Analyzing the impact of digital classrooms on mathematics calculation skills and learners' motivation

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ABSTRACT

This paper presents the findings of a comprehensive experimental study examining the impact of computer-assisted instruction (CAI) compared to traditional teaching methods on learner performance and motivation in mathematics education. The study, conducted with 80 first-year college learners from a primary school in Morocco, aimed to assess the effectiveness of CAI in enhancing learning outcomes and promoting learner engagement. Through pre- and post-intervention tests, the study evaluated mathematical calculation abilities, while questionnaires were utilized to measure changes in learner motivation. The results revealed significant improvements in both mathematical performance and motivation within the experimental group following the CAI intervention. In contrast, minimal changes were observed in the control group receiving traditional instruction. These findings underscore the potential of CAI to not only improve academic achievement but also foster greater motivation among learners in mathematics education. The study contributes valuable insights to the ongoing discourse on technology integration in education, emphasizing the importance of innovative instructional methodologies in optimizing learner learning experiences and outcomes.

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1. INTRODUCTION

The integration of technology in education offers a multitude of opportunities to enhance teaching and learning. Nowadays, educators can utilize digital resources to comprehensively assess learners' interests while offering personalized pedagogical guidance [1]. Additionally, the availability of interactive and engaging content transforms the learning process into an exciting journey. Advancements in computer technology have revolutionized the educational landscape, with information and communication technologies (ICT) being widely adopted in schools globally [2]. Teachers now incorporate computers and related technologies into their teaching practices, revolutionizing educational approaches.

In the field of mathematics, computer applications have transformed the teaching and learning of concepts [3]. Instead of relying solely on abstract examples and theoretical explanations, learners can now interactively explore mathematical concepts through specialized software. This interactive approach makes complex subjects more accessible and engaging, leading to deeper understanding and improved knowledge retention. Computer-assisted instruction (CAI) provides new learning opportunities, fostering creativity and problem-solving skills through immersive, and interactive environments. Studies have shown that learners exposed to computer-enhanced geometry activities demonstrate a stronger understanding of geometric concepts compared to those using traditional teaching methods [4]. The study of mathematics holds fundamental importance in education and individual development, stimulating critical thinking, creativity, and problem-solving abilities across diverse contexts. Mathematics provides a structured framework for analyzing and understanding the world around us [5]. Often regarded as the foundation of many disciplines, from physics to biology to computer science, the study of mathematics promotes the development of analytical skills and logical reasoning essential in numerous professional fields.

Furthermore, mathematics serves as a universal language transcending cultural and linguistic boundaries. By understanding mathematical concepts, individuals can effectively communicate and collaborate in an increasingly interconnected world [6]. Teachers play a crucial role in imparting mathematics to learners, aiding them in developing a deep understanding of mathematical concepts and encouraging them to explore complex ideas. By sparking learners' interest in mathematics and demonstrating its relevance in daily life, teachers can inspire a lasting passion for the discipline.

In summary, the study of mathematics offers much more than computational skills; it develops essential transferable skills such as critical thinking, problem-solving, and communication, while providing a common language to understand the world around us. In recent years, improving learner experiences and addressing their needs and expectations have been major concerns in the educational field. Extensive research has been conducted to explore ways to enhance the learning environment, with blended learning (BL) emerging as a potentially transformative method to complement traditional teaching methods and enhance learner learning quality [7].

Although increasingly popular, there is no universal definition of BL in the literature. Some define BL as an educational program utilizing various delivery modes to increase learner success and reduce costs. Others see it as a flexible approach combining technology and classroom teaching, leveraging the benefits of online learning while retaining other methods to ensure a comprehensive and cost-effective learning experience. Some describe BL as a thoughtful integration of face-to-face and online learning, involving a redesign of courses to encourage learner engagement and a reorganization of traditional class hours. In summary, BL is viewed as a combination of face-to-face and online delivery methods aimed at improving learner learning while streamlining costs.

Flipped classroom represents an emerging pedagogical model where traditional lesson delivery occurs outside the classroom through technology and is given as homework, while in-class time focuses on inquiry-driven collaborative learning. Recent research highlights the effectiveness of integrating digital technologies in outdoor mathematics learning, allowing for a deeper exploration of real-world mathematical concepts while engaging learners through attractive digital content. Meanwhile, addressing individual learning styles remains a challenge, but this method offers flexibility to adapt to various learning preferences.

2. LITERATURE REVIEW

2.1. General overview of mathematics education and its evolution towards technology integration

Mathematics education has long been a cornerstone of formal education systems worldwide, essential for developing critical thinking, problem-solving skills, and logical reasoning. Rooted in ancient civilizations and evolving through centuries, it has adapted to societal changes, technological advancements, and pedagogical innovations [8]. Traditionally, mathematics education involved classroom instruction with lectures and practice problems, which, while foundational, often struggled to engage learners and address diverse learning styles. In recent decades, however, integrating technology into mathematics education has significantly shifted instructional methodologies. The rapid advancement of digital technologies, such as computers, software applications, interactive multimedia resources, and online learning platforms, has transformed teaching and learning experiences [9]. Technology has introduced interactive simulations, virtual manipulatives, graphing calculators, educational software, and online resources, enhancing the exploration of mathematical concepts and the visualization of abstract ideas. These tools have facilitated personalized learning, allowing educators to adapt instruction to individual needs, provide immediate feedback, and track progress. Online assessments, adaptive learning algorithms, and data analytics help educators gain insights into learner performance and tailor instructional strategies [10].

Technology has expanded access to mathematics education by breaking down geographical barriers and reaching underserved populations through online courses, virtual classrooms, and digital learning platforms, promoting lifelong learning and professional development [11]. This shift is reflected in the increased emphasis on STEM education, integrating mathematics with other scientific disciplines to prepare a technologically proficient workforce. However, challenges include ensuring equitable access to technology, providing adequate training for educators, and maintaining educational content quality. Balancing technology use with traditional methods is crucial to preserving the core principles of mathematical thinking and problem-solving [12].

2.2. Importance of technology integration in education and the potential benefits of digital classrooms

Mathematics education holds a central position in formal education systems globally, serving as a cornerstone in cultivating critical thinking, problem-solving skills, and logical reasoning. Historically, it relied predominantly on traditional classroom methodologies characterized by teacher-centered instruction, rote learning, and textbook-based approaches. However, as noted by Bahari *et al.* [13], the integration of technology, particularly in mathematics education, marks a profound evolution in instructional practices and learning environments. This shift has been driven by the rapid advancement of digital technologies, including computers, software applications, interactive multimedia resources, and online learning platforms. These innovations have revolutionized mathematics teaching and learning, offering numerous opportunities to enhance educational experiences. Interactive simulations, virtual manipulatives, graphing calculators, educational software, and online resources have become invaluable tools for exploring mathematical concepts, visualizing abstract ideas, and promoting active engagement among learners. As emphasized by Castro-Alonso and Sweller [14], technology has facilitated personalized learning experiences, enabling educators to adapt instruction effectively to individual learner needs.

Online assessments, adaptive learning algorithms, and data analytics provide educators with insights into learner performance, enabling them to identify areas for improvement and tailor instructional strategies. This adaptability maximizes learning outcomes and fosters success in diverse educational settings. Furthermore, technology has democratized access to mathematics education, overcoming geographical and logistical barriers and reaching marginalized populations. Online courses, virtual classrooms, and digital learning platforms have expanded educational opportunities, fostering lifelong learning and academic enrichment beyond traditional classrooms. Almasifar and Heidari [15] emphasize that this accessibility is crucial for promoting equitable education and ensuring that all learners have access to high-quality resources. Integrating technology has also transformed the nature of mathematical knowledge, emphasizing computational thinking, data science, digital modeling, and algorithmic problem-solving, thus preparing learners for the modern workforce and equipping them with essential skills for success in an increasingly digitized world.

The review of studies on technology in the classroom, especially digital classrooms, has garnered significant attention from researchers and educators, offering insights into the effectiveness, challenges, and implications of using technology to enhance teaching and learning experiences [16]. Empirical studies have explored the impact of digital classrooms on various aspects of education, including learner engagement, academic achievement, teacher pedagogy, and institutional practices, using diverse research methodologies [17]. A common theme is the positive influence of digital classrooms on learner engagement and motivation. Interactive multimedia resources, virtual simulations, and online learning platforms capture learners' interest and encourage active participation [18]. Additionally, digital classrooms have the potential to enhance academic performance across subjects. Interactive software, adaptive learning systems, and virtual labs offer personalized instruction and immediate feedback, leading to improved learning outcomes, particularly in mathematics [19].

However, challenges such as access to technology, digital equity, teacher professional development, and technological infrastructure pose significant obstacles. Issues like digital distractions, information overload, and cyberbullying require careful planning and thoughtful integration of technology into pedagogy [20]. In conclusion, while digital classrooms have transformative potential, continuous efforts are needed to address challenges, promote digital equity, and maximize educational benefits. Future research should explore innovative strategies to optimize technology integration in classrooms, advancing education and fostering learner success in the digital age [21].

2.3. Theoretical framework for the effectiveness of digital classrooms

Traditional instruction (TI) involves conventional, teacher-centered methods using standard tools like rulers, pencils, and paper for delivering mathematical content. Teachers typically explain concepts with abstract examples and verbal explanations, demanding high cognitive skills from learners, which often results in pressure, loss of confidence, and reduced learning capacity [22]. Primary education predominantly relies on traditional methods, emphasizing lectures and questioning, leading to rote memorization rather than true comprehension. Despite some innovative approaches, such as technology integration, traditional techniques remain prevalent. In the past two decades, developed countries have shifted focus from whether to integrate computers into education to how to use them effectively to enhance learning outcomes [23].

Based on various studies, it has been hypothesized that educational software in mathematics classes could improve learning outcomes. To assess the impact of CAI on learner achievement, attitudes towards mathematics, and attitudes towards computer-assisted learning, researchers have examined the effectiveness of integrating computers into math education. CAI is becoming widely accepted as a useful educational technology [24]. Compared to traditional methods like lecturing and discussion, CAI offers the advantage of tailoring materials to individual learners' needs, making the context more relevant [25]. The integration of technology in math education also promotes learner autonomy, allowing students to explore concepts at their own pace and according to their learning styles. Digital tools such as instructional videos, interactive tutorials, and practice exercises with instant feedback enable learners to revisit complex topics, seek help as needed, and progress confidently, fostering a more personalized and self-directed learning experience [26].

Furthermore, technology has significantly enhanced collaborative learning in mathematics education. Digital platforms and tools enable group work, allowing students to collaborate on projects, share ideas, and solve problems collectively, regardless of physical location. Tools such as online discussion forums, collaborative document editors, and virtual whiteboards foster communication and teamwork, essential skills in today's interconnected world. Studies indicate that students engaging in collaborative learning with technology show improved problem-solving abilities and a deeper understanding of mathematical concepts [27]. Additionally, integrating technology in mathematics education supports differentiated instruction. Digital tools enable teachers to create diverse learning activities tailored to students' varying needs and abilities. Adaptive learning technologies adjust task difficulty based on performance, providing personalized support and challenges, addressing individual learning gaps, and promoting an inclusive environment where all students can succeed [28].

Additionally, data analytics in education provides significant benefits. Educators can use data from digital learning platforms to gain insights into student performance, identify learning trends, and make informed decisions about instructional strategies. Learning management systems (LMS) can track student progress, highlight struggling areas, and suggest targeted interventions. This data-driven approach enhances student outcomes and continuously improves teaching practices [29]. Lastly, technology integration in mathematics education impacts teacher professional development. Effective use of digital tools requires teachers to be proficient in both subject matter and technology. Ongoing professional development programs are crucial for equipping educators with the skills and knowledge needed to integrate technology effectively. These programs should emphasize both technical training and pedagogical strategies to enhance learning, ensuring educators are prepared to leverage technology and improve the quality of mathematics education [30].

3. METHOD

This study adopts an experimental methodology designed to assess the impact of CAI on learners' performance and motivation in mathematical calculations. The experimental protocol involves the random assignment of participants into two groups: an experimental group receiving additional sessions with digital tools and a control group following traditional teaching methods. To ensure scientific rigor, both pre- and post-intervention tests were administered to measure the mathematical skills and motivation of the learners before and after the intervention. Data collection relied on quantitative assessments of performance and motivation questionnaires using a Likert scale. The statistical analysis will compare the progress of both groups, thus allowing for an evaluation of the effectiveness of CAI in comparison to conventional pedagogical methods. This methodological approach ensures that the results obtained are valid, reliable, and generalizable to the broader context of mathematics education at the middle school level.

3.1. Research questions

This study seeks to investigate the impact of CAI on learners' performance and motivation in the context of mathematical calculations. CAI, with its interactive and engaging features, has been suggested to enhance student learning outcomes when compared to traditional teaching methods. Understanding how this modern instructional approach affects learners' mathematical proficiency and their enthusiasm for learning is critical for educators and policymakers aiming to integrate technology in education. To address this, the following research questions are posed:

- How does CAI impact learner performance in mathematical calculations compared to traditional teaching methods?
- What effect does CAI have on learner motivation in mathematics education, relative to traditional instruction?
- Are there significant differences in mathematical performance and motivation between learners exposed to CAI and those receiving traditional instruction?

3.2. Hypotheses

In alignment with the research questions, the study formulates several hypotheses based on the theoretical premise that CAI offers a more engaging and effective learning environment. Given that CAI can

offer personalized learning experiences, instant feedback, and interactive content, it is anticipated that learners in the experimental group will demonstrate better performance in mathematical calculations and higher motivation levels than those receiving traditional instruction. The hypotheses are as follows:
– The use of CAI will lead to higher scores in mathematical calculations compared to traditional teaching methods.
– Learners exposed to CAI will exhibit greater motivation in mathematics education compared to those receiving traditional instruction.
– There will be significant differences in both mathematical performance and motivation between the experimental group (CAI) and the control group (traditional instruction).

3.3. Experiment

The platform detailed herein is engineered to facilitate teacher-learner interaction within an educational setting, purposefully tailored for implementation within a local network infrastructure. The platform operates within a secure local network, accessible exclusively to authorized users, with the teacher's computer serving as the primary administrative interface, affording comprehensive control over course and exercise management. Each learner is provided with an individual account, necessitating authentication via a designated username and password, ensuring restricted access to pedagogical resources solely by duly authorized individuals. Instructional content is disseminated by the teacher through the platform, presented in varied formats including images, simulations, and interactive media, empowering learners to engage with course materials visually and interactively. In addition to course delivery, the platform facilitates the distribution of exercises in a step-by-step manner, where learners respond by selecting correct options or completing fields with numerical or textual inputs, contingent upon the exercise specifications. Upon completion of exercises, the teacher possesses the capability to review learner responses and identify errors through a dedicated dashboard interface. Furthermore, comprehensive statistical analyses of learner responses are provided, enabling the teacher to assess overall comprehension levels and identify areas warranting additional attention.

3.4. Participants

Eighty first-year middle school students, aged 12 to 13, participated in this experiment, divided equally into two groups of 40. They were from a primary school in southern Morocco, all sharing the same mathematics teacher and following a standard math curriculum for their level. The participants were randomly assigned to groups without specific selection criteria. The sample size of 80 was chosen based on Cohen's [31] guidelines for achieving sufficient statistical power in experimental studies. Cohen [31] suggests that to detect a medium effect size with a power of 0.80 and a significance level of 0.05, a sample of 64 participants is recommended. Our sample of 80 exceeds this recommendation, ensuring adequate statistical power to detect significant effects [31].

3.5. Experimental design

This study employed an experimental design with two groups: a control group and an experimental group. The control group (n=40) attended mathematics sessions in a traditional classroom environment, while the experimental group (n=40) received two additional sessions per week in a computer-equipped classroom, where CAI was used. Both groups were assessed before and after the intervention using pre- and post-intervention tests to measure performance in mathematical calculations as well as motivation to attend the sessions.

3.6. Procedures

The study spanned a period of 8 weeks. At the beginning of the study, a math skills test was administered to each group to assess their initial level. Additionally, a questionnaire measuring the degree of learner motivation was distributed, utilizing a likert scale ranging from 1 to 5. Throughout the 8-week intervention period, both groups followed the planned program: the experimental group engaged in CAI sessions, while the control group participated in traditional classroom sessions. At the end of the 8-week period, another math skills test was administered to each group to evaluate progress. Furthermore, the same motivation questionnaire, based on the Likert scale, was distributed to assess changes in learner motivation.

4. RESULTS

4.1. Mathematical calculations

The means and standard deviations of learners' scores on the mathematical calculation tests are presented in Table 1. A two-way mixed design analysis of variance (ANOVA) was conducted on the pre- and post-test scores in the experimental and control groups, with a significance level of 0.05 throughout the study. Bartlett's homogeneity test was performed and indicated that the variances of the two groups were not heterogeneous (p>0.05), suggesting homogeneous variances.

Table 1. Descriptive statistics of performance measures in mathematical calculations

Group statistics			
Group	N	Mean	SD
Experimental (pre-test)	40	8.10	2.40
Control (pre-test)	40	7.00	2.60
Experimental (post-test)	40	9.60	2.80
Control (post-test)	40	7.40	3.00

The ANOVA results on learners' mathematical calculation tests revealed that the group factor was significant (F(1.78)=15.20, p<0.05), indicating potential differences in scores between the two groups. The test factor was also significant (F(1.78)=4.23, p<0.05), suggesting differences between the pre-test and post-test scores. Additionally, the interaction between groups and tests was significant (F(1.78)=4.23, p<0.05), indicating that the magnitude of differences varied across levels.

Simple main-effect analysis showed a statistically significant difference between the two groups in the post-test for mathematical calculation (F(1.156)=8.10, p<0.05), but not in the pre-test (F(1.156)=2.60, p>0.05). Thus, we conclude that at the post-test, the experimental group (M=8.10, SD=2.40) exhibited significantly better mathematical calculation abilities than the control group (M=7.00, SD=2.60). Furthermore, the comparison between pre-tests and post-tests within the experimental group revealed a significant difference (F(1.78)=14.72, p<0.05, M=8.10, SD=2.40 and M=9.60, SD=2.80 for pre-tests and post-tests, respectively), but not within the control group (F(1.78)=0.97, p>0.05, M=7.00, SD=2.60 and M=7.40, SD=3.00 for pre-tests and post-tests, respectively). This indicates that the intervention led to significant improvements only in the experimental group.

4.2. Degree of motivation

In examining the paired t-tests conducted for both the experimental and control groups, significant differences in motivation scores before and after the experience were observed. For the experimental group, the mean motivation score increased substantially from 2.35 before the experience to 3.44 afterward. This change yielded a t-value of 1.76, surpassing the significance threshold (sig. p<0.05), indicating a statistically significant increase in motivation. This suggests that the observed rise in motivation within the experimental group is unlikely to be due to random chance. These findings are further detailed in Table 2.

Conversely, the control group exhibited a more modest increase in mean motivation scores, from 2.52 before the experience to 2.69 afterward, resulting in a t-value of 0.93. Notably, the significance level (sig. p>0.05) indicates that this change is not statistically significant, implying that the observed increase in motivation within the control group could plausibly have occurred randomly. As shown in Table 2, these results underscore that while the experience had a notable positive impact on motivation within the experimental group, no such statistically significant effect was observed in the control group. This stark contrast reinforces the notion that the experience effectively enhanced motivation specifically within the experimental group compared to the control group. These findings are further detailed in Table 3.

Table 2. Paired t-test for the experimental group

Variable	Mean_before	Mean_after	t-value	Sig.
Motivation	2.35	3.44	1.76	p<0.05

Table 3. Paired t-test for the control group

Variable	Mean_before	Mean_after	t-value	Sig.
Motivation	2.52	2.69	0.93	p<0.05

4.3. Discussion

The integration of CAI in mathematics education has been widely explored in educational research, highlighting its transformative impact on learning outcomes. Our study contributes to this body of knowledge by demonstrating significant improvements in mathematical calculation abilities among learners exposed to

CAI [32]. This aligns with previous research indicating that interactive and personalized approaches facilitated by technology enhance engagement and comprehension of mathematical concepts.

Comparative analyses with prior studies underscore the effectiveness of CAI in enhancing both mathematical performance and motivation. Studies have consistently shown that learners engaged in technology-enhanced mathematics instruction exhibit higher levels of motivation and academic achievement [33]. Our findings further support this, where the experimental group, exposed to CAI, demonstrated statistically significant improvements in motivation scores compared to the control group [34].

Furthermore, the benefits of technology integration extend beyond academic outcomes to include the development of essential skills such as critical thinking and problem-solving. Our study supports previous research suggesting that digital tools and online resources not only facilitate access to mathematical content but also encourage collaborative learning and the application of theoretical knowledge to real-world scenarios [35]. This integration prepares learners for the demands of the modern workforce by emphasizing computational thinking and digital literacy skills essential in today's technological landscape [36].

However, despite the advantages of CAI, challenges persist in its implementation. Issues such as equitable access to technology, adequate training for educators, and maintaining instructional quality remain significant concerns [37]. Addressing these challenges is crucial to ensuring that all students benefit equally from technology-enhanced learning environments and that educational outcomes are not compromised by technological disparities [38].

In conclusion, our study contributes empirical evidence to the ongoing discourse on the effectiveness of CAI in mathematics education. By highlighting significant improvements in both mathematical performance and motivation among learners exposed to technology-enhanced instruction, our findings underscore the transformative potential of CAI in shaping future educational practices [39]. This research reinforces the importance of ongoing professional development for educators and strategic investments in educational technology to support effective teaching and learning in mathematics [40]. It also emphasizes the need for comprehensive policies that promote equitable access to educational technologies and ensure that all learners have the opportunity to thrive in digitally enhanced learning environments [41].

5. CONCLUSION

The evolution of teaching methodologies towards a learner-centric approach signifies a fundamental shift in the educational landscape. In this paradigm, learners are no longer passive recipients of information but active participants in their own learning journey. This shift necessitates that educators explore innovative methods of assessing learner progress and tailor their instructional strategies to meet the diverse needs of students. As educational institutions embrace this change, there is a growing emphasis on fostering innovation to accommodate the changing dynamics of learning. However, alongside this push for innovation, educators are confronted with the challenge of effectively utilizing the myriads of available tools to enhance teaching and learning outcomes.

A significant tool that has transformed the educational landscape is technology. The integration of technology in classrooms, through the use of interactive displays, tablets, and multimedia systems, has revolutionized traditional teaching practices. These technological advancements have paved the way for more engaging and interactive learning experiences, breaking down the barriers between learners and information. By leveraging technology, educators can create dynamic learning environments that cater to the diverse learning styles and preferences of learners. Moreover, the integration of technology holds particular promise in mathematics education. Interactive software, virtual manipulatives, and online resources provide learners with opportunities to explore mathematical concepts in a hands-on manner, fostering deeper understanding and conceptual mastery. In summary, the integration of technology in education represents a transformative shift towards more dynamic and inclusive learning environments, enriching the learning experiences of learners across diverse disciplines.

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