Journal of Asian Scientific Research
ISSN(e): 2223-1331
ISSN(p): 2226-5724
DOI: 10.55493/5003.v16i1.5866
Vol. 16, No. 1, 93-112.

URL: www.aessweb.com

Integrating bibliometric insights and pedagogical intervention for enhanced mathematical learning in basic education: An Ecuadorian case study

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Article History
Received: 1 July 2025
Revised: 5 December 2025
Accepted: 7 January 2026
Published: 2 February 2026

Keywords
Educational bibliometrics
Gamification
Mathematics education
Pedagogical intervention
Problem-based learning
Game-based learning
Problem-based learning.

ABSTRACT

This study integrates bibliometric analysis and pedagogical intervention to enhance mathematical learning among tenth-grade students at the 17 de Septiembre Educational Units in Milagro, Ecuador. The initial diagnosis revealed low performance in algebra, particularly in factorization and quadratic functions. In response, active methodologies such as Problem-Based Learning (PBL) and Game-Based Learning (GBL) were implemented, complemented by personalized tutoring and teacher training. The bibliometric review, based on 42 articles indexed in Scopus and Web of Science (2010–2025), identified global trends in mathematics education related to pedagogical innovation, inclusion, and teacher development. These insights informed the design of contextualized educational games and micro-workshops aligned with the local curriculum. Post-intervention results showed more than a 30% increase in academic performance, confirmed by paired t-tests indicating statistically significant improvements across all topics. Additionally, higher student motivation, reduced mathematics anxiety, and greater classroom participation were observed. The study demonstrates that integrating low-cost active learning strategies with global research evidence can substantially improve outcomes in vulnerable contexts. It also validates bibliometric analysis as a practical tool for aligning classroom practice with international scientific knowledge, offering a replicable model for strengthening equity, innovation, and quality in basic mathematics education systems worldwide and promoting sustainable teaching practices.

Contribution/ Originality: This study uniquely integrates bibliometric analysis with a real-world pedagogical intervention in a vulnerable school context. It offers a replicable model that bridges global research with local practice, demonstrating how data-driven insights can inform low-cost, active teaching strategies to enhance mathematics learning and promote equity in basic education.

1. INTRODUCTION

The development of mathematical competencies in basic education is a cornerstone for meaningful learning and future academic success. Mathematics not only fosters logical and analytical thinking but also serves as a crosscutting foundation for developing skills in science, technology, and economics [1, 2]. However, numerous studies highlight persistent deficiencies in this area, particularly in Latin America, where educational inequality, traditional methodologies, and inadequate teacher training hinder effective learning [3, 4].

In Ecuador, results from standardized assessments such as PISA and the national Ser Estudiante tests reflect low achievement in mathematics standards [5]. This situation is exacerbated in urban-marginal and rural areas, where limited resources, student disinterest, and uncontextualized expository methods widen learning gaps. This challenge is particularly pronounced in the tenth grade of General Basic Education (10th EGB), a transitional stage toward high school, where consolidating key skills is critical for future academic success.

The State University of Milagro (UNEMI) initiated a community engagement project titled 'Strengthening Mathematical Knowledge for Tenth-Grade Students of General Basic Education at the 17 de Septiembre Educational Unit in Milagro, Ecuador' in 2024 and 2025. This project aims to enhance students' mathematical understanding by employing tutoring and innovative teaching methods centered on Problem-Based Learning (PBL) [6, 7]. The initiative was based on a contextual assessment that included tests, interviews with teachers, and an evaluation of the educational setting.

From 2020 to 2024, the institution experienced a decline in mathematical achievement, as evidenced by poor grades, difficulties in addressing real-world problems, and unfavorable attitudes toward the subject. Insufficient teacher training in active methodologies and a lack of academic support were identified as significant contributing factors. Educators emphasized the need for training in strategies such as PBL and the use of contextualized materials. Although there is an extensive body of literature on mathematics education and methodological innovation, a disconnect exists between theoretical understanding and its practical application in local settings [8, 9]. This study aimed to bridge this gap by integrating international scientific evidence with practical pedagogical implementation in a real-world environment. Although numerous studies have focused on developed nations or affluent urban areas, local experiences, such as those in Milagro, remain insufficiently explored from a systematic perspective. This research is notable for its mixed-method approach, combining bibliometric analysis with a contextualized pedagogical intervention. Unlike most studies that address these aspects separately, this study integrates the mapping of international scientific production with the direct application of teaching strategies in a vulnerable school setting.

This dual strategy not only highlights the contrast between theory and practice but also reveals how global trends can guide context-specific, empirically based educational decisions. Consequently, this study integrates two complementary methods: a bibliometric analysis of scientific output in secondary school mathematics education, focusing on strategies such as problem-based learning (PBL), technological resource utilization, and teacher training, and a case study centered on the intervention in Milagro. This dual perspective facilitates mapping global trends and comparing them with a specific application, offering valuable insights for both theoretical and practical realms. Bibliometric analysis can be used to identify research patterns, influential authors, methodological approaches, and thematic gaps in the field [10-12]. Using databases such as Scopus and Web of Science, this study determines how well the project aligns with current trends and identifies elements that can be adapted for future educational interventions. This study primarily aims to perform a bibliometric analysis of teaching methods in mathematics education at the secondary school level, concentrating on Latin America. It also seeks to compare these findings with a project carried out at the 17 de Septiembre Educational Unit. By doing so, this study intends to make a meaningful contribution to both academic literature and educational practices, emphasizing the opportunities and challenges involved in enhancing mathematical learning in underprivileged communities.

2. LITERATURE REVIEW AND BIBLIOMETRIC METHODOLOGY

Extensive research has focused on teaching mathematics in basic education, emphasizing the need for more effective teaching methods, particularly in disadvantaged settings. International studies acknowledge that mathematics enhances logical and analytical thinking and is crucial for developing cross-disciplinary skills in science, technology, and economics [1, 2]. Nevertheless, research has consistently revealed significant disparities in learning outcomes, which are often due to educational inequality, dependence on traditional teaching methods, and inadequate teacher training [3, 4].

Problem-Based Learning (PBL) is frequently referenced in academic literature as an effective approach for enhancing conceptual understanding, mathematical reasoning, and the application of knowledge to real-world contexts [6, 13]. This approach is further supported by game-based learning (GBL), which has become increasingly popular as an engaging and educationally valuable method of teaching mathematical concepts [14].

Numerous studies have emphasized the importance of teacher training. Ongoing professional development, both during initial teacher education and throughout their careers, plays a crucial role in fostering innovative teaching methods and enhancing student outcomes [15, 16]. Additionally, it is necessary to incorporate a critical and contextual approach to mathematics education that focuses on sustainability and equity [17, 18].

Educational technologies have contributed significantly to methodological advancements. Diego-Mantecon et al. [19] and Jiménez-Jaraba et al. [20] illustrated that incorporating digital environments and simulations can improve learning outcomes, especially when implemented with a focus on the student. Likewise, studies conducted by Nicolete et al. [21] and Alcalde et al. [22] indicate that one-to-one models and digital tools play a role in transforming teaching methods while also highlighting the necessity of pedagogical support.

In the field of bibliometrics, tools such as Scopus and Web of Science are widely used to map trends, identify influential authors, and detect thematic gaps in mathematics education [11, 12, 23]. These techniques help us understand how research has evolved, particularly in recent years, and how mathematics teaching has been approached from various methodological perspectives [24, 25]. The use of specialized software, such as VOSviewer, has been essential for identifying keyword clusters, thematic interrelations, and emerging areas.

In summary, some studies advocate for teaching mathematics in an embedded, contextual, and critical manner, considering the distinct characteristics of the environment and the social issues associated with learning [26, 27]. Recommendations from Picado-Alfaro et al. [28] and Palencia et al. [29] emphasize the importance of educators reflecting on their teaching approaches and adapting their methods to address the real needs of their students.

This literature review highlights a substantial body of evidence supporting the implementation of active teaching methods, enhanced teacher training, and the integration of technology to improve mathematics education. Nonetheless, there remains a disconnect between theoretical concepts and their practical application, especially in vulnerable environments. This emphasizes the importance of research, such as that conducted at the 17 de Septiembre Educational Unit in Milagro, Ecuador.

2.1. Bibliometric Analysis Methodology

This bibliometric study utilized the Scopus and Web of Science (WoS) databases, which are known for their comprehensive and interdisciplinary scope [30, 31]. The data were collected from June 10 to June 15, 2025. The selected documents, published between 2010 and 2025, reflect recent developments in mathematics education research, particularly in the context of the pandemic.

Compared to other review methods, such as systematic or integrative reviews, the bibliometric approach is particularly well-suited for the aims of this study. It enables a structured and quantitative mapping of the global research landscape [24, 25, 32]. By utilizing indicators such as publication frequency, keyword co-occurrence, and the analysis of sources and authors, this method helps identify emerging trends, thematic gaps, and established knowledge areas. Its use in comprehensive databases such as Scopus and Web of Science offers a thorough and current overview of the state of the art [23, 33], which is crucial for comparing local pedagogical experiences with the most influential international research lines. This methodological choice not only bolsters the theoretical framework of the intervention but also provides empirical evidence to inform future educational policies and practices.

2.2. Inclusion and Exclusion Criteria

The following inclusion criteria were applied.

- Records published between 2010 and 2025, covering the consolidation of active pedagogical approaches in mathematics teaching and the emergence of new strategies driven by the post-pandemic context, which necessitated rethinking educational practices and technology use in the classroom.
- Original research articles.
- Documents in English or Spanish.
- Studies focused on secondary or upper basic education.
- Topics related to mathematics teaching, PBL, mathematical didactics, teacher training, and educational technologies.

Excluded were documents such as systematic reviews, bibliometric studies, conference papers, book chapters, records focused on university education, advanced mathematical engineering, or purely theoretical approaches without educational applications.

2.3. Search Equation

The following search equation was adapted for Scopus and WoS, using Boolean operators and truncations to cover the broadest terminological diversity.

Scopus: TITLE-ABS-KEY ("Mathematics education" OR "math learning" OR "mathematics teaching") AND TITLE-ABS-KEY ("Secondary education" OR "basic education" OR "middle school") AND TITLE-ABS-KEY ("Active learning" OR "problem-based learning" OR "PBL" OR "didactics" OR "pedagogical strategies" OR "teacher training" OR "educational innovation").

The structure was adapted for Web of Science: WoS: TS= ("mathematics education" OR "math learning" OR "mathematics teaching") AND TS= ("secondary education" OR "basic education" OR "middle school") AND TS= ("active learning" OR "problem-based learning" OR "PBL" OR "didactics" OR "pedagogical strategies" OR "teacher training" OR "educational innovation").

2.4. Data Processing and Analysis

Once the selected references, including titles, authors, keywords, abstracts, and sources, were downloaded, the data were processed using R version 4.4.2 and visualized with VOSviewer version 1.6.20. The following procedures were applied.

- Analysis of scientific productivity and citations: number of publications and citations per year.
- Keyword co-occurrence analysis: to identify the main areas of focus and how different concepts are interrelated.
- Source analysis: journals with the highest volume of publications and citations.
  This analysis enabled the creation of a detailed knowledge map of strategies for teaching mathematics in secondary education, providing a robust framework to contrast with the local experience implemented in the community engagement project in Ecuador.

3. BIBLIOMETRIC ANALYSIS

The search, conducted on June 1, 2025, yielded 110 records in Scopus and 65 in WoS. After applying inclusion and exclusion criteria, 111 records were selected (59 from Scopus and 52 from WoS). Following the removal of duplicates (n=17), 94 records remained for title and abstract review, resulting in the final selection of 42 articles.

3.1. Temporal Evolution of Scientific Production and Its Impact

The temporal analysis of scientific production in mathematical learning in basic education (see Figure 1) demonstrates a growing yet heterogeneous trend in both publication volume and impact, as measured by citations.

Between 2010 and 2025, a total of 14 years of editorial activity were recorded, resulting in 42 publications. The initial phase (2010–2016) exhibited a moderate pace, with an average of 1 to 3 publications per year. Notably, in 2015, three articles were published with low impact, receiving only 2 citations. Conversely, in 2016, despite having only one publication, it garnered a high number of citations (19), indicating its significant influence within the field.

From 2020 onward, a sustained increase in productivity has been observed, peaking in 2024 with 10 publications. This trend indicates a recent expansion in academic interest in the topic. However, citation analysis reveals a different pattern. The highest number of citations is concentrated in 2022 (37 citations), 2021 (31), and 2010 (21), demonstrating that the most influential publications originate from both the early period and the last five years, with a natural time lag favoring studies with longer academic exposure.

The most recent years (2023–2025), despite high productivity (5, 10, and 4 publications, respectively), have not yet accumulated significant citations (0, 1, and 1). This phenomenon is attributable to the short time since publication. The lag between publication and impact is expected and reflects the time needed for studies to be read, applied, and cited in new research.

Collectively, these findings reveal an expanding field with growing scientific production and an academic impact that is unevenly distributed, depending on both the content and the age of the work. The citation behavior underscores the importance of not only increasing the quantity of publications but also promoting their quality, visibility, and applicability in the educational field.

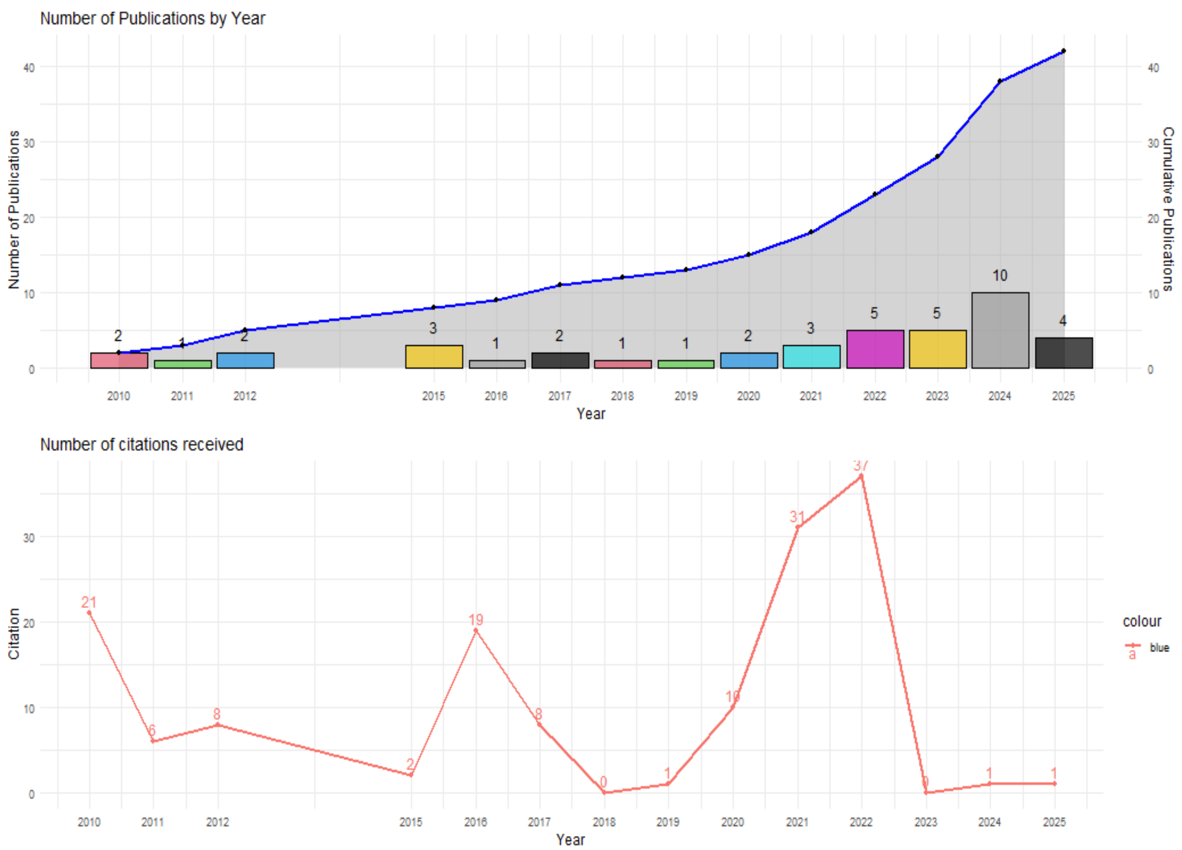

Figure 1. Evolution over time of the scientific production on mathematical learning in elementary education.

3.2. Keywords with the Highest Co-Occurrence

The co-occurrence analysis of author keywords, conducted using VOSviewer software, identified a significant set of recurring terms in the literature related to mathematical learning in basic education. The keywords with the highest frequency and total link strength include: *teacher training* (9 occurrences; total link strength: 37), *mathematics* (6; 29), *secondary education* (5; 24), and *mathematics education* (5; 20). These keywords reflect the main conceptual themes addressed by the studies included in the analysis corpus. The graphical representation of these connections is shown in the co-occurrence map presented in Figure 2.

3.2.1. Identified Thematic Clusters

The visualization map generated by VOSviewer displays five thematic clusters that group keywords based on their semantic affinity and co-occurrence frequency. Each cluster represents a common area of interest within research on mathematics education.

3.2.1.1. Cluster 1: Teacher Training and Pedagogical Strategies

This cluster includes terms such as *teacher training* [15] *preservice teachers* [29] *in-service teacher education* [16], and *pedagogical strategies* [34]. It relates to studies analyzing initial and continuous teacher training processes, as well as the implementation of active and reflective didactic methodologies in the mathematics classroom [17, 29]. The literature indicates that strengthening mathematical learning is closely tied to innovative, practice-based teacher training.

3.2.1.2. Cluster 2: Mathematics Education and Concept Acquisition

This group comprises terms such as *mathematics*, *mathematics education*, *mathematics learning*, and *mathematical concepts acquisition* [19, 26, 35]. It represents the disciplinary core of the studies, focusing on the teaching and learning processes of mathematics. The studies emphasize conceptual understanding and the assessment of mathematical learning in various school contexts.

3.2.1.3. Cluster 3: Basic and Middle Educational Levels

This cluster includes keywords such as *primary education*, *primary school*, *secondary education*, and *ks4* [27, 36, 37]. It delineates the focus of studies according to educational levels, highlighting interventions in both primary and secondary education. While research predominantly focuses on secondary education, there are significant contributions at the primary level, particularly in the area of didactic innovation.

3.2.1.4. Cluster 4: Educational Innovation and Technologies

This set of terms includes *educational technology*, *educational innovation*, *active methodologies*, *simulation-based learning*, *STEAM*, and *assessment* [18, 20-22]. It reflects the incorporation of emerging methodological approaches and digital technologies in mathematics teaching.

The literature demonstrates a growing interest in adapting mathematics education to digital, inclusive, and student-centered environments.

3.2.1.5. Cluster 5: Emerging and Critical Dimensions

This cluster includes terms such as *critical mathematics education*, *curriculum for sustainability*, *gender biases*, *equal opportunity*, and *motivational dialogue* [18, 22]. Although less frequent, these concepts introduce critical and inclusive perspectives in mathematics teaching.

An emerging research area has been identified, focusing on equity, social justice, and sustainability within the educational field.

3.2.2. Connectivity Between Clusters

The co-occurrence map reveals a strong connection between *teacher training* and *mathematics education*, suggesting that improvements in mathematical learning are closely linked to teacher training. Similarly, a convergence is observed between *educational technology* and *active methodologies*, highlighting the growing role of technology in transforming educational practices.

Specifically, Cluster 1 (Teacher Training and Pedagogical Strategies) is directly related to the intervention experience implemented at the 17 de Septiembre Educational Unit, as one of the project's key components was teacher training through micro-workshops and the transfer of active methodologies, such as Problem-Based Learning (PBL). This connection suggests that strengthening teachers' professional development is a critical factor for the sustainability and success of pedagogical innovations in vulnerable contexts.

Cluster 4 (Educational Innovation and Technologies) also aligns with the local intervention due to the design and application of gamified educational games that incorporate simulation dynamics, printed resources, and, in some cases, simple digital tools. This approach allows methodological proposals to be adapted to the school context without relying on costly equipment.

Finally, Cluster 5 (Emerging and Critical Dimensions) resonates with the project's objectives, as it promotes educational equity and inclusion. By focusing on students with low performance and adapting teaching to their needs, the intervention contributed to reducing learning gaps, aligning with approaches oriented toward social justice and sustainability in mathematics education.

These findings not only reflect the conceptual alignment between international scientific production and the Ecuadorian case but also strengthen the contextual validity of the project, demonstrating that the strategies applied in Milagro are framed within trends recognized by the global academic community.

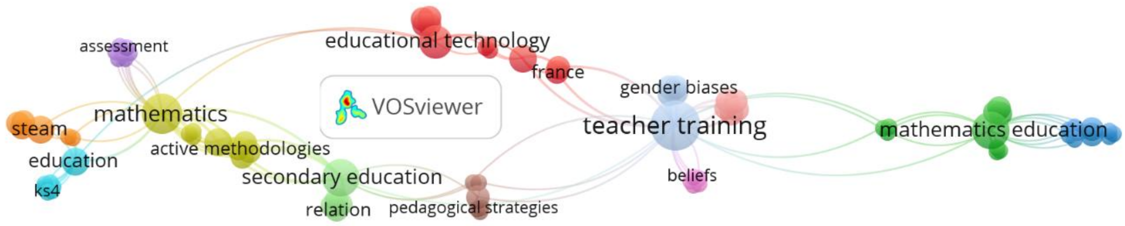

Figure 2. Map of cooccurrence of keywords in studies on mathematical learning in elementary education.

The map represents the thematic structure of the scientific literature by means of the author's keyword cooccurrence analysis using VOSviewer software. The nodes indicate frequently used terms, and their size corresponds to the number of occurrences. The connections reflect the strength of associations between terms, and the colors group the identified thematic clusters. Among these clusters, the following stand out: teacher training, mathematics education, educational levels, technological innovation, and critical approaches.

3.3. Source Analysis

Table 1 presents the three journals with the highest number of publications within the analyzed set of studies. The source with the most documents is *Education Sciences*, with a total of 9 articles published, followed by *ZDM – Mathematics Education* and *Educación Matemática*, each with 2 publications.

From the perspective of impact, measured by citations, a distinct dynamic emerges. Although *Education Sciences* leads in document volume with 33 accumulated citations, *ZDM – Mathematics Education* stands out for its higher relative citation count (34), despite having fewer publications. This suggests that articles published in *ZDM* have a higher average impact per article, positioning this journal as a highly prestigious and influential source in the field of mathematics education.

In contrast, *Mathematics Education* shows no citations for its two registered documents, which may be related to factors such as the language of publication, limited geographical reach, or the recent appearance of the studies in its repository.

This analysis indicates that, while *Education Sciences* is the most frequently cited source among the reviewed studies, *ZDM – Mathematics Education* is a highly influential publication. Therefore, these two journals should be considered strategic for future literature searches and for disseminating research related to mathematical learning in school contexts.

Table 1. Scientific journals with the highest number of publications and citations in the analyzed corpus.

Source title	Documents	Citations
Education sciences	9	33
ZDM - mathematics education	2	34
Mathematics Education	2	0

4. EMPIRICAL APPLICATION: CASE STUDY OF THE PROJECT IN MILAGRO, ECUADOR

In response to the low academic performance in mathematics observed among tenth-grade students of General Basic Education (10th EGB) at the 17 de Septiembre Educational Unit in Milagro, Guayas Province, Ecuador, a community engagement project titled "Strengthening Mathematical Knowledge for Tenth-Grade Students of Upper General Basic Education" was implemented between August 2024 and August 2025. This initiative was developed by the State University of Milagro (UNEMI) within the framework of the "Comprehensive Health and Education Care" program, adopting a territorial and knowledge-transfer approach.

4.1. Diagnosis and Justification

The institutional diagnosis conducted between 2020 and 2023 revealed a critical deficit in the understanding of basic mathematical concepts among 10th EGB students, reflected in unsatisfactory grades in internal assessments and low performance in national tests administered by the National Institute for Educational Evaluation [38]. The results showed that the most deficient curricular block was Geometry and Measurement, with a high proportion of students at the "beginning" achievement level.

This issue was linked to several factors: traditional teaching methodologies focused on rote memorization, limited training in mathematical didactics, scarce use of updated educational resources, and socioeconomic conditions affecting student motivation and learning continuity. In response, the project aimed to intervene through active pedagogical strategies, emphasizing Problem-Based Learning (PBL), personalized academic tutoring, and teacher training.

4.2. Intervention Objectives

The project's main objective was.

1. To improve academic performance in Algebra through student-centered active methodologies.

Specific objectives included.

2. Diagnosing prior knowledge in fundamental algebraic topics.
3. Designing and implementing gamified activities based on Game-Based Learning (GBL) and Problem-Based Learning (PBL).
4. Developing individual and group tutoring processes for students with academic lag.
5. Training teachers in innovative methodologies and formative assessment.
6. Evaluating the impact of the strategies through diagnostic tests, surveys, and direct observations.

4.3. Intervention Methodology

The project's methodology was based on three pillars.

a. Problem-Based Learning (PBL): Each game and activity begins with a contextualized situation that requires the application of mathematical knowledge to solve it, thereby fostering connections with real-life scenarios.

b. Game-Based Learning (GBL): Over ten educational games were designed, aligned with curricular topics such as first-degree equations, linear and quadratic functions, factorization, notable products, and expression simplification. Notable games included *Function and Evolution*, *Equations Bingo*, *S.E.L.D.I. Roulette*, *Algebraic Battle*, and *Solve and Advance!*.
c. Tutoring and Reinforcement: Extracurricular group and individual tutoring sessions were implemented, focusing on students who scored below 50% on the initial diagnostic test, using differentiated activities.
d. Teacher Training: Micro-workshops were conducted with the institutional teaching staff to transfer the methodology, share printed and digital resources, and foster a community of practice around classroom gamification.

4.4. Implementation Timeline

This subsection outlines the chronological sequence of activities planned to implement the pedagogical intervention at the 17 de Septiembre Educational Unit. The timeline was structured to progress from diagnosis and instructional design to classroom implementation and subsequent evaluation, ensuring coherence between the proposed pedagogical strategies and their assessment.

Table 2. Implementation Schedule for the Educational Intervention Project at the 17 de Septiembre Educational Unit

Activity	Date
Diagnosis and planning design	March 2025
Application of diagnostic tests	First week of April
Development of materials and games	April–May 2025
Application of games in the classroom	May–June 2025
Group and individual tutoring	May–June 2025
Application of posttests	Second week of June
Systematization and result analysis	Second half of June
Report preparation and dissemination	July 2025

Table 2 presents the implementation schedule of the intervention, specifying the month or week in which each activity is carried out. The process begins with diagnosis and planning in March 2025. It continues with the administration of diagnostic tests, as well as the development and classroom application of games, alongside group and individual tutoring from April to June. The process concludes with the application of post-tests, followed by the analysis and systematization of results. Finally, the final report is prepared and disseminated in June and July 2025.

4.5. Student Intervention

The direct intervention reached 54 students, including 28 from 10th-grade "A" and 26 from 10th-grade "C." Over 12 gamified sessions were conducted, each lasting between 30 and 45 minutes. All students participated in at least 8 sessions.

Each activity focused on a specific algebra topic and combined written exercises with game mechanics such as roulettes, bingo, card decks, and customized boards. Covered topics included exponentiation, notable products, factorization, quadratic functions, and more. For a detailed description of the topics and their relation to the activities, see Annex 1.

Notable games included *Function and Evolution*, *Equations Bingo*, *Algebraic Battle*, *Solve and Advance!*, and *S.E.L.D.I. Roulette*. The latter was distinguished by integrating multiple-choice questions with varying difficulty levels and chance elements to encourage equitable participation and collaborative learning.

The approach promoted active learning, problem-solving, and a positive attitude toward mathematics. Games were designed with progressive difficulty levels, enabling all students, regardless of their initial level, to engage meaningfully.

4.6. Participation Data and Preliminary Results

4.6.1. Participation

- Average attendance at gamified activities: 93%.
- Active participation (observed): Over 90% of students per session.
- Positive feedback (observation + surveys): High motivation, low mathematical anxiety

Table 3 presents the diagnostic test results by subtopic for the 10th "A" and 10th "C" classes. The average percentages of correct answers are generally low in both groups, ranging from 24% to 40% in 10th "A" and from 27% to 48% in 10th "C". While 10th "C" shows slightly higher performance in all subtopics, particularly in exponentiation and roots, both classes obtain their lowest scores in quadratic functions and factorization. These results confirm the existence of significant learning gaps in foundational algebraic skills, which justified the design of the subsequent pedagogical intervention.

Table 3. Diagnostic Test Results by Subtopics in 10th "A" and 10th "C" Classes

Section	Topic	Average % Correct 10th A	Average % Correct 10th C
A	Exponentiation and roots	40%	48%
B	Notable products	36%	39%
C	Factorization	28%	32%
D	Quadratic functions	24%	27%

4.6.2. Diagnostic Test Results

Although the post-test is still pending to measure the definitive impact, classroom observations already indicate:

- Reduction in common errors when solving equations.
- Greater willingness to participate orally and in teams.
- Improved the use of step-by-step algebraic procedures.

4.7. Project Contributions

This practical case demonstrates how a structured, gamified, and active-principle-based pedagogical intervention can generate sustainable improvements in vulnerable contexts. Additionally:

- It promotes teacher innovation by utilizing accessible resources such as paper, cardboard, and physical roulettes.
- It fosters educational equity by providing meaningful learning opportunities for low-performing students.
- It generates valuable empirical evidence for future educational interventions within the framework of mathematics improvement policies in basic education.

4.8. Instruments Applied and Sample Characterization

4.8.1. Instruments

Two types of instruments were used for data collection: a diagnostic test and a student perception survey. The diagnostic test was designed by the project's teaching team based on the Ecuadorian Ministry of Education's curricular guidelines for the Algebra block in tenth grade. The instrument consisted of 20 multiple-choice items with a single correct answer, covering four topics: exponentiation and roots, notable products, factorization, and quadratic functions, with progressive difficulty levels. The same structure was used for the post-test, enabling direct comparison between the two evaluation moments.

To ensure content validity, the test was reviewed by three experts in mathematical didactics. A pilot test was conducted with 10 students from a parallel course not included in the intervention, allowing adjustments to the wording of some items. The instrument's reliability was estimated using the Kuder-Richardson coefficient (KR-20), which yielded a value of 0.82, indicating acceptable reliability for diagnostic purposes.

Additionally, a brief survey was conducted at the end of the intervention to gather perceptions regarding the usefulness of the games, the motivation generated, and the difficulties experienced. The survey included eight Likert-scale items (four points, ranging from “strongly disagree” to “strongly agree”) and two open-ended questions. Its validation was empirical, aimed at informing the design of future didactic strategies.

4.8.2. Sample Characterization

The sample consisted of 54 tenth-grade students: 28 from 10th "A" and 26 from 10th "C" at the 17 de Septiembre Educational Unit in Milagro. The group was distributed by gender as 29 females (53.7%) and 25 males (46.3%). The average age was 14.2 years (SD = 0.7), with a range of 13 to 15 years. Most students come from urban-marginal areas with limited socioeconomic conditions, reinforcing the relevance of the inclusive approach applied in this intervention.

5. RESULTS AND DISCUSSION

5.1. Posttest Results

Following the implementation of the pedagogical intervention based on mathematical games, tutoring, and PBL, a post-test was administered in the third week of June 2025. The evaluation followed the same content matrix as the initial diagnostic test, allowing for a comparison of progress in each topic based on the average percentage of correct answers per class.

5.1.1. Comparative Results (Pretest vs. Posttest)

This subsection compares students' performance on the pretest and posttest to assess the learning progress achieved through the pedagogical intervention. The analysis focuses on changes in results by algebraic subtopic and by class group (10th "A" and 10th "C"), providing evidence of the extent to which the proposed activities contributed to strengthening students' mathematical understanding.

Table 4. Comparison of results between pretest and post-test by subtopic and parallel.

Section	Topic	Pretest 10th A	Posttest 10th A	Pretest 10th C	Posttest 10th C
A	Exponentiation and roots	40%	72%	48%	75%
B	Notable products	36%	68%	39%	70%
C	Factorization	28%	64%	32%	66%
D	Quadratic functions	24%	60%	27%	63%
Average		32%	66%	36.5%	68.5%

Table 4 presents a comparison between pretest and posttest results for each subtopic in the 10th "A" and 10th "C" classes. In both groups, the percentages of correct answers increase markedly across all topics: for 10th "A", the average score rises from 32% to 66%, while for 10th "C", it increases from 36.5% to 68.5%. The greatest improvements are observed in factorization and quadratic functions, which were initially the weakest areas. These gains indicate a substantial positive effect of the gamified activities and tutoring on students’ algebraic performance.

5.2. Inferential Statistical Analysis

To verify whether the observed improvements between the pretest and posttest were statistically significant, a paired Student’s t-test was applied, comparing the average percentage of correct answers per topic. The analysis revealed highly significant differences in both classes. For 10th grade "A," a t-value of 29.44 with $p = 0.00009$ was obtained, while for 10th grade "C," the t-value was 16.34 with $p = 0.00050$. These results confirm that the increase in correct answers following the pedagogical intervention is statistically significant, reinforcing the validity of the observed improvements in mathematical understanding.

These results quantitatively support the effectiveness of the implemented pedagogical strategy, demonstrating that the increase in correct answers is not due to chance but to a real improvement attributable to the developed activities.

The results reflect a substantial improvement in all evaluated topics, with an average increase exceeding 30% in both classes. The greatest gains were observed in factorization and quadratic functions, areas that initially had the lowest correct answer rates.

5.3. Discussion of Results

The posttest results demonstrate substantial improvements in students' academic performance, particularly in the topics addressed through active strategies such as Game-Based Learning (GBL) and Problem-Based Learning (PBL). As shown in Table 4, the average correct answers in 10th-grade "A" increased from 32% to 66%, and in 10th-grade "C" from 36.5% to 68.5%, representing a significant improvement in the conceptual and procedural understanding of algebraic content. This improvement is directly associated with the use of gamified dynamics that facilitated the appropriation of complex concepts, reduced mathematical anxiety, and fostered more active participation.

The effectiveness of this approach is supported by specialized literature. Dólera-Almaida and Sánchez-Jiménez [13] highlight the value of Puig Adam's heuristic method, which promotes active mathematical thinking through non-linear didactic strategies. This approach, centered on autonomous exploration and problem-solving, is closely related to the PBL implemented in this intervention. Similarly, Martín-Cudero et al. [27] emphasize the positive impact of mathematical experiences designed as math trails or similar activities on student motivation and meaningful understanding, reflected in the 92% of students who expressed a desire to apply games in other subjects and the 89% who acknowledged learning more with these methodologies.

Another significant aspect is the reduction of academic performance gaps. Eighty-seven percent of students who scored below 30% on the initial diagnostic test achieved over 60% on the post-test, demonstrating the effectiveness of personalized tutoring and differentiated support strategies. This finding aligns with Nwabude [35], who demonstrated that virtual learning environments (VLEs) can reduce barriers to access to mathematical knowledge for students with diverse academic backgrounds. Although this intervention did not utilize advanced digital technologies, the use of adapted physical resources such as boards, roulettes, and bingo achieved similar results in terms of learning outcomes and equity.

Complementarily, Gutiérrez et al. [39] highlight the importance of adapted statistical reasoning during initial teacher training, reinforcing the value of the differentiated approaches implemented in this educational experience.

Teacher training plays a fundamental role in ensuring the sustainability and coherence of educational interventions. The active participation of teachers in methodological micro-workshops has strengthened their pedagogical understanding and enabled them to replicate their strategies across different grade levels. This experience aligns with Oliveira and Pereira [15], who emphasized the importance of practical training spaces, such as geometry laboratories, in fostering the development of pedagogical and mathematical knowledge during initial teacher training. The autonomous replication of activities by the teaching staff at the 17 de Septiembre Educational Unit highlights the potential of this training approach to promote sustainable changes in classroom practices.

It is worth noting that the bibliometric analysis not only served a diagnostic function but also directly guided pedagogical decisions adopted in the intervention. The identification of thematic clusters related to *teacher training* [40] and *active methodologies* [29] revealed the focus of teacher workshops, prioritizing PBL and gamification as key tools. Similarly, terms such as *mathematics learning* and *simulation-based learning* influenced the selection of algebraic content and the design of games such as *Equations Bingo* and *Algebraic Battle*, which addressed the deficits identified in the initial diagnosis. Additionally, concepts such as *equal opportunity* and a *curriculum for sustainability* reinforced the implementation of differentiated tutoring and inclusive strategies for low-performing students. This alignment between international scientific evidence and local decisions strengthens the project's internal coherence and contextual relevance.

The intervention's findings are not only empirically supported by the obtained results but also align with the international trends identified in the bibliometric analysis. In particular, the thematic clusters of *active methodologies*, *teacher training*, and *mathematics learning* [28] closely correspond to the project's key components (see Figure 2). From a critical and contextualized perspective, Moreno-Pino et al. [17] advocate for mathematics education oriented toward sustainability and social justice, emphasizing the need to apply active methodologies in real and vulnerable contexts, as addressed in this study. This coherence between theory and practice reinforces the validity and relevance of the implemented intervention.

Finally, although the experience focused on printed and physical manipulative resources, the results in terms of motivation, participation, and learning align with Alcalde et al. [22], who documented improvements in pedagogical mediation through one-to-one (1:1) models with digital devices. This suggests that the positive impact of gamification does not depend solely on advanced technology but on its strategic, contextualized, and student-centered pedagogical implementation.

A distinctive contribution of this study is its ability to bridge global scientific research and concrete educational action. Specifically, it presents an innovative approach by combining bibliometric analysis tools with the planning and implementation of a real didactic intervention. This methodological integration constitutes an original contribution to the field of mathematics education, demonstrating that data from scientific databases can be leveraged not only for theoretical analysis but also as direct input for designing pedagogically relevant practices with a high degree of local pertinence.

Collectively, the findings of this educational experience not only provide evidence of the effectiveness of active methodologies for mathematical learning but also contribute to the international debate on transforming pedagogical practices in vulnerable contexts from a critical, inclusive, and evidence-based perspective.

5.4. Study Limitations

While the findings of this study provide valuable empirical evidence of the impact of active methodologies on mathematical learning, certain limitations must be acknowledged regarding the scope and generalizability of the results.

First, the sample size was relatively small (n=54), which, while allowing for detailed and contextualized analysis, limits the ability to extrapolate findings to other student populations. Second, the intervention had a short duration of approximately three months; therefore, the sustainability of learning outcomes in the medium or long term, as well as the impact on other curricular areas, was not evaluated.

Additionally, the methodological design did not include a control group, which prevents direct comparisons with students who did not receive the intervention. This necessitates cautious interpretation of the results, as other uncontrolled variables may have influenced the observed performance.

Finally, the study's focus is situated within a specific educational context a public school in an urban-marginal area of Ecuador so its results must be understood in light of its particular sociocultural and structural conditions. While this specificity is a strength for contextualized analysis, it also presents a limitation in terms of generalizability to other settings with different characteristics.

Acknowledging these limitations does not diminish the value of the obtained results; rather, it helps delineate their scope and guides future research to complement, expand, or replicate this study in other educational contexts.

6. CONCLUSIONS

This study integrated a bibliometric review with a real-world educational intervention in Milagro, Ecuador, aimed at strengthening mathematical learning among tenth-grade students. The results indicate that combining global scientific evidence with contextualized educational practices is an effective strategy for enhancing academic performance, increasing student motivation, and promoting educational equity in vulnerable contexts.

From a theoretical perspective, bibliometric analysis identified the main research lines in mathematics education at the secondary school level, highlighting the prominence of active methodologies such as Problem-Based Learning (PBL), the use of gamified and technological resources, and ongoing teacher training.

These findings not only provided an updated reference framework but also directly influenced the pedagogical design of the intervention by guiding the selection of didactic strategies aligned with the most relevant and effective international trends.

From an empirical perspective, the intervention implemented at the 17 de Septiembre Educational Unit proved effective in significantly improving academic performance in algebra, with an average increase exceeding 30% between the initial diagnostic test and the posttest. Additionally, increased active student participation, reduced mathematical anxiety, and a more positive attitude toward the subject were observed. Gamified activities, personalized tutoring, and teacher training contributed to a more meaningful, participatory, and inclusive learning experience.

In light of these results, it is recommended that local educational policies institutionalize continuous teacher training programs focused on active methodologies such as PBL and GBL, incorporating practical modules with direct classroom application. It is also suggested to establish gamified pilot programs in public schools located in rural and urban-marginal areas, with academic support and impact evaluation, to scale successful experiences. Educational authorities could also create incentives for teachers to systematize and publish their best pedagogical practices through institutional journals or open repositories, thereby strengthening a culture of innovation and professional reflection.

Furthermore, it is proposed that mathematics curricula include explicit spaces for integrating contextualized and gamified resources tailored to territorial realities. Future research could focus on longitudinal monitoring of these strategies, their adaptation to other knowledge areas, such as natural sciences or language, and the analysis of their sustainability within school systems with limited resources.

Ultimately, this experience demonstrates that it is possible to innovate in mathematics teaching from a situated perspective by articulating scientific knowledge, pedagogical practice, and territorial commitment. The documented project serves as a replicable reference for other educational institutions in the region and provides a solid empirical basis for designing public policies aimed at improving learning in vulnerable communities.

Funding: This research was funded by the State University of Milagro (UNEMI), Ecuador, through Memorandum No. UNEMI-R-2025-3599-MEM, under Budget Reform No. 127, to cover the expenses of article publication.
Institutional Review Board Statement: Not applicable.
Transparency: The authors state that the manuscript is honest, truthful, and transparent, that no key aspects of the investigation have been omitted, and that any differences from the study as planned have been clarified. This study followed all writing ethics.
Competing Interests: The authors declare that they have no competing interests.
Authors' Contributions: All authors contributed equally to the conception and design of the study. All authors have read and agreed to the published version of the manuscript.

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Annex 1. Description of Gamified Sessions.

The main gamified formats used in the 12 sessions are summarized below. Each game was adapted with progressive difficulty levels, allowing all students—regardless of their initial performance—to participate meaningfully. The games Function and Evolution, Equations Bingo, Algebraic Battle, Solve and Advance! and S.E.L.D.I. Roulette combined problem-solving with chance elements, teamwork, and multiple representations of algebraic concepts.

Session S1
Topic: Exponentiation and roots
Subtopic: Laws of exponents
Duration 35 min

Table 5 presents a detailed description of activity session S1, focused on the laws of exponents. It summarizes the learning objective, the dynamics of the S.E.L.D.I. Roulette game, where teams answer multiple-choice items of increasing difficulty and the corresponding grouping and assessment criteria based on the number of correct responses and a final exit question.

Table 5. Description of the activity session 1.

Learning objective	Game-based activity & mechanics	Grouping	Assessment
Students apply the laws of exponents to simplify numerical and algebraic expressions.	**S.E.L.D.I. Roulette**: teams spin a roulette that selects multiple-choice items on exponents at basic or advanced levels. Correct answers earn tokens, and difficulty increases across rounds.	Teams of 3–4	Number of correct items by level; quick exit question on a selected exponent rule.

Session S2
Topic: Exponentiation and roots
Subtopic: Radicals and rational exponents
Duration 40 min

Table 6 presents a description of activity session S2, which addresses radicals and rational exponents. It specifies the learning objective of converting between both notations and simplifying basic radical expressions, outlines the Equations Bingo (Radicals Edition) game mechanics, and summarizes the grouping in small teams and the assessment based on correct matches and a teacher checklist of conversion accuracy.

Table 6. Description of the activity session 2.

Learning objective	Game-based activity & mechanics	Grouping	Assessment
Students convert between radical notation and rational exponents and simplify basic radical expressions.	**Equations Bingo (Radicals Edition)**: bingo cards show radical and rational exponent forms. The teacher calls simplified or equivalent forms, and students mark the matching expression.	Teams of 3–4	Correct matches per card; teacher checklist on accuracy in conversions and simplifications.

Session S3

Topic: Notable products

Subtopic: Square of a binomial

Duration 35 min

Table 7 presents the description of activity session S3, focused on the square of a binomial. It specifies the learning objective of expanding and simplifying expressions of the form $(a\pm b)^2$, outlines the Algebraic Battle I game in which two large teams solve binomial-square exercises projected on the board, and summarizes the assessment based on points per correct solution and a brief written justification of the $(a\pm b)^2$ pattern.

Table 7. Description of the activity session 3.

Learning objective	Game-based activity & mechanics	Grouping	Assessment
Students expand and simplify expressions of the form $(a\pm b)^2$ using notable products.	**Algebraic Battle I**: two teams solve pairs of binomial-square exercises projected on the board. Each round mixes basic and intermediate items, with points for correct solutions.	Two large teams	Points per correct solution; short written justification of the $(a\pm b)^2$ pattern.

Session S4

Topic: Notable products

Subtopic: Product of sum and difference

Duration 40 min

Table 8 presents the description of activity session S4, focused on the product of sum and difference. It specifies the learning objective of recognizing and applying the identity $(a + b)(a - b) = a^2 - b^2$), describes the Algebraic Battle II game, which uses the same duel format centered on this identity and progressively incorporates short word problems, and summarizes assessment through a log of correct algebraic transformations and contextual problems solved.

Table 8. Description of the activity session 4.

Learning objective	Game-based activity & mechanics	Grouping	Assessment
Students recognize and apply the identity $(a + b)(a - b) = a^2 - b^2$.	**Algebraic Battle II**: same duel format focused on the sum–difference identity. Later rounds add short word problems requiring the use of $a^2 - b^2$.	Two large teams	Log of correct transformations and contextual problems solved.

Session S5

Topic: Factorization

Subtopic: Common factor

Duration 35 min

Table 9 presents the description of activity session S5, focused on factorization by greatest common factor. It states the learning objective of factoring expressions by extracting the GCF, describes the *Solve and Advance! I* board game, in which teams move only if their factorization is correct and items become progressively more complex, and summarizes assessment through the number of correctly factored expressions and a teacher record of the most frequent errors made when identifying the common factor.

Table 9. Description of the activity session 5.

Learning objective	Game-based activity & mechanics	Grouping	Assessment
Students factor expressions by extracting the greatest common factor (GCF).	**Solve and Advance! I**: on a board game, each space shows an expression to factor by GCF. Teams move only if their factorization is correct, with items increasing in complexity.	Teams of 3–4	Number of correctly factored expressions; teacher notes on typical errors in GCF identification.

Session S6

Topic: Factorization

Subtopic: Difference of squares

Duration 35 min

Table 10 presents the description of activity session S6, focused on factorization by difference of squares. It specifies the learning objective of factoring binomials of the form $a^2 - b^2$, outlines the *Solve and Advance! II* board game where later spaces mix true $a^2 - b^2$ patterns with distractors that require students to justify whether the identity applies and summarizes assessment through the correct identification and factorization of $a^2 - b^2$ and a short exit item.

Table 10. Description of the activity session 6.

Learning objective	Game-based activity & mechanics	Grouping	Assessment
Students factor binomials of the form $a^2 - b^2$	**Solve and Advance! II**: variant focused on difference of squares. Later spaces combine true $a^2 - b^2$ patterns with distractors, forcing students to justify whether the identity applies.	Teams of 3–4	Correct identification and factorization of $a^2 - b^2$; one short exit item.

Session S7

Topic: Quadratic functions

Subtopic: Elements and graph of a quadratic

Duration 40 min

Table 11 presents the description of activity session S7, focused on the elements and graph of a quadratic function. It states the learning objective of identifying the vertex, axis of symmetry, and intercepts, describes the Function and Evolution I game in which teams match tables, equations, and graphs of quadratic functions while parameters change, and summarizes assessment through a checklist of correctly identified elements and a quick sketch of one parabola per student.

Table 11. Description of the activity session 7.

Learning objective	Game-based activity & mechanics	Grouping	Assessment
Students identify vertex, axis of symmetry, and intercepts of a quadratic function.	**Function and Evolution I**: teams work with cards containing tables, equations, and graphs of quadratic functions. They match representations and identify key elements as parameters change.	Teams of 3–4	Checklist of correctly identified elements; quick sketch of one parabola per student.

Session S8

Topic: Quadratic functions

Subtopic: Solving quadratic equations in context

Duration 45 min

Table 12 presents the description of activity session S8, focused on solving quadratic equations in real-world contexts. It states the learning objective of solving and interpreting quadratic equations, describes the *Function and Evolution II + Equations Bingo* game, where students first solve contextual problems that lead to quadratic equations and then use the solutions to play bingo and summarizes assessment through the correct setup and solution of the equations and notes on students' interpretation of the roots in context.

Table 12. Description of the activity session 8.

Learning objective	Game-based activity & mechanics	Grouping	Assessment
Students solve quadratic equations from real-world contexts and interpret their solutions.	**Function and Evolution II + Equations Bingo**: students solve contextual problems leading to quadratic equations, then play bingo using the solutions. Difficulty grows from integer to rational roots.	Teams of 3–4	Correct setup and solution; notes on students' interpretation of roots in context.