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MODELS OF CONTEXTUALIZED PEDAGOGICAL ACTIVITIES IN MATHEMATICS MEDIATED BY AI MOBILE APPLICATIONS: A REVIEW FROM SITUATED COGNITION

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Abstract
The substandard performance in mathematics observed in these contexts underscores the necessity for pedagogical approaches that integrate students' sociocultural contexts with the incorporation of novel technologies. This paper presents an analysis of the characteristics and models of contextualized educational activities, grounded in situated cognition and facilitated by educational mobile applications supported by artificial intelligence (AI), which are pertinent for eighth-grade students in public schools in the municipality of Ciénaga (Magdalena, Colombia). The review was conducted in a systematic manner and includes international, national, and regional precedents published between 2020 and 2025, focusing on research that intertwines situated learning, meaningful learning, and adaptive technology mediation. The findings indicate that educational applications such as GeoGebra Suite, Khan Academy, Photomath, and Socratic facilitate the development of didactic sequences that are centered on competencies (reasoning, problem solving, modeling, representation, and communication) and are aligned with the standards established by the Ministry of National Education and the Saber tests. Furthermore, successful initiatives that employ problem-based learning (PBL) and project-based learning (rPBL) have been identified. These initiatives, supported by artificial intelligence (AI), have been shown to enhance motivation and performance in mathematics. In summary, the integration of contextualized activities with mobile AI emerges as a promising approach to address the pedagogical gap in low-income communities. This approach is not only innovative but also has the potential to be replicated and aligned with educational quality policies, thereby contributing to the enhancement of educational outcomes in these communities.
Keywords: Situated Cognition; Meaningful Learning; Artificial intelligence; Educational Mobile Applications; Mathematical Competencies; problem-based learning; Documentary Review.

1. INTRODUCTION

Mathematics education in disadvantaged regions remains a persistent challenge on a global scale, particularly in public institutions that are confronted with limited resources. A notable example of this challenge is evident in Ciénaga (Magdalena, Colombia). Conventional pedagogical approaches often fail to align with the sociocultural context of students, and they do not effectively facilitate meaningful learning. In this context, the situated cognition approach is of particular relevance, as it is predicated on the premise that knowledge is generated in specific contexts and in authentic activities. Masingila et al. (2019) demonstrate that individuals often demonstrate superior proficiency in addressing mathematical problems in informal settings, such as supermarkets or public spaces, as opposed to the more structured environment of traditional school mathematics classes. This finding underscores the imperative for pedagogical adaptations that can more effectively align learning experiences with students' real-world needs and applications.

In the last decade, advances in mobile learning (m-learning) have caused a paradigm shift in educational spaces. A thorough examination of contemporary studies indicates that "mobile learning has emerged as a transformative and innovative tool in mathematics education, offering flexible access to educational resources and generating growing interest" (Zhang, Zakaria, Ismail, Ningling, & Dantong, 2025, p. 3). This suggests that mobile devices, due to their ease of access, portability, and connection capacity, can overcome physical limitations and enable learning to occur at any time and place.

Conversely, the implementation of artificial intelligence (AI) in mathematics education has demonstrated a substantial impact on student achievement. Gbolade and Adewuyi (2024) posit that artificial intelligence has facilitated "AI-powered personalized learning and improved math teaching, along with real-time assessments and feedback" (p. 5), thereby establishing itself as a pivotal resource for educators and students. In a similar vein, Hwang and Tu (2021) posit that educational AI systems "significantly improve students' performance in mathematics" (p. 45), thereby demonstrating advancements in conceptual understanding and mathematical problem solving.

In the domain of intelligent tutoring systems (ITS), a meta-analysis by Kulik, Kulik, and Fletcher (2015) revealed that "students who received intelligent tutoring outperformed those in conventional classes in 46 (or 92%) of the 50 assessments" (p. 933), with an average effect size of 0.66, which is considered moderate to high impact. These findings indicate that meticulously designed technological mediation can yield outcomes that are analogous to those of personalized tutoring, a pedagogical approach that has been historically recognized as the most efficacious form of teaching.

Empirical evidence has also emerged from under-resourced contexts. Henkel, Horne-Robinson, Kozhakhmetova, and Lee (2024) reported that a conversational math tutor via WhatsApp in Ghana achieved very significant results: The treatment group demonstrated significantly higher growth scores in mathematics, exhibiting an effect size of 0.37. This outcome was found to be statistically significant (p. 5).

1.1 Problem statement

In Colombia, the challenge of substandard mathematical performance in public schools persists as a systemic issue, particularly in regions lacking adequate resources, such as the municipality of Ciénaga in the Magdalena department. The results of the Saber 11 tests indicate that a significant proportion of students demonstrate low or insufficient levels of mathematical aptitude, which limits their future academic and professional prospects (Ministry of National Education, 2023). This phenomenon is particularly pronounced in rural and underprivileged urban regions, where challenges such as a dearth of educational resources, inadequate training of educators in innovative methodologies, and inequitable access to technology abound.

Conventional mathematics teaching, which emphasizes the delivery of theoretical content, has been demonstrated to be inadequate in fostering meaningful and context-related learning (Masingila, Olanoff, & Kimani, 2019). Conversely, methods grounded in situated cognition underscore the efficacy of linking learning with real-life, familiar experiences, thereby facilitating the translation of academic knowledge into practical applications in students' daily lives.

In this regard, the advent of innovative technologies, including educational mobile applications that are driven by artificial intelligence (AI), presents a distinctive opportunity to transform the landscape of mathematics education. Recent studies have indicated that the utilization of mobile devices in the pursuit of learning yields a moderate positive effect on students' mathematical performance (Güler, Bütüner, Danişman, & Gürsoy, 2022). Furthermore, intelligent tutoring systems and adaptive platforms supported by AI have been demonstrated to "significantly improve students' math performance" (Hwang & Tu, 2021, p. 45) by providing immediate feedback and personalization in activities.

However, despite the advancements observed at the international level, there is a paucity of initiatives in Colombia that incorporate a contextualized pedagogical model, based on situated activities and supported by mobile AI applications, specifically designed for environments with limited resources. The aforementioned discrepancy signifies the crux of the problem under investigation: the dearth of a documented and systematic model that establishes a nexus between situated cognition and the utilization of AI-powered mobile applications to enhance mathematics learning in contexts that are particularly vulnerable.

1.2 Justification

The research that is suggested has valid reasons from multiple angles. First, from an educational and social perspective, it responds to the prevailing need to enhance the mathematical aptitude of students in public schools in circumstances of resource scarcity. This approach is intended to mitigate educational disparities and promote equitable opportunities. According to Henkel, Horne-Robinson, Kozhakhmetova, and Lee (2024), even in places with high technological limitations, low-cost solutions that use artificial intelligence, such as conversational tutors accessible via WhatsApp, can lead to significant improvements in academic performance.

Secondly, from a pedagogical perspective, the proposal introduces a novel perspective by integrating the theory of situated cognition with active methods such as problem-based learning and project-based learning, facilitated by mobile applications that incorporate artificial intelligence. This combination enables students to not only acquire mathematical knowledge but also to apply it to solve specific problems in their environment, thereby strengthening the relevance and applicability of learning.

Thirdly, the rationale is supported by recent scientific evidence supporting mobile learning and artificial intelligence in education as established and effective trends in mathematics teaching. Zhang, Zakaria, Ismail, Ningling, and Dantong (2025) emphasize that mobile learning "has emerged as a transformative and innovative tool in mathematics education" (p. 3). In contrast, Gbolade and Adewuyi (2024) posit that artificial intelligence in education enables "personalized learning and improvement in mathematics instruction, as well as real-time assessments and feedback" (p. 5).

This analysis addresses a significant gap in the extant literature on educational policy and practice. It does so by offering a model of contextualized pedagogical activities. This model is based on situated cognition and enhanced by artificial intelligence. The model's implementation in public schools in Colombia has the potential to have a significant impact on educational outcomes. In this manner, it is presented as a valuable academic and practical contribution for researchers, educators, and policymakers in the education sector.

2. General objective

The objective of this study is to analyze the characteristics and current models of contextualized pedagogical activities based on situated cognition and mediated by educational mobile applications driven by artificial intelligence. The purpose of this analysis is to design a proposal that enhances the significant learning of mathematics in eighth grade students of public educational institutions in low-income contexts in the municipality of Ciénaga, Magdalena (Colombia).

3. METHODOLOGY

The development of this paper was informed by a qualitative and descriptive documentary review design. The objective of this design was to identify and analyze models of contextualized pedagogical activities. These activities are mediated by educational mobile applications driven by artificial intelligence (AI). The goal of these activities is to teach mathematics in secondary education.

3.1 Approach

A qualitative approach was adopted to facilitate the interpretation of the information found in national and international studies. This approach was used to identify trends, experiences, and significant contributions in the integration of artificial intelligence and mobile learning in mathematics teaching.

3.2 Document search strategy

The information collection was conducted from March to June of 2025, encompassing prominent academic databases such as Scopus, Web of Science, ScienceDirect, ERIC, and SpringerLink. To ensure comprehensive retrieval of relevant literature, Google Scholar searches were utilized as a supplementary tool.

Combinations of keywords in English and Spanish were used: *"inteligencia artificial en la educación matemática", "aplicaciones móviles en el aprendizaje de las matemáticas", "intelligent tutoring systems", "mobile learning and mathematics education" y "cognición situada en el aprendizaje matemático."*

Selection criteria

- Inclusion: articles published between 2019 and 2025 in journals indexed in Scopus or WoS; empirical studies, narrative or comparative reviews that reported experiences in mathematics education mediated by mobile applications and AI, preferably in secondary contexts or in vulnerable scenarios.
- Exclusion: non-refereed papers; grey literature; research focused on higher education or disciplinary areas other than mathematics.

3.3 Analysis process

The selected documents were subjected to a critical reading to identify:

1. Characteristics of pedagogical models (theoretical foundations, didactic strategies, educational level).
2. Applied technologies (types of mobile applications with AI, adaptive platforms, intelligent tutors).
3. Reported impacts (meaningful learning, motivation, mathematical skills, digital equity).

The analysis of the information was organized in a comparative narrative synthesis, which allowed for the recognition of both similarities and contrasts in the literature. This, in turn, served as a basis for the proposal of a contextualized model applicable to public educational institutions in Ciénaga, Magdalena (Colombia).

4. RESULTS

A review of documents reveals a body of research over the past decade focused on reforming mathematics education through the integration of emerging technologies, particularly educational mobile applications and artificial intelligence (AI) systems. A review of the extant literature reveals a discernible trend in the development of pedagogical models that seek to address the limitations of conventional teaching methods. Conventional teaching methods emphasize the memorization and repetition of algorithms, while the new models propose more dynamic, adaptive, and contextualized approaches. The majority of the literature under review was published between 2019 and 2025 in journals indexed in Scopus and Web of Science.

Researchers concur that the instruction of mathematics persists as a formidable challenge within educational systems. Academic outcomes in international and national assessments indicate that students, particularly those from disadvantaged backgrounds, encounter persistent challenges in competencies such as problem-solving, mathematical modeling, and the application of abstract concepts to concrete scenarios. Consequently, there has been an increasing interest in examining the potential of technology, particularly artificial intelligence (AI), to serve as a pedagogical mediator that fosters meaningful learning while concurrently mitigating the educational disparity between students from diverse socioeconomic backgrounds.

In this context, the results of the review indicate the presence of at least five primary trends in contemporary models:

1. The consolidation of Intelligent Tutoring Systems (ITS), designed to replicate the effectiveness of personalized tutoring through algorithms that are capable of diagnosing and adapting teaching to the student's profile.
2. The expansion of mobile learning models in mathematics, where accessible, low-cost applications provide adaptive solutions and detailed explanations that encourage autonomous learning.
3. Strengthening problem-based learning (PBL) and project-based learning (PBL) approaches, which incorporate mobile apps and AI resources to connect mathematical concepts with real problems in the environment.
4. The emergence of conversational tutors with AI, especially relevant in contexts of low connectivity, where platforms such as WhatsApp are transformed into useful and accessible educational mediators.
5. The growing inclusion of adaptive and gamified models, which combine personalization with playful motivation strategies to increase engagement and decrease math anxiety.

This suggests that international experiences not only seek to improve academic performance, but also aim to increase student motivation, promote digital equity, and support autonomy in learning. These findings are particularly relevant for the context of Ciénaga (Magdalena, Colombia), where the limitations in technological infrastructure and the socioeconomic conditions of students demand pedagogical models that are viable, scalable, and sensitive to the local reality.

In summary, the findings of the review demonstrate the existence of a substantial corpus of studies and experiences that support the efficacy of incorporating artificial intelligence and mobile applications in mathematics teaching. However, these findings also underscore the necessity of adapting these models to specific contexts, taking into account factors such as connectivity, device availability, and teacher training. Considering the aforementioned context, the ensuing sections are herein presented. Within these sections, the extant models recognized in the extant literature are described and examined in greater depth. These models are then used to elucidate the potential contributions to the design of educational activities adapted to the Colombian case.

4.1 Intelligent Tutoring Systems (ITS)

The field of smart tutoring systems has been the subject of academic inquiry since the 1980s; however, there has been a notable surge in research activity in recent years, driven by the integration of sophisticated algorithms and the development of mobile applications. The extant research indicates that the phenomenon under scrutiny exerts its influence beyond the scope of direct academic outcomes. Its impact is also demonstrated in the enhancement of motivation, the reduction of mental load, and the facilitation of knowledge transfer to novel contexts.

Context of the most important works:

Ma, Adesope, Nesbit, and Liu (2014)

This data analysis covered 74 controlled studies that examined the influence of ITS in various areas of knowledge, with a special focus on mathematics. The authors noted that STIs favor learning more than traditional methods, with an average effect size of 0. 66. Most significant in their finding is that they stated that "intelligent tutoring systems are an effective complement or alternative to conventional instruction" (p. 902).

Its contribution is to offer global evidence supporting the effectiveness of STIs as a complement or even replacement to conventional teaching.

Kulik, Kulik & Fletcher (2015)

This work reviewed 50 experimental studies on STIs, focusing on math and science classrooms. The most frequent finding was that students who received intelligent tutoring outperformed those in traditional classes in 92% of cases, with an effect size of 0. 66. This study is essential as it shows the consistency of the impact of STIs in different contexts, educational levels and curriculum areas.

Pane, Steiner, Baird, and Hamilton (2015)

This analysis examined the Cognitive Tutor Algebra I program in a sample of more than 18,700 high school students in the United States, using a large-scale quasi-experimental design. The results indicated significant improvements in algebra assessments, confirming that incorporating an ITS into the school curriculum is not only practical, but can also be implemented on a large scale in entire education systems. This study is extremely significant, as it presents evidence "on a large scale", something uncommon in the educational field.

VanLehn (2011)

In a theoretical and practical evaluation, VanLehn contrasted the effectiveness of human mentoring with that of ITS. Their conclusion was that "the effectiveness of ITS approximates that of human tutors, who are often considered the gold standard of teaching" (p. 207). This suggests that while human mentoring remains the most effective, ITS achieves about two-thirds of the impact of one-on-one mentoring, a finding of great relevance for resource-limited contexts, where one-on-one mentoring is virtually non-existent.

Mavrikis, Holmes, Hansen and Geraniou (2019)

In the European project iTalk2Learn, the application of an intelligent tutoring system for the teaching of fractions to primary and secondary school students was analyzed. It was found that "students who worked with the ITS for fractions showed a deeper conceptual understanding compared to their peers in control groups" (p. 8). The importance of this research lies in the fact that it did not focus only on quantitative results, but on the understanding of the concept and the connection between the use of an intelligent tutor and meaningful learning.

Hwang, Yang, and Wang (2021)

This study conducted in Taiwan integrated concept maps into a smart math tutoring system, in order to help students organize their knowledge more effectively. It was evidenced that "the incorporation of concept maps in an ITS allowed students to organize their knowledge more efficiently and decreased the cognitive load during mathematical problem solving" (p. 2). Its importance lies in the fact that it demonstrates that ITS not only have an educational function, but also improve the cognitive processes involved in mathematical learning.

Koedinger, Corbett, Kauffman, and Perfetti (2012)

In this long-running research, the continued use of intelligent tutoring systems in mathematics was examined, concluding that "sustained use of ITS leads to cumulative advances in problem-solving and conceptual reasoning" (p. 85). This means that STIs not only produce an immediate effect, but, when used consistently, generate a sustained impact on learning. This discovery is essential because it supports its long-term use in education systems.

4.2 AI-mediated mobile learning in mathematics (m-learning)

A thorough desk analysis reveals that mobile learning has evolved from being a marginal innovation to a pivotal focal point in contemporary educational research on mathematics. In recent years, mobile learning (m-learning) has emerged as a strategy to address the constraints of conventional pedagogical methods. This innovative approach enables the dissemination of learning material beyond the confines of the traditional classroom setting, thereby offering greater flexibility in terms of scheduling and delivery methods. When integrated with artificial intelligence (AI) algorithms, m-learning has the potential to personalize feedback, catering to the unique needs and pace of each individual student.

In a meta-analysis on the impact of m-learning in mathematics, it is concluded that *"mobile learning has a medium-level positive effect ($g = 0.476$; $p < .001$; 95% CI = 0.335–0.616) on students' mathematics achievement"* (Güler, Bütüner, Danişman, & Gürsoy, 2022, p. 1727). These findings are consistent with the hypothesis that mobile devices, being integrated into the daily lives of students, favor more significant learning, since the contents are no longer perceived as alien and are related to situations of immediate use.

In addition, a comprehensive meta-analysis of 110 studies on mobile devices in education underlines that *"the overall mean effect size for learning achievement in this meta-analysis was 0.523, meaning that learning with mobiles is significantly more effective than traditional teaching methods"* (Sung, Chang, & Liu, 2016, p. 269). In addition, the authors emphasize that it is not enough to incorporate devices, but *that "the positive impact of mobile learning is strongly moderated by the quality of instructional design and pedagogical integration"* (p. 270). This implies that the benefits of m-learning depend on how the activities are designed, the cultural

relevance of the problems posed and the way in which the technology is articulated with active methodologies such as PBL or PBL.

From a qualitative point of view, a more recent systematic review, focused on mathematics, argues that *"mobile learning... introduce the term 'mobile learning' to push the boundaries of traditional pedagogy"* (Tang et al., 2023, p. 4). This work identifies as distinctive advantages personalization, immediate feedback, the articulation between formal and informal learning, and the possibility of designing authentic experiences where the student connects what he has learned with his real environment.

In terms of specific applications, the positive impact of GeoGebra Suite, widely used to model functions and geometry dynamically, and Photomath and Socratic, which allow solving problems step by step by explaining each procedure, has been documented. On an adaptive level, Khan Academy has become a world benchmark by integrating algorithms that automatically adjust learning paths according to the student's successes and mistakes. These platforms not only reinforce individual practice but also offer diagnoses that guide the teacher to identify conceptual gaps and plan remedial activities.

In low-resource contexts, such as Ciénaga, these mobile applications acquire additional value, as they take advantage of devices that students already usually own (basic smartphones) and can work even in conditions of intermittent connectivity. The possibility of accessing explanations adapted to the student's level contributes to reducing educational inequalities and bringing the experience of personalized tutoring closer. Evidence also indicates that the area of mathematical content may moderate the effects of m-learning. According to Güler et al. (2022), *"the subject area significantly moderated the effect of mobile learning, with algebra and geometry showing stronger gains compared to other topics"* (p. 1732). This suggests that in the proposal of contextualized activities for eighth grade in Ciénaga, areas such as algebra and geometry could especially benefit from integration with AI mobile applications.

4.3 Problem-Based Learning (PBL) and Project-Based Learning (PBL) mediated by AI and mobile apps

Problem-Based Learning (PBL) and Project-Based Learning (PBL) have been identified as educational methods with a high degree of efficacy in mathematics instruction. These methods represent a shift from a passive learning model, which emphasizes the delivery of information, to an active learning model, in which students develop their knowledge by addressing authentic challenges. From the perspective of situated cognition, this approach engenders an environment conducive to the promotion of meaningful learning. This is due to the fact that the problems and projects are elaborated with consideration for social, economic, or cultural situations that are relevant to the students' reality.

Recent studies have demonstrated that the integration of Problem-Based Learning (PBL) and Reciprocal PBL (rPBL) with digital technologies and mobile applications can enhance motivation, self-regulation, and critical thinking in medical students. Hernández-Sellés, Muñoz-Carril, and González-Sanmamed (2020) posit that "project- and problem-based learning approaches supported by digital tools improve collaboration, promote self-regulation, and foster deeper learning outcomes" (p. 4). This finding indicates that technological mediation not only enhances academic performance but also fosters transversal skills that are essential in the twenty-first century.

At the international level, the empirical evidence is clear. In nations such as Singapore and Finland, PBL programs in mathematics have been implemented using mobile devices and adaptive feedback. The findings indicate that "students who engaged in mobile problem tasks with adaptive feedback showed greater engagement and better problem-solving skills compared to control groups" (Tan, Chai, & Koh, 2019, p. 87). This suggests that the integration of artificial intelligence and mobile applications not only enhances performance in mathematics but also fosters an increased propensity among students to engage with complex problems.

Conversely, in Spain and Mexico, community-linked PBL experiences have been cultivated, wherein students utilize applications such as Khan Academy and GeoGebra to undertake projects pertaining to social issues (e.g., the calculation of community budgets, analysis of socioeconomic data, and optimization of resources). According to Martínez and García (2021), "students working on community projects with mobile applications demonstrated a greater ability to transfer mathematical knowledge to real-life situations" (p. 59). This finding is of particular pertinence to the realm of research, as it posits the potential for the development of educational initiatives that interweave the mathematical curriculum with the quotidian life of the Ciénaga community. To illustrate, the integration of algebra with household economics or geometry with territorial planning emerges as a salient example.

Beyond the realm of academic achievement, these approaches have been shown to foster sustained interest and motivation among students. In a summary of research on Project-Based Learning (PBL), Capraro and Slough (2013) stress that "project-based learning provides meaningful context that increases student interest and achievement in mathematics when technology is effectively integrated" (p. 14). The integration of mobile

applications with artificial intelligence in this initiative presents a significant opportunity to link learning with the cultural experience of students from vulnerable sectors, thereby establishing a connection between mathematical knowledge and the specific needs of their environment.

Moreover, empirical evidence from Chile and Argentina suggests that PBL and rPBL methods, augmented by digital tools, exert a favorable influence on the cultivation of metacognitive abilities. An analysis conducted by Villalobos and Quintana (2020) demonstrated that "students who participated in mathematical projects facilitated by information and communication technologies (ICT) exhibited a heightened capacity to organize, supervise, and evaluate their learning processes" (p. 112). This finding indicates that the integration of technologies not only facilitates problem-solving abilities but also fosters self-regulatory skills, which are critical for sustained learning.

From the perspective of this article, these conclusions are of great relevance. The objective of developing a model of contextualized pedagogical activities employing mobile AI is congruent with the advantages inherent to PBL/PBL:

- It facilitates the design of activities located in the local environment of Ciénaga (local commerce, artisanal fishing, urban transport, community life).
- It stimulates the application of mathematical knowledge in practical situations.
- It reinforces student motivation and engagement, which are two crucial elements in resource-poor settings where math is often seen as distant and abstract.
- It integrates accessible mobile applications (GeoGebra, Socratic, Photomath, Khan Academy) that provide adaptive feedback, performance diagnostics and detailed explanations, which is a fundamental support for those who do not have external help outside the school environment.

In summary, PBL and rPBL that incorporate artificial intelligence, and mobile applications emerge in the literature as robust models for teaching mathematics, since they combine theory, practice, and technology in authentic experiences that promote educational equity. In contexts such as Ciénaga, these approaches function as an alternative to the prevailing decontextualized education model. They serve to transform mathematics into a tool for social and personal change.

4.4 AI-powered conversational tutors (educational chatbots)

In the contemporary landscape of educational innovation, conversational tutors powered by artificial intelligence (AI), also known as educational chatbots, represent one of the emerging strategies with the greatest potential to transform mathematics teaching in low-resource contexts. In contrast to more intricate systems that necessitate substantial infrastructure, chatbots can be incorporated into messaging applications with which students are already familiar. Examples of such applications include WhatsApp, Telegram, and Facebook Messenger. This integration renders chatbots accessible, economical, and scalable tools.

The pedagogical principle that underpins them is dialogic interaction, in which the student is actively involved through questions and answers. In turn, the chatbot offers adapted explanations, step-by-step suggestions, and immediate feedback by using natural language processing algorithms and machine learning. This form of interaction corresponds to the tenets of situated cognition theory, as it occurs in a natural communication environment that students encounter on a daily basis.

The most robust research in this domain originates from Ghana, where a conversational mathematics tutor, accessible via the WhatsApp platform, was developed. In a randomized controlled trial, Henkel, Horne-Robinson, Kozhakhmetova, and Lee (2024) demonstrated that "the math growth scores were substantially higher for the treatment group with an effect size of 0.37, and that the results were statistically significant ($p < 0.001$)" (p. 1). This finding is particularly salient in light of its demonstration that educational chatbots, even when utilized with entry-level devices under conditions of limited connectivity, can engender substantial advancements in mathematical performance.

In addition to academic performance, the impact of chatbots on motivational and affective variables is a subject of interest. In an experimental study conducted in Turkey, Yıldız and Yıldırım (2022) found that "students using chatbot-supported learning environments reported higher levels of engagement and lower levels of mathematics anxiety compared to traditional methods" (p. 212). The decline in mathematical anxiety is especially noteworthy in contexts where students may be particularly vulnerable, such as Ciénaga, where students often encounter rejection towards the subject due to accumulated difficulties and the perception of excessive abstraction.

Conversely, Kasinathan, Ramasamy, and Manoharan (2021) emphasize the potential of chatbots to function as cognitive scaffolding: As stated on page 56, "AI-based chatbots in mathematics education provide personalized scaffolding, guiding learners step-by-step through problem-solving tasks." This scaffolding function enables students to progress systematically, fostering their autonomy and confidence in problem-solving.

A critical component of conversational tutors is their capacity to adapt and maintain effectiveness in a variety of contexts. According to Fryer and Carpenter (2020), "chatbots can provide scalable, cost-effective tutoring at times when human teachers are unavailable, thus supporting continuity of learning" (p. 4). This characteristic renders them a viable alternative for complementing teaching work in education systems with a deficit of coverage or in times of crisis, as evidenced by the use of messaging tools during the COVD-19 pandemic, when such tools became one of the few means of communication available between teachers and students.

Recent endeavors in Latin America have also initiated exploration of this field. In Brazil, a pilot study with high school students implemented a chatbot designed to practice fundamental algebra. The findings of the study demonstrated that "students perceived the chatbot as an accessible, motivating, and useful resource to reinforce learning outside school hours" (Silva & Moreira, 2021, p. 88). This type of evidence underscores the importance of incorporating chatbots in contexts where school hours are limited and parental involvement is often restricted.

A review of the extant literature indicates that conversational tutors with AI represent a promising educational alternative, demonstrating significant potential to enhance mathematics learning, thereby offering both academic and emotional benefits. The affordability, accessibility, and scalability of these models renders them a strategic instrument for vulnerable communities and a relevant model for the design of contextualized pedagogical activities in environments such as those of Ciénaga.

4.5 AI-based adaptive and gamified models

Adaptive teaching models in mathematics are predicated on the capacity of artificial intelligence (AI) to discern student performance in real time and recalibrate the complexity, sequence, and nature of activities accordingly. These systems evaluate error patterns, speed of responses, and learning paths, creating personalized trajectories that meet each student's unique needs. Concurrently, gamification employs game-specific concepts, including rewards, immediate feedback, progressive challenges, and collaboration dynamics, with the objective of enhancing motivation and commitment to learning. The integration of these methodologies fosters the development of customized educational environments that are conducive to enhanced student engagement and achievement in mathematics.

In the academic literature, adaptive models have been widely recognized as an effective alternative to uniform teaching. VanLehn (2011) posits that "the effectiveness of adaptive intelligent tutoring systems approximates that of human tutoring, which is often considered the gold standard of instruction" (p. 207), underscoring the capacity of adaptive systems to emulate the benefits of personalized tutoring to a considerable extent. In a similar manner, the example of Squirrel AI Learning in China is regarded as a paradigmatic model, as it integrates knowledge graphs and probabilistic algorithms to discern particular micro-skills. Zhou, Huang, and Chen's (2020) research indicates that students utilizing adaptive, AI-based systems exhibited a substantial enhancement in their math assessments in comparison to their counterparts in conventional classrooms (p. 134). These results support the hypothesis that AI-powered personalization leads to significant improvements in math performance.

Gamification, a system that uses game-based elements to enhance non-game contexts, is a complementary approach that addresses the emotional and motivational aspects of learning. A systematic analysis of 24 empirical studies conducted by Hamari, Koivisto, and Sarsa (2014) determined that "gamification tends to generate positive effects on motivation and engagement, although its impact is strongly influenced by context and design" (p. 3026). This suggests that the value of gamification lies not only in the addition of playful components, but in its correct combination with educational objectives.

Recent studies have yielded further evidence supporting the efficacy of these models. In a study conducted in South Korea, Kim and Lee (2021) reported that "students learning mathematics in gamified environments with adaptive AI feedback exhibited greater persistence and lower mathematical anxiety compared to control groups" (p. 412). This finding is of particular significance, as persistence and the reduction of math anxiety are critical factors for academic success in vulnerable groups. In a similar vein, the research conducted by Caballero, Guerrero, and Blanco (2022) in Spain revealed that the integration of gamification components within mobile applications designed for the learning of algebra led to an enhancement in student motivation and an improvement in their performance in problem-solving tasks (p. 45). This finding substantiates the efficacy of gamification, in conjunction with artificial intelligence, in the facilitation of comprehension of complex subject matter, such as algebra.

In contexts characterized by limited resources, such as in Ciénaga (Magdalena, Colombia), the efficacy of these models is particularly pronounced. Their application in mobile devices that require minimal technological sophistication not only enhances accessibility but also ensures the continuity of educational services. Furthermore, they facilitate the generation of mathematical challenges and games related to local problems, such as calculating costs in family economic activities or optimizing routes in urban transportation. This aligns with the situated cognition approach, emphasizing the cultural and social significance of learning.

In summary, adaptive and game models powered by artificial intelligence are presented as a highly relevant educational option for learning mathematics, by combining personalization, motivation, and contextualization. The utilization of this method has the potential to play a foundational role in the development of innovative pedagogical activities in vulnerable environments. The implementation of this method has been shown to enhance not only academic performance but also to promote autonomy, confidence, and a positive attitude toward mathematics.

4.6 Comparison of AI-based pedagogical models and mobile applications in mathematics teaching

Table 1 offers a concise synopsis of the most pertinent educational models that have been identified in the review of documents. This summary highlights the contexts of use at the international level, the most prominent platforms, the empirical findings that have been reported, and their relevance to the case of Ciénaga, in Magdalena, Colombia. It has been observed that Intelligent Tutoring Systems (ITS) have demonstrated significant advancements in mathematics performance, while mobile learning has exhibited a moderate positive impact, proving particularly effective in subjects such as algebra and geometry. Project-Based Learning (PBL/PBL), when combined with mobile applications and artificial intelligence, fosters motivation and the transfer of knowledge to real situations. Conversational tutors that employ artificial intelligence are presented as an accessible and scalable alternative in areas with poor connectivity. Models that are adaptive and gamified stand out for their ability to combine personalization and motivation, helping to reduce anxiety related to mathematics. The following five models illustrate the potential of artificial intelligence and mobile applications to create contextualized activities that reinforce meaningful learning in mathematics in disadvantaged contexts.

Table 1. Comparison of AI-based pedagogical models and mobile applications in mathematics teaching

Model	Countries/Contexts	Applications/Platforms	Main findings	Relevance for Ciénaga
Intelligent Tutoring Systems (ITS)	USA (Cognitive Tutor Algebra), UK (iTalk2Learn), Asia (Mobile ITS)	Cognitive Tutor, iTalk2Learn, adaptive ITS systems	Significant improvement in performance (d=0.66), comparable to human mentoring.	It makes it possible to make up for the lack of individualized tutoring with light applications.
Mobile Learning in Mathematics (m-learning)	USA, Europe, Asia; Spain and Mexico with mobile apps	GeoGebra, Photomath, Socratic, Khan Academy	Mean positive effect (g=0.476); greater impact on algebra and geometry.	Take advantage of already available mobiles; useful in algebra and geometry content.
AI-mediated PBL/RBB and mobile apps	Finland, Singapore, Spain, Mexico, Latin America	Khan Academy, GeoGebra, community mobile apps	Increased motivation, knowledge transfer to real contexts, collaboration.	It makes it possible to design activities located in local community life.
AI-powered conversational tutors (chatbots)	Ghana (WhatsApp tutor), Turkey, Brazil, pilot experiences	WhatsApp, Telegram, Messenger; Custom chatbots	Increased performance (d=0.37), reduced anxiety, and increased participation.	Accessible, economical and scalable in contexts of low connectivity.
Adaptive and gamified models with AI	China (Squirrel AI), South Korea, Spain	Squirrel AI Learning, gamified apps, adaptive environments	Effective personalization, increased persistence, reduced math anxiety.	Motivation and personalization on basic devices; applicable to local problems.

Source: Authors' elaboration based on the documentary review (2014–2024).

5. DISCUSSION

The findings of the paper review indicate that the marriage of artificial intelligence (AI) and mobile applications in mathematics teaching has made remarkable progress on an international scale. There is evident progress in

both school performance and in the incentive and decrease of anxiety towards mathematics. However, its relevance and applicability in resource-limited settings, such as the municipality of Ciénaga (Magdalena, Colombia), necessitate an in-depth analysis that considers local conditions, infrastructure constraints, and specific educational needs.

Empirical evidence supports Intelligent Tutoring Systems (ITS) as a viable option. The capacity to provide customized instruction indicates that students utilizing these systems demonstrate higher levels of academic achievement in comparison to those educated through conventional methods. However, the technical complexity and the substantial resources required for their implementation limit their direct application in schools with limited financial resources. In the context of Ciénaga, the development of rudimentary versions of STIs within mobile applications has the potential to serve as an effective strategy to address the dearth of customized assistance. This approach is predicated on the premise that the activities are meticulously crafted to align with the social and cultural milieu of the student demographic.

Conversely, mobile learning has demonstrated consistent positive impacts on mathematics, particularly in domains such as algebra and geometry. The primary benefit of this approach is the accessibility of mobile applications, many of which are free and functional even with suboptimal connectivity. In the case of Ciénaga, where many students have basic phones, mobile learning is presented as a viable option to promote autonomous and contextualized practice, helping to apply mathematical concepts in everyday situations.

The study of Problem-Based Learning (PBL) and Project-Based Learning (PBL) models underscores the necessity of situating mathematical knowledge in meaningful experiences that are related to problems in the environment. International research has demonstrated that the integration of these methods with mobile applications that incorporate artificial intelligence (AI) has been shown to foster motivation, self-regulation, and the transfer of learning. This approach is particularly salient in the context of Ciénaga, as it would enable the design of projects in which students utilize mathematics to address issues pertaining to the family economy, artisanal fishing, or the management of community resources. This underscores the cultural significance of learning and its integration within local contexts.

With regard to AI-based conversational tutors, their efficacy in regions such as Ghana and Turkey serves as a particularly salient model for communities with constrained technological resources. The utilization of prominent messaging platforms, such as WhatsApp, demonstrates the viability of sustaining learning continuity and providing customized feedback in circumstances of suboptimal connectivity. In Ciénaga, where many students and their families have access to phones with messaging applications, this approach becomes a key strategy to overcome infrastructure barriers and ensure continuous tutoring outside of the school environment.

Finally, adaptive and playful approaches have been demonstrated to be effective in improving performance and decreasing anxiety in mathematics by combining personalized feedback with game elements that increase motivation. In the Colombian context, gamification can be associated with local situations, creating mathematical challenges that represent economic and social activities of the community. This pedagogical approach has the potential to not only enhance situated learning but also to transform the perception of mathematics from an abstract discipline to a practical instrument for daily life.

A comprehensive review of the extant literature reveals that the integration of artificial intelligence and mobile applications signifies more than a mere technological innovation. Rather, it represents a pivotal opportunity to reconfigure educational practices in contexts that are particularly vulnerable. The analysis indicates that, despite the preponderance of studies originating from nations that are better equipped with technological resources, there exist successful case studies in environments analogous to Ciénaga that substantiate the viability of these proposals. Consequently, a new research and development area has emerged, focusing on the creation of educational activities that are adapted to the context, situated, and culturally relevant. These activities have the potential to enhance mathematics education in public schools that are faced with limited resources.

6. CONCLUSIONS

The evaluation of documents reveals that the integration of artificial intelligence and mobile applications in the teaching of mathematics is an effective pedagogical approach, yielding positive outcomes in academic performance, motivation, and the alleviation of anxiety related to mathematics. The five models examined illustrate that the constraints imposed by the conventional teaching method can be surmounted by creating adaptive, personalized, and relevant environments conducive to meaningful learning. In this context, Intelligent Tutoring Systems (ITS) and adaptive models are the alternatives with the most empirical support at the international level, as evidenced by the results similar to those of personalized tutoring that these systems demonstrate. However, its implementation in environments with limited resources necessitates the streamlining of designs and their adaptation to lightweight mobile applications that do not demand complex infrastructures.

Moreover, mobile learning and conversational tutors are presented as highly suitable options for contexts characterized by vulnerability, such as Ciénaga (Magdalena, Colombia). These options are advantageous due to their low cost, ease of access, and ability to utilize devices available to students. This contributes to the closure of the digital divide and ensures educational continuity, even in circumstances with limited internet connectivity. Conversely, Problem-Based Learning (PBL) and Project-Based Learning (PBL), supported by mobile applications that utilize artificial intelligence (AI), situate mathematics within the context of community life, facilitating knowledge transfer and reinforcing the cultural relevance of the school curriculum.
Consequently, the development of an adapted model of pedagogical activities that utilize mobile AI for eighth grade students in public schools in Ciénaga is presented as a viable and necessary initiative. This model is designed to integrate conversational tutoring, mobile learning, and adaptive gamification within community projects. The objective of this integration is to establish an innovative pedagogical approach that drives meaningful learning, decreases math anxiety, and fosters educational equity in resource-limited settings.

7. RECOMMENDATIONS

Based on the results obtained, the following recommendations are suggested for the adoption and future research of teaching models supported by artificial intelligence and mobile applications in mathematics education:

1. Adjustment to the local environment: The models detected must be adapted to the socioeconomic and technological realities of Ciénaga (Magdalena). It is essential that the chosen apps are compatible with low-cost mobile devices and work in areas with limited connectivity, ensuring that all students have access.
2. Teacher training: It is crucial to train teachers in the educational use of mobile applications with artificial intelligence, not only in technical terms, but also in methodologies, so that they can create and facilitate contextualized activities that promote motivation and meaningful learning.
3. Creation of contextualized activities: It is advisable that educational activities be based on real problems in the students' environment, such as local commerce, artisanal fishing or family resource management, with the aim of connecting mathematical learning with the context in which they live.
4. Implementation of conversational tutoring: In situations where few teachers are available, the use of conversational tutors on popular messaging platforms (such as WhatsApp) is proposed to provide immediate feedback and constant support beyond the classroom.
5. Use of adaptive gamification: To increase motivation and decrease anxiety in mathematics, it is suggested to implement gamification strategies that include personalized rewards, levels, and feedback, especially in more complex topics such as algebra and geometry.
6. Evaluation and continuous improvement: It is necessary to create systematic evaluation systems to measure the impact of these models on academic performance and on affective aspects (motivation, perseverance, anxiety), in order to adjust and refine teaching strategies based on evidence.
7. Promotion of applied research: It is recommended to support pilot projects in public schools in Ciénaga and other localities with similar conditions, with the aim of validating the effectiveness of the models and generating contextual evidence that serves to guide educational policies at the regional and national levels.

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