counting numbers, continuing the sequence by moving leftward or downward from zero (Kumar et al., 2019). The second model is to think about negative numbers in terms of magnitude and opposites. In this view, negative integers are not just a place on a line, but they represent quantities that are the inverse of positive values, where zero becomes a balance point (Wessman-Enzinger & Mooney, 2019).

The third model is the idea of direction or movement, or the directed number model. In this view, the sign of the number (positive or negative) shows the direction, while the numerical value tells how far to move. Wessman-Enzinger and Mooney (2019) opine that the actual motion or shifts of objects from zero is the movement, and show relative changes instead of exact positions.

1.3.2 Student Reasoning of Integer Operations

Research shows that many students connect their reasoning about negatives to their prior understanding of positive number operations (Bofferding et al., 2018). One common strategy involves thinking about the linear order of numbers, where students use counting methods based on the sequence of integers (Lamb et al., 2018). Another widely observed method is counting up or down by ones. For example, a student might solve $3 - 5$ by counting backward five steps. However, such students who reason based on magnitude alone see -9 as larger because they ignore the negative sign. In contrast, students interpreting size based on linear value count differently, such as starting at 0 and counting five back to reach -2 (Aqazade & Bofferding, 2021).

Directionality suggests that counting down is a decrease, matching both magnitude and position. Students often use number lines to provide a visual model of ordinal relationships between numbers, typically increasing to the right for positives and to the left for negatives (Wessman-Enzinger, 2018). In many cases, students interpret addition as a movement to the right and subtraction as a movement to the left. On vertical number lines, this corresponds to moving upward for addition and downward for subtraction (Aqazade & Bofferding, 2021).

1.3.3 Common Models for Teaching Integer Operations

On the Number Line, teachers use horizontal number line models with positive numbers increasing to the right and negative numbers decreasing to the left, but vertical layouts are also common, with positive values extending upward and negative values downward. These models help learners to visually organize numbers to zero and grasp how values shift above and below that central point (Bofferding & Farmer, 2019). Though horizontal number lines dominate textbooks, vertical versions help make sense of certain real-world systems (Wessman-Enzinger, 2018).

In addition, teachers rely on manipulative-based models, such as two colors to distinguish between positive and negative values. For instance, yellow chips represent positive units, while red chips represent negative ones. When combined, a positive and a negative chip cancel each other out, visually modeling the

International Journal of Didactic Mathematics in Distance Education
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concept of additive inverses and the role of zero as a balancing point (Murray, 2018). This helps students understand that the addition of +2 and −2 makes zero. The third model involves financial modeling, where students think of positive values as credits or gains and negative values as debts or losses. Students begin to associate negative numbers with everyday experiences, such as spending money or owing someone, which deepens their conceptual understanding (Whitacre et al., 2015).

2 Methods

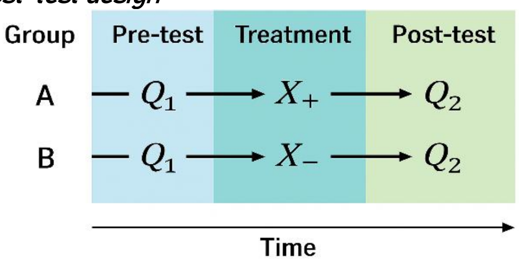
2.1 Research Design

A quasi-experimental method was chosen for this study because it allowed the researcher to examine the effects of an intervention in a real classroom setting without the need for randomly assigning students to groups (Saunders et al., 2019). This method made it possible to work with existing classes while still exploring the relationship between the intervention and students' learning outcomes (Creswell & Creswell, 2018). In particular, the pretest-posttest nonequivalent groups design had a treatment group that was given a pretest, received a treatment, and then was given a posttest. But at the same time, there was an equivalent control group that was given a pretest, did not receive the treatment, and then was given the posttest. Although quasi-experiments did not offer full control over all variables, they were instrumental in determining whether the CAI method made any difference. So, the researchers compared the performance of the experimental group with the control group.

Initially, both groups took a pre-test to establish a baseline. Following the administration of the treatment to the experimental group, both groups underwent a post-test to assess the impact of the intervention (Asanre et al., 2025). The experimental group received CAI, whereas the control group was taught using the traditional approach. The content to be taught and learned was the same for the two groups; it was the modes of delivery that were different (Saunders et al., 2019). The development of the treatment went through phases, as shown in Figure 1.

Figure 2

Equivalent groups pre-test-post-test design



Information:

A = Experimental Group; **B** = Control Group, Q_1 = Pre-test, Q_2 = Posttest, X_+ = CAI treatment, X_- = TIM treatment

Figure 2 consists of two groups, namely the experimental group (Group A) and the control group (Group B). To establish a baseline, both groups were initially given a Pre-test (Q_1) Measurement. Subsequently, Group A was administered the treatment intervention with a CAI (X_+). In contrast, Group B was taught using TIM (X_-). This group was taught using lecture, discussion, and interactive question-answer sessions. Both the experimental group and the control group received instruction over four weeks. Once the treatment was given, both groups underwent a post-test measurement (Q_2). Thereafter, the researchers evaluated whether any changes had occurred.

2.2 Participants

Creswell and Poth (2018) describe a population as the entire group of individuals or objects to which researchers want to generalize their findings, Thacker et al. (2019) explains a population as the complete set of items or individuals that are of interest in a research study, Creswell and Poth (2018) describe a target population as the specific population that the researcher intends to study and draw conclusions about, while Cohen et al. (2017) assert that the target population is the portion that can be reached by the researcher for data collection. In this study, the accessible population consisted of all year 2A and 2B students of 44.

In this study, one experimental group (EG) and one control group (CG) came from the accessible population. This was necessary to conduct in schools that have computers, and students who possess a certain level of computer literacy. The Year 2A students demonstrated the necessary computer literacy and access to technology, while Year 2B provided a comparison to ensure that both groups came from the same educational environment with similar academic backgrounds. The sample involved an intact class of 22 Year 2A students as the Experimental Group and 22 Year 2B students as the Control Group. Each group had an equal distribution of 11 male and 11 female students.

2.3 Data Collection

The tools used to gather information aligned with the study's theoretical and philosophical foundations (Creswell & Creswell, 2018). The data collection was a thoughtful and systematic process aimed at producing accurate and relevant evidence that supports the study's purpose (Saunders et al., 2019). The data was suitable for the quantitative analysis to consistently maintain the quality and credibility of the results. The instrument used for data collection was the Mathematics Achievement Test.

2.3.1 Mathematics Achievement Test (MAT)

In the MAT instrument, the pre-treatment test consisted of 15 items, including multiple-choice questions and problem-solving tasks. The questions revolved around identifying integers, performing addition and subtraction operations, and solving real-world problems. Following the treatment, the 20-item Post-Treatment Test was administered to measure the immediate impact of the teaching strategies employed. This covered conceptual understanding and procedural skills, ensuring alignment with the instructional content.

To assess long-term retention of the concepts learned, a Retention Test was conducted four weeks after the post-treatment test. This test mirrored the structure of the previous assessments, comprising 20 items that focused on recalling and applying knowledge of the addition and subtraction of integers. To ensure the validity of the test instrument, the questions were developed based on established curriculum standards and best practices in mathematics education. The results from the pre-treatment, post-treatment, and retention tests were analyzed to determine the effectiveness of the instructional strategies and to draw conclusions about students' learning outcomes in addition and subtraction of integers on the number line using CAI.

2.3.2 Questionnaire

A questionnaire was employed to gather data on the perceptions of CAI. These were meticulously designed to address specific research questions, highly effective, as well as explore their perceptions (Sollars, 2020). The questionnaire consisted of two sections (A and B) measured on the same Likert-type scale. Section A gathered demographic data, while Section B included items measured on a 5-point Likert scale (1 = Strongly Disagree, 2 = Disagree, 3 = Neutral, 4 = Agree, 5 = Strongly Agree), elicited information from students about their views on the use of CAI as an instructional strategy.

2.4 Validity and Reliability of Research Instruments

The items were reviewed and validated by the subject experts and a panel of experienced mathematics educators, who provided feedback on clarity, relevance, and appropriateness. The content validity was given to experts and lecturers to scrutinize for clarity and ambiguity, and meaningful and useful inferences to be drawn from the items relative to the objectives of the study (Sollars, 2020). In establishing the reliability of the research instruments, the instruments were tested using the test-retest reliability method. Each test was administered under standardized conditions to minimize variability in responses, with clear instructions and adequate time allocated for completion. The instruments were first administered and then re-administered to the same respondents after one week. Scoring was conducted using a rubric that emphasized accuracy and completeness, with specific criteria for evaluating open-ended responses. The results of the first and second test outcomes were compared to ascertain the reliability of the instruments. Cronbach's coefficient alpha, a measure of internal consistency, was calculated to be 0.72.

2.5 The Research Treatment Procedures

International Journal of Didactic Mathematics in Distance Education
Volume 3, Issue 1, pp. 22-43, E-ISSN: 3047-9207
https://jurnal.ut.ac.id/index.php/ijdmde

The study was conducted in three main phases: the pre-treatment phase, the treatment phase, and the post-treatment phase. In the first phase, the pre-treatment phase, a pre-test was administered to both the experimental and control groups. The test consisted of 15 items focused on integer operations, designed to establish a baseline of students' prior knowledge and performance in this topic. In the second phase, the treatment phase, which lasted for four weeks, both groups were taught the same content to allow for a direct comparison between the effectiveness of CAI and the TIM. The researchers ensured that both groups followed a consistent schedule and received equal instructional time throughout the intervention (Doku & Adherr, 2019).

2.5.1 Experimental Group

In this study, the instructional steps implemented in the experimental class can be seen in Figure 3. The figure serves to visualize the stages of the applied instructional model, making it easier for readers to understand the learning process.

Figure 3. Experimental Group

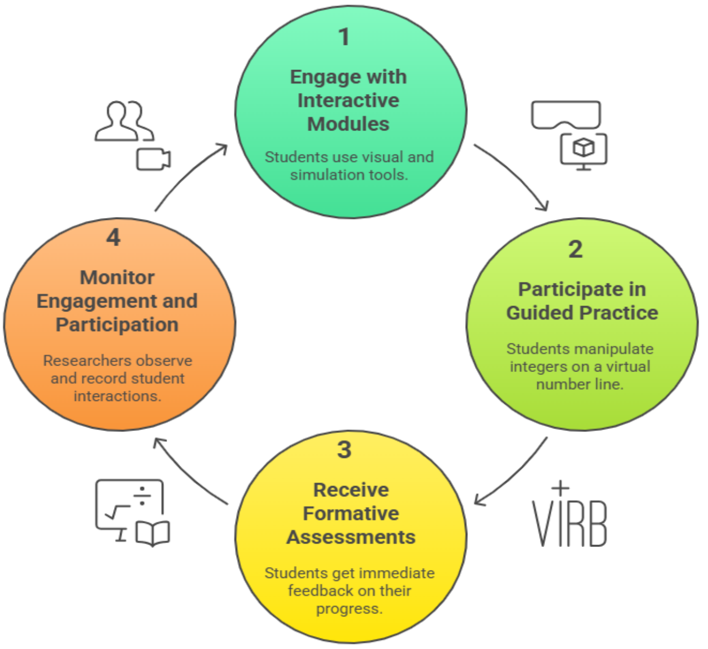


Figure 3 illustrates the instructional procedures implemented in the experimental group during the treatment phase. The experimental class utilized interactive learning modules designed to actively engage students through visual representations and simulations of the number line. During the learning process, students participated in guided practice sessions where they could manipulate integers on a virtual number line, thereby reinforcing their conceptual understanding of addition and subtraction operations. Each lesson was followed by formative assessments administered by the researchers to provide immediate feedback, enabling students to monitor their learning progress and correct misconceptions in real time. In addition, the researchers systematically observed and recorded students' interactions throughout the lessons to monitor engagement levels and ensure consistent participation in the learning activities. This structured approach allowed for a comprehensive evaluation of how computer-assisted instruction supported students' conceptual understanding and learning outcomes.

2.5.2 Control Group

In the control class, instruction was conducted using the Traditional Instructional Method (TIM), with the learning steps illustrated in Figure 4. The control group received delivered lessons using well-prepared lesson notes, focusing on direct instruction and practice problems.

International Journal of Didactic Mathematics in Distance Education
Volume 3, Issue 1, pp. 22-43, E-ISSN: 3047-9207
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In the control class, students participated in group discussions and completed paper-based exercises designed to strengthen their procedural knowledge and mastery of step-by-step problem-solving techniques. Learning activities emphasized the application of rules and algorithms for integer operations, with the teacher guiding students through worked examples and providing corrective feedback as needed. The formative assessments administered during this phase consisted of paper-based quizzes that required students to demonstrate their understanding independently, without the aid of visual or interactive learning tools. These assessments were intended to measure students' ability to apply learned procedures accurately and consistently. Throughout the instructional sessions, the researchers observed classroom interactions to document the level of student engagement, participation, and responsiveness to teacher instructions. Informal assessments, such as questioning and brief discussions, were also conducted to gather qualitative insights into students' learning progress. This traditional instructional approach reflected a structured but less interactive learning environment, focusing more on procedural fluency than on conceptual understanding or exploratory learning.

In the third phase, known as the post-treatment phase, a post-test was administered to both the experimental and control groups to evaluate the effectiveness of the Computer-Assisted Instruction (CAI). The post-test instrument followed the same structure as the pre-test but contained different items to accurately assess students' understanding after the intervention. The collected scores were systematically marked and analyzed to identify any significant differences in performance between the two groups. In addition to the post-test, a questionnaire was administered to gather students' perceptions regarding the effectiveness, engagement, and overall learning experience associated with CAI. The feedback obtained provided valuable insights into how students responded to the use of CAI in learning integer operations and contributed to understanding its impact on their motivation and comprehension.

2.6 Data Analysis

The statistical analysis of the tests (pre-test, post-test, and retention test) used descriptive statistics, including means, standard deviations, and mean differences, for both groups. These statistics provided insights into general patterns in the data. The inferential statistical analyses were used to determine whether there were statistically significant differences in students' performance before and after the treatments. Specifically, a t-test at a 0.05 level of significance compared the pre-test, post-test, and retention test scores of the experimental and control groups. This aimed to show whether CAI had a significant impact as compared to TIM. Additionally, the retention test scores assessed the long-term effectiveness of CAI in reinforcing students' understanding of integer operations.

2.7 Ethical Consideration

International Journal of Didactic Mathematics in Distance Education
Volume 3, Issue 1, pp. 22-43, E-ISSN: 3047-9207
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An ethical approval was obtained from the school authorities to ensure that all research activities met established ethical standards. Informed consent was sought from both the students and their parents or guardians, clearly outlining the purpose of the study, the procedures involved, and the potential risks and benefits. Participants were assured that their involvement was voluntary and that they could withdraw from the study at any time without any negative consequences. Again, confidentiality was a paramount concern; all data collected was anonymized and securely stored to protect the identities of the participants. Personal information was not disclosed in any reports or publications resulting from the study. Additionally, the researchers maintained transparency throughout the research process, providing participants with the opportunity to ask questions and receive clarifications.

3. Results

In this section, the study addressed three key research questions that guided the investigation. The first research question examined the effect of CAI on students' performance in integer operations. This question aimed to determine whether the use of CAI significantly improved students' achievement compared to those taught using the TIM. The second research question explored the differential effect of CAI based on gender, seeking to identify whether male and female students benefited differently from the use of technology-enhanced learning in mathematics. This analysis was important to understand if gender-related factors influenced learning outcomes when exposed to digital instructional tools. The third research question focused on students' perceptions of CAI in learning integer operations, emphasizing their views on the effectiveness, engagement, and overall learning experience provided by the computer-assisted approach. Addressing these three questions provided a comprehensive understanding of the impact of CAI not only on cognitive achievement but also on affective and social dimensions of learning.

3.1 What is the effect of CAI on the performance in integer operations?

This subsection presents the findings related to the first research question, which examined the effect of CAI on students' performance in integer operations. The analysis focuses on how the implementation of CAI enhanced students' conceptual understanding and computational skills through interactive modules, visual simulations, and instant feedback mechanisms. These features provided learners with opportunities to explore mathematical relationships more dynamically, promoting both engagement and accuracy in solving integer-related problems. The evaluation of students' learning outcomes was conducted based on their post-test results to measure the progress achieved after exposure to CAI. The detailed results of the test are presented in Table 1.

Table 1
Sample t-test for Pre-test Scores of the Treatments

Item	Experimental	Control
Mean	8.52	8.76
Variance	10.66	14.79
Observations	21	21
Pooled Variance	15.72	-
t-Statistics	-0.19	-
P(T<=t) one-tail	0.42	-
t-Critical one-tail	1.68	-
P(T<=t) two-tail	0.84	-
t-Critical two-tail	2.02	-

The results presented in Table 1 indicate that there was no statistically significant difference between the groups prior to the intervention ($p > 0.05$). This finding suggests that both groups were relatively equivalent in terms of their initial knowledge and performance in integer operations before the implementation of CAI. Specifically, the experimental group obtained a mean score of 8.52 with a standard deviation of 3.26, while the control group recorded a mean score of 8.76 with a standard deviation of 3.85. The similarity in these mean scores demonstrates that the participants from both groups started the study at nearly the same academic level. Establishing this equivalence was essential to ensure that any subsequent differences observed in the post-test results could be attributed to the treatment effect rather than to pre-existing disparities in ability or prior knowledge. Thus, the pre-test outcomes confirmed that the groups were comparable and that the research design maintained internal validity prior to the introduction of CAI.

To determine the effectiveness of CAI on students' performance in integer operations, a sample t-test was conducted to compare the pre-test and post-test scores of the experimental group. This analysis aimed to identify whether there was a statistically significant improvement in students' achievement after being exposed to CAI-based learning activities. The test evaluated the mean difference between students' initial performance and their performance after the treatment, taking into account the variance and degrees of freedom to ensure the reliability of the statistical results. The findings from this analysis provide evidence of the extent to which CAI contributed to students' learning progress. The detailed results of the analysis are presented in Table 2.

Table 2
Sample t-test of Pre-test and Post-test Scores of the Treatments

Experimental Group	Pre-Test	Post-Test
Mean	8.52	13.19
Variance	16.68	17.56
Observations	21	21
Pooled Variance	17.11	-
Hypothesized Mean Difference	0	-
Df	40	-
t-Stat	-3.65	-
P(T<=t) one-tail	0.01	-
t-Critical one-tail	1.68	-
P(T<=t) two-tail	0.01	-
t-Critical two-tail	2.02	-

The results presented in Table 2 revealed a notable improvement in students' performance following the implementation of CAI. The mean score increased from a pre-test mean of 8.52 (SD = 4.08) to a post-test mean of 13.19 (SD = 4.19), indicating a substantial enhancement in students' understanding and mastery of integer operations after participating in CAI-based learning activities. The calculated t-statistic value of −3.66 exceeded the critical t-value of 2.02, and the corresponding p-value (0.000738) was significantly lower than the 0.05 threshold. These results confirm that the observed improvement was statistically significant and unlikely to have occurred by chance. The findings suggest that the interactive and self-paced features of CAI effectively supported students in developing deeper conceptual comprehension and greater procedural fluency in solving integer problems. Furthermore, the consistent rise in mean scores highlights the positive impact of technology-enhanced learning environments on student engagement and achievement in mathematics.

Table 3
Dependent T-Test of Pre-test and Post-Test Scores of the Control Group

Control Group	Pre-test	Post-test
Mean	8.76	10.71
Variance	14.79	13.71
Observations	21	21
Pooled Variance	14.25	-
Hypothesized Mean Difference	0	-
Df	40	-
t-Stat	-1.67	-
P(T<=t) one-tail	0.05	-
t-Critical one-tail	1.68	-
P(T<=t) two-tail	0.10	-
t-Critical two-tail	2.02	-

The results in Table 3 indicate that the mean post-test score (M = 10.71, SD = 3.70) was higher than the mean pre-test score (M = 8.76, SD = 3.85), suggesting an improvement after instruction using the TIM method. However, the computed t-statistic (t = -1.68) was less than the critical t-value (2.021), and the p-value (p = 0.10) was greater than the 0.05 significance, suggesting that the scores were not statistically significant. So, the slight improvement in scores might have occurred by chance and not because of TIM. If the control group improved slightly, but TIM did not lead to any statistical significance, then technology-based instructional strategies were more effective than TIM methods.

To further examine the effect of CAI on students' achievement, an independent sample t-test was conducted to compare the post-test scores of the two groups. This analysis aimed to determine whether there was a statistically significant difference in performance between students exposed to CAI and those who received conventional instruction. By focusing on the post-test results, the test assessed the impact of CAI after the treatment phase, providing empirical evidence of its effectiveness in enhancing mathematical understanding and problem-solving skills in integer operations. The results of this comparative analysis are summarized in Table 4.

Table 4
Independent Sample t-test of Post-test Scores of MAT

Post-test Scores	Experimental	Control
Mean	13.19	10.71
Variance	17.56	13.71
Observations	21	21
Pooled Variance	15.63	-
Hypothesized Mean Difference	0	-
df	40	-
t-Stat	2.02	-
P(T<=t) one-tail	0.02	-
t-Critical one-tail	1.68	-
P(T<=t) two-tail	0.04	-
t-Critical two-tail	2.02	-

The results displayed in Table 4 indicate a clear difference in students' post-test performance between the two instructional approaches. The experimental group, which received instruction through CAI, achieved a higher mean post-test score (M = 13.19, SD = 4.19) compared to the control group (M = 10.71, SD = 3.70). This difference suggests that students exposed to CAI demonstrated greater mastery of integer operations and benefitted more from the interactive and visual learning environment provided by the technology-based approach. The computed t-statistic (t = 2.03) exceeded the critical t-value (2.021), while the p-value (0.0491) was below the 0.05 significance level, indicating that the difference in performance between the two groups was statistically significant. These findings confirm that the observed improvement in the experimental group's performance was not due to random variation but rather to the instructional benefits derived from CAI. The evidence supports the conclusion that the integration of multimedia elements, immediate feedback, and self-paced learning features inherent in CAI effectively enhanced students' understanding and engagement in learning integer operations. Consequently, CAI can be considered a viable pedagogical alternative for improving mathematical performance, particularly in areas requiring conceptual visualization and procedural accuracy.

3.2. What is the differential effect of CAI on gender in integer operations?

This subsection addresses the second research question, which sought to determine the differential effect of CAI on gender in learning integer operations. The purpose of this analysis was to examine whether male and female students benefited differently from the use of CAI as a digital instructional approach. Understanding gender-based differences is important in educational research, as it provides insights into how learners of different genders interact with technology-enhanced learning environments and how these interactions influence learning outcomes. To establish the equivalence of male and female students before the treatment, an independent t-test was conducted on their pre-test scores within the experimental group. This test aimed to ensure that any observed difference in post-test performance could be attributed to the effect of CAI rather than pre-existing disparities in prior knowledge or ability. The results of this analysis are presented in Table 5.

Table 5

Independent T-test for Pre-test Scores of Genders in the Experimental Group

Experimental Group	Male	Female
Mean	8.8	8.9
Variance	20.62	11.43
Observations	10	10
Pooled Variance	16.02	-
Hypothesized Mean Difference	0	-
Df	18	-
t-Stat	-0.05	-
P(T<=t) one-tail	0.48	-
t-Critical one-tail	1.73	-
P(T<=t) two-tail	0.96	-
t-Critical two-tail	2.10	-

The results presented in Table 5 show that there was no statistically significant difference between the pre-test scores of male and female students in the experimental group prior to the implementation of Computer-Assisted Instruction (CAI). The mean pre-test score for male students was 8.8 (SD = 4.54), while the mean for female students was 8.9 (SD = 3.38). The computed p-value of 0.96 was far greater than the 0.05 level of significance, indicating that the observed difference between the two means was not statistically significant. This implies that both male and female students began the study with nearly the same level of prior knowledge and ability in integer operations. The absence of a significant difference at the pre-treatment stage confirms the initial equivalence of the two gender groups, thereby strengthening the internal validity of the study. Consequently, any differences observed in the post-test performance could be confidently attributed to the effect of CAI rather than to pre-existing disparities in mathematical ability or understanding between male and female students. This finding establishes a sound basis for interpreting the subsequent analysis of gender-based outcomes following the CAI intervention.

Table 6

Independent T-test for Post-test of Gender in the Experimental Group

Experimental Group	Male	Female
Mean	13.6	13.5
Variance	17.15	15.83
Observations	10	10
Pooled Variance	16.49	-
Hypothesized Mean Difference	0	-
df	18	-
t-Stat	0.055	-
P(T<=t) one-tail	0.47	-
t-Critical one-tail	1.73	-
P(T<=t) two-tail	0.96	-
t-Critical two-tail	2.1	-

The results displayed in Table 6 were analyzed to determine whether there were statistically significant differences in post-test performance between male and female students after exposure to CAI. The findings revealed that the mean post-test score of male students (M = 13.6, SD = 4.14) was only slightly higher than that of female students (M = 13.5, SD = 3.67). Despite this marginal numerical difference, the computed t-statistic (t = 0.05) and the corresponding p-value (p = 0.96) indicated that the difference was not statistically significant at the 0.05 level. This statistical outcome suggests that both male and female

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students achieved comparable levels of improvement in their understanding of integer operations following the use of CAI. The near-identical mean scores further imply that the CAI environment provided an equitable learning platform, allowing students of both genders to engage effectively with the digital content and interactive learning tasks. These findings demonstrate that the effectiveness of CAI was not influenced by gender differences, reinforcing the notion that technology-enhanced learning can promote inclusive participation and equal learning opportunities across diverse student groups.

3.3. What are students' perceptions of CAI in learning integer operations?

This subsection addresses the third research question, which explores students' perceptions of CAI in learning integer operations. Understanding learners' perceptions is essential, as it provides valuable insights into how students experience, engage with, and respond to the integration of technology in mathematics instruction. Beyond measuring academic performance, this analysis aimed to capture the affective and attitudinal dimensions of learning with CAI—specifically, students' views regarding its usability, effectiveness, level of engagement, and contribution to their overall learning motivation. A perception questionnaire was administered to students in the experimental group after the treatment phase. The instrument consisted of several items designed to gauge their opinions on how CAI influenced their understanding of integer operations, their interest in mathematics, and their confidence in problem-solving. The responses were analyzed descriptively to determine general trends and identify areas of strength and potential improvement in the CAI-based learning experience. The summarized results of students' perceptions are presented in Table 7.

Table 7
The Perception of CAI in Integer Operation

Items	SA	A	N	D	SD	N	M	SD
1. CAI made integer operations more engaging and enjoyable.	8	7	4	2	1	22	3.73	1.10
2. The use of CAI helped me understand integer operations better than traditional methods.	10	6	3	2	1	22	3.86	1.06
3. I found it easier to follow lessons using CAI compared to textbooks	9	8	2	2	1	22	3.91	1.02
4. The visual and interactive nature of CAI improved my ability to solve integer problems.	11	5	3	2	1	22	3.91	1.12
5. I felt more confident in solving integer problems after using CAI.	8	8	3	2	1	22	3.82	1.05
6. CAI made it easier to remember the rules for adding and subtracting integers.	10	9	1	2	1	22	4.14	0.96
7. I prefer to use CAI for learning other mathematics topics as well.	10	9	2	1	1	22	4.09	0.98
8. I found CAI to be a distraction rather than a helpful learning tool.	1	2	1	8	10	22	2.00	1.26
Average Mean							2.5	0.5

The results in Table 7 reveal that students generally held positive perceptions toward the use of CAI in learning integer operations. Overall, the data indicate a strong acceptance of CAI as a valuable pedagogical tool that not only facilitated understanding but also increased students' enthusiasm and confidence in mathematics. A substantial number of students rated CAI as engaging and enjoyable (M = 3.73, SD = 1.10), suggesting that the digital and interactive features of CAI successfully captured learners' attention and maintained their motivation throughout the instructional sessions. This level of engagement is crucial in mathematics learning, where traditional approaches often struggle to sustain student interest, particularly in abstract topics such as integer operations. Furthermore, students strongly believed that CAI helped them understand integer operations better (M = 3.86, SD = 1.06). This perception aligns with previous findings that technology-assisted learning environments support conceptual understanding by providing immediate feedback, step-by-step guidance, and visual representations of mathematical processes. Such affordances likely reduced cognitive load and made abstract mathematical concepts more tangible and accessible to learners. Students also reported feeling more confident when solving integer-related problems after exposure to CAI (M = 3.82, SD = 1.05). This improvement in self-efficacy indicates that the interactive nature of CAI, coupled with its self-paced learning environment, allowed students to practice repeatedly until mastery was achieved without the fear of judgment that sometimes accompanies traditional classroom settings. Increased confidence is a positive psychological outcome, as it contributes to sustained engagement and better long-term achievement in mathematics.

4. Discussion

4.1 The Effect of CAI on the Performance in Integer Operations

The findings revealed that the experimental group's performance in the post-test was significantly superior to their pre-test performance, demonstrating that Computer-Assisted Instruction produced a statistically significant improvement in students' mastery of integer operations. This substantial gain provides compelling evidence that CAI represents a pedagogically effective intervention for teaching this challenging mathematical domain. In contrast, while students in the control group showed some improvement using the Traditional Instructional Method, the t-Test results indicated that this increase was not statistically significant, suggesting that TIM produced only modest learning gains that could potentially be attributed to practice effects, maturation, or random variation rather than genuine instructional effectiveness. The stark difference between these outcomes, significant improvement in the experimental group versus non-significant improvement in the control group, underscores CAI's superior efficacy in facilitating meaningful learning of integer operations.

These findings align closely with the broader research literature documenting CAI's advantages over traditional instruction. Rabi et al. (2023) similarly demonstrated that students taught using CAI performed significantly better than those taught using TIM methods, attributing these differences to CAI's capacity to enhance students' understanding, engagement, and retention of mathematical concepts. The mechanisms underlying CAI's effectiveness are multifaceted. First, CAI makes problem-solving both quicker and easier by providing computational support, immediate feedback, and step-by-step guidance that reduces cognitive load and allows students to focus on conceptual understanding rather than purely procedural execution (Rabi et al., 2023). Second, CAI enables students to demonstrate significantly deeper understanding of mathematical concepts by providing multiple representations—numerical, graphical, and symbolic, that help learners develop more robust and flexible mental models (Asamoah, 2023). Third, the interactive nature of CAI environments allows students to actively manipulate mathematical objects, test hypotheses, and observe immediate consequences of their actions, thereby supporting constructivist learning processes that promote genuine comprehension rather than rote memorization.

The significant positive impacts of CAI observed in this study can be further understood through the lens of the training and mentoring activities that accompanied the intervention. Rawa et al. (2020) confirm that structured training and ongoing mentoring are critical factors in realizing CAI's potential benefits, as these support mechanisms ensure that students develop the technical proficiency needed to use the software effectively and the metacognitive strategies necessary to leverage technology for mathematical learning. In the present study, students received systematic instruction in using the CAI tools and ongoing support during the intervention period, which likely contributed to their ability to maximize the learning opportunities afforded by the technology. This training component improved students' accuracy in solving mathematics problems by familiarizing them with efficient solution strategies, reducing errors associated with manual computation, and building confidence in their problem-solving abilities (Rizki & Widyastuti, 2019).

Several specific features of CAI likely account for the observed performance improvements. The interactive and visually engaging nature of the software transformed abstract integer operations into concrete, manipulable representations that students could see and explore. For example, number lines with moveable markers allowed students to visualize addition and subtraction of negative numbers as directional movements, while colored chips or tiles representing positive and negative quantities enabled them to model operations such as adding a negative number or subtracting a negative number through concrete actions of combining and removing objects. These visual representations address the documented challenge that students struggle with integers because TIM presents them through abstract symbols disconnected from everyday experience (WAEC, 2021). By grounding integer operations in visual-spatial representations, CAI bridges the gap between abstract mathematical notation and students' intuitive understanding.

Furthermore, CAI's capacity for providing immediate, corrective feedback likely enhanced both conceptual understanding and retention of mathematical concepts. When students made errors, the software immediately identified the mistake and often provided hints or explanations to guide them toward the correct solution, creating a responsive learning environment that prevented the reinforcement of misconceptions. This stands in sharp contrast to TIM, where students may practice incorrect procedures for extended periods before receiving feedback through homework review the following day, by which time the errors have become entrenched. The immediacy of CAI feedback supports the development of accurate mental models and procedural fluency simultaneously.

The individualized pacing afforded by CAI also contributed to the observed improvements. Unlike TIM's one-size-fits-all approach that assumes all students learn at the same rate, CAI allowed each student to progress through the material at a pace appropriate to their individual needs. Struggling students could spend additional time on foundational concepts, review material as needed, and access multiple worked examples, while more advanced students could move quickly through familiar content and engage with extension activities. This differentiation addresses the well-documented limitation of TIM, which assumes homogeneity among learners and fails to accommodate individual differences in prior knowledge and processing speeds (Adarkwah et al., 2024).

4.2 The differential Effect of CAI on Gender

The analysis of gender-based performance differences yielded findings that contribute important nuance to ongoing debates about technology's role in either perpetuating or ameliorating educational inequities. The pre-test results presented in Table 5 revealed no statistically significant difference between male and female students' baseline performance in integer operations, establishing essential comparability between gender groups prior to the CAI intervention. This equivalence at baseline is methodologically crucial, as it ensures that any post-intervention differences, or lack thereof, can be confidently attributed to the instructional method rather than to pre-existing performance disparities. The comparability of male and female students at the outset provides a clean foundation for evaluating whether CAI produces differential effects based on gender.

The post-intervention analysis presented in Table 6 demonstrates that both male and female students benefited equally from CAI, with no statistically significant gender-based differences in learning gains or final achievement levels. This finding of gender equity in CAI outcomes aligns with a substantial body of research suggesting that technology-mediated instruction can provide a level playing field for diverse learners. Agwagah et al. (2019) similarly found no significant effect of gender on students' achievement when using CAI, indicating that male and female students responded comparably to the computer-based instructional approach. Olanrewaju et al. (2016) extended this finding by arguing that computer programs lack inherent gender attributes that would systematically advantage one gender over another, and empirically demonstrated no significant differential impact on male and female students' mathematics achievement. These researchers contend that the neutral nature of technology, its lack of gendered expectations, stereotypes, or differential treatment patterns that can characterize human instruction, creates conditions where students' gender becomes irrelevant to their learning outcomes.

The absence of significant gender differences observed in this study carries profound educational implications. It suggests that CAI provides an equitable learning platform that enables both male and female students to develop their mathematical skills without the gender-based barriers or biases that can emerge in traditional classroom contexts. In conventional mathematics instruction, research has documented various mechanisms through which gender disparities can develop: differential teacher expectations and attention patterns, gendered beliefs about mathematical ability, peer dynamics that position mathematics as a masculine domain, and classroom interaction patterns that afford boys more opportunities to respond and engage (Cai et al., 2017). The computer-mediated learning environment of CAI potentially disrupts these patterns by providing each student with individualized instruction that responds solely to their demonstrated understanding rather than to gender-based assumptions. The software treats all students identically, offering the same problems, feedback, hints, and learning pathways regardless of gender, thereby eliminating potential sources of differential treatment. Moreover, the privacy afforded by working individually with computer software may reduce social pressures or anxieties that some students, particularly girls in mathematics contexts, experience when solving problems publicly in front of peers and teachers.

However, the literature on gender and CAI presents a more complex picture than universal equity, with some studies documenting gender-based performance differences that warrant careful consideration. Mchiri (2018) found that male students outperformed their female counterparts when using CAI, a finding that suggests technology does not automatically eliminate gender gaps and may, under certain conditions, reproduce or even exacerbate existing disparities. This male advantage might reflect differential prior experience with technology, varying levels of computer self-efficacy, or gender differences in comfort with technology-mediated learning environments. Cai et al. (2017) corroborate this pattern, finding that male students demonstrate greater confidence and engagement when utilizing technology for mathematics learning, potentially translating this affective advantage into superior performance outcomes. These findings raise important concerns about whether CAI implementations adequately support female students' technological and mathematical development.

Intriguingly, other research documents the opposite pattern, with female students demonstrating superior performance with CAI tools. Ibrahim et al. (2025) discovered that female students outperformed male students in their CAI-based mathematics intervention, while Asamoah (2023) specifically rejected the notion that males are inherently better than females at using technological tools like Microsoft Math Solver, instead finding that female respondents demonstrated superior mastery of the software in learning quadratic equations. These findings challenge simplistic assumptions about gender and technology, suggesting that female students are fully capable of, and may excel at, leveraging technological tools for mathematical learning when provided with appropriate support and opportunities.

The apparent contradictions in the literature, some studies finding male advantages, others finding female advantages, and still others (including the present study) finding no gender differences, suggest that the relationship between CAI, gender, and mathematics achievement is contextually dependent rather than universal. Asanre et al. (2025) argue that the impact of CAI on gender performance varies substantially depending on the specific subject matter being taught, the particular technological tools employed, the implementation context including teacher support and classroom culture, and the broader sociocultural environment in which learning occurs. Different CAI applications may present varying levels of challenge, require different types of prior technological knowledge, align more or less well with different learning preferences, or embed different assumptions about learners that interact with gender in complex ways. Similarly, the specific mathematical content being taught may interact with gender in ways that either amplify or minimize technology's role. Integer operations, the focus of the present study, may represent a domain where the visual-spatial representations afforded by CAI are equally accessible and beneficial to both genders, whereas other mathematical topics might show different patterns.

Despite these variations across studies and contexts, a consistent thread emerges from the research literature: the overall effectiveness of CAI as an instructional method is more pedagogically significant than any gender differences in response to the technology. Doku and Adherr (2019) emphasize this crucial point, arguing that the primary finding of interest is CAI's general capacity to improve learning outcomes rather than whether it benefits one gender marginally more than another. In the present study, both male and female students demonstrated substantial and statistically significant learning gains through CAI compared to traditional instruction, indicating that the technology effectively serves all students regardless of gender. This represents a fundamentally different, and more educationally meaningful, finding than if CAI had produced learning gains for one gender while leaving the other unchanged or worse off.

The mechanisms through which CAI promotes equitable learning experiences warrant explicit attention. The smooth engagement, active participation, collaborative opportunities, and peer-learning structures that CAI environments nurture benefit students regardless of their gender. Computer-based learning can facilitate collaborative problem-solving where students work together to navigate software, interpret representations, and construct solutions, creating opportunities for peer learning that transcend gender boundaries. The engaging, interactive nature of CAI motivates both male and female students to persist with challenging problems, while the immediate feedback helps all learners identify and correct misconceptions promptly. The individualized pacing ensures that neither gender is disadvantaged by instructional timing that moves too quickly or too slowly for their learning needs. The multiple representation systems, numerical, graphical, symbolic, and sometimes physical simulations, provide diverse entry points to understanding that accommodate different learning preferences that may or may not align with gender.

From a practical standpoint, these findings support the integration of CAI into mathematics instruction as a strategy that serves educational equity goals. Rather than exacerbating gender gaps in mathematics achievement, a persistent concern in STEM education, CAI appears, when properly implemented, to provide equivalent learning benefits for male and female students. This suggests that educational investments in technology infrastructure, CAI software, and teacher professional development for technology integration are likely to advance gender equity alongside overall achievement improvements. However, educators and policymakers should remain attentive to implementation factors that may influence whether CAI realizes its equity potential. Ensuring that both male and female students receive adequate training and support in using CAI tools, creating classroom cultures that position technology as accessible to all learners rather than as a masculine domain, monitoring for gender differences in technology engagement or self-efficacy, and selecting CAI applications that employ inclusive design principles are all important considerations for maximizing equitable outcomes. The finding of gender equity in the present study should not lead to complacency but rather to continued vigilance in ensuring that technology serves as a tool for inclusion rather than a vehicle for reproducing existing disparities.

4.3 Students' Perceptions of CAI in Integer Operations

The examination of students' perceptions revealed overwhelmingly positive attitudes toward Computer-Assisted Instruction, providing important affective dimensions to complement the cognitive achievement findings. The Likert scale items in Table 7 demonstrate that students found CAI beneficial, engaging, and effective for learning integer operations. These consistently high mean scores are pedagogically significant because student perceptions substantially influence their engagement, persistence, and ultimate learning outcomes. When students view an instructional approach favorably, they invest greater cognitive effort, maintain attention during lessons, and approach challenging problems with confidence rather than anxiety.

The questionnaire item addressing whether CAI made it easier to remember integer operation rules recorded the highest mean score of 4.14, indicating strong agreement. This finding is particularly noteworthy given that retention of mathematical rules represents a persistent challenge in mathematics education. The interactive and visual aspects of CAI likely account for this perceived enhancement in retention. Rather than presenting rules as abstract verbal statements, as occurs in traditional instruction, CAI embedded these rules within dynamic visual representations that students could manipulate and explore. For example, when learning that "subtracting a negative number is equivalent to adding a positive number," students could visually observe this relationship through number lines, colored chips representing positive and negative quantities, or animated demonstrations. These concrete, visual representations provided mental anchors that made rules more memorable by connecting them to spatial-visual memory systems rather than relying solely on verbal-symbolic memory.

Moreover, the interactive nature of CAI transformed students from passive recipients into active investigators who discovered patterns through guided exploration. This active engagement enhanced retention by creating stronger memory traces associated with personal discovery experiences. The immediate feedback allowed students to practice rules repeatedly with instant error correction, preventing consolidation of incorrect procedures and reinforcing correct understandings through successful problem-solving experiences.

These positive perceptions align with broader research literature. Asare (2022) similarly found that students demonstrated positive attitudes toward CAI, expressing appreciation for its engaging qualities and perceiving it as more effective than traditional instruction. Pilli (2013) documented that students hold favorable attitudes toward computer use in education generally, suggesting that technology-mediated learning resonates with students' preferences. The success of CAI can be traced to its capacity to present mathematical concepts in visually engaging and interactive ways that contrast sharply with traditional instruction's abstract presentations. Doku and Adherr (2019) emphasize that this visual engagement and interactivity lead directly to both higher retention and increased motivation, creating a virtuous cycle where enhanced understanding breeds greater confidence and interest.

Beyond general motivation, students' positive perceptions suggest that CAI specifically enhanced their critical thinking and problem-solving skills. The software presented problems in varied formats, word problems, visual diagrams, real-world scenarios, requiring students to translate between representations and apply integer concepts flexibly rather than simply executing memorized procedures. The immediate feedback helped students develop metacognitive awareness by prompting them to reflect on why particular strategies succeeded or failed, fostering the self-monitoring characteristic of skilled problem solvers. The convergence of positive student perceptions with demonstrated achievement gains provides particularly compelling evidence for CAI's effectiveness. Students not only learned better with CAI but also enjoyed the learning experience and perceived it as beneficial. This dual success addressing both cognitive and affective dimensions positions CAI as a holistic instructional approach that develops mathematical competence while simultaneously fostering positive attitudes toward mathematics—a significant pedagogical advancement given the well-documented problem of mathematics anxiety that can persist into adulthood and influence career choices.

5. Conclusion

This study provides compelling empirical evidence that CAI represents a pedagogically superior alternative to Traditional Instructional Methods for teaching integer operations. The findings demonstrate that CAI significantly improves students' cognitive achievement in integer operations, produces equitable learning outcomes across gender groups, and generates overwhelmingly positive student perceptions. The engaging and interactive nature of CAI, characterized by dynamic visual representations, immediate feedback, individualized pacing, and active learner engagement—ensures that students not only understand integer concepts more deeply during instruction but also retain mathematical knowledge longer and apply it more flexibly across contexts. This enhanced retention and transferability positions CAI as a more effective tool for fostering lifelong learning, as students develop robust mental models and positive attitudes toward mathematics that persist beyond the immediate instructional period.

This research makes several significant contributions to educational theory and practice. Theoretically, the study extends understanding of how technology-mediated instruction supports learning of abstract mathematical concepts by demonstrating that visual-spatial representations and interactive manipulation can bridge the gap between concrete experience and formal mathematical reasoning, supporting constructivist learning theories. The findings also contribute to gender equity research by providing evidence that appropriately implemented CAI creates equitable learning environments where both male and female students benefit equally, challenging assumptions about gender-based technology disparities. Empirically, this research addresses a critical gap in the literature by focusing specifically on integer operations, a foundational yet persistently challenging mathematical domain, rather than examining CAI's effects broadly. The convergence of achievement gains, gender equity, and positive student perceptions offers comprehensive evidence of CAI's multidimensional impact. Practically, the study demonstrates that CAI can be successfully implemented in real classroom contexts with measurable benefits, providing a replicable model for schools seeking to enhance mathematics instruction.

Based on these findings and contributions, several recommendations emerge. First, teachers should receive adequate training through continuous professional development workshops and seminars focused on effective CAI implementation, addressing both technical proficiency and pedagogical integration strategies. Second, school authorities should invest strategically in technological infrastructure including sufficient computers, appropriate mathematical software, reliable internet connectivity, and technical support to enable effective CAI-based instruction. Third, policy makers and educational leaders should create inclusive learning environments that encourage all students, regardless of gender or background, to engage confidently with technology-enhanced mathematics instruction through supportive classroom cultures and equitable technology access. Finally, policy makers should incorporate CAI into national and regional teaching strategies and curricula as a core instructional approach, including clear learning standards, recommended applications for different topics, and resource allocation mechanisms. By implementing these recommendations, educational systems can leverage CAI's demonstrated benefits to improve mathematics learning outcomes, reduce achievement gaps, and prepare students with essential quantitative reasoning and technological competencies for success in increasingly digital societies.

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