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INFLUENCE OF KHANMIGO-BASED ARTIFICIAL INTELLIGENCE ON THE DEVELOPMENT OF MATHEMATICAL COMPETENCIES IN SECONDARY SCHOOL STUDENTS

Jesus Vilchez-Guizado[1*], Edwin Esteban-Rivera[2], Julia Ramon-Ortiz[3] and Amancio Rojas-Cotrina[4]

[1]Principal Professor, Faculty of Educational Sciences, Hermilio Valdizan National University of Huánuco, Peru. Email: jvilchez@unheval.edu.pe Orcid ID: https://orcid.org/0000-0002-5962-8703
[2]Principal Professor, Faculty of Educational Sciences, Hermilio Valdizan National University of Huánuco, Peru. Orcid ID: https://orcid.org/0000-0003-4669-1268
[3]Assistant Professor, Faculty of Educational Sciences, Hermilio Valdizan National University of Huánuco, Peru. Email: https://orcid.org/0000-0003-4532-1476
[4]Principal Professor, Faculty of Educational Sciences, Hermilio Valdizan National University of Huánuco, Peru. Orcid ID: https://orcid.org/0000-0002-5767-8416

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Corresponding Author: Jesus Vilchez-Guizado (jvilchez@unheval.edu.pe)

ABSTRACT

Artificial Intelligence (AI) has been consolidating itself as a relevant tool in various areas of human activity, especially in education, due to its ability to energize, personalize and optimize teaching-learning processes. The study aimed to determine the influence of the use of Khanmigo-based artificial intelligence on the development of mathematical competencies in secondary school students. The research was developed under a quantitative approach, with an explanatory level and pre-experimental design. The experimental intervention was carried out on 38 students in the last year of secondary education, selected through random cluster sampling. For data collection, two instruments were developed and applied: a multiple alternative questionnaire on the usefulness of AI in the teaching-learning process and tests to evaluate the development of mathematical competencies, applied before and after the experimental treatment, which lasted eight weeks. The data were analysed by percentage interpretation, descriptive statistics and the t-test for paired samples. The results showed a significant increase in the positive assessment of the use of AI tools in the four dimensions considered in the study. Likewise, measures of central tendency such as the mean of the pre-test and post-test showed a significant increase, likewise, the measures of dispersion of coefficient of variation and range experienced a notable decrease; Similarly, the t-test for related samples showed statistically significant differences between the scores obtained by the study participants before and after the experimental intervention. It is concluded that the integration of AI through Khanmigo favours the strengthening of learning and the development of mathematical skills in secondary school students. Consequently, it is essential to promote the use of AI tools by teachers for the design of learning activities and by students to strengthen their motivation towards the study and use of mathematics in problem solving.

KEYWORDS: Artificial Intelligence, Mathematical Competence, Digital Tools, Secondary Education, Teaching-Learning Process.

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1. INTRODUCTION

Since the beginning of the third decade of the twenty-first century, transcendental changes have been intensifying in the performance of human activities caused by the use of technology, in the educational field these changes bring new ways of learning, teaching and researching (Ayuso & Gutiérrez, 2022). These changes have also contributed to reshaping learning environments, redefining the processes of acquiring knowledge among students, and modifying the roles of teachers (UNESCO, 2024). In this context, artificial intelligence (AI) has become one of the most widely used tools for learning and teaching. This tool has been diversifying academic activities and pedagogical methods improved by technology, emphasizing learning (Richards & Dede, 2020). However, for their integration at the service of students, they require support within educational institutions, to be adapted in a diversified way to the profile of students, marked to the learning needs and expectations of the future citizen.

The evolution of AI has been causing a revolution in teaching and learning methodologies, discarding conventional paradigms has become the driver of future advances in the educational field (Cheung et al., 2021). AI tools make it possible to carry out complex activities based on data and information existing on the network, updating their objectives by adapting to changes in pedagogical approaches, according to technological advances and requirements of today's society. In this context, education must be aligned with disciplines considered essential for social progress, while harnessing the potential of AI to respond to the needs of the present (Vodenko & Lyausheva, 2020). This orientation is aligned with the recommendations of international academic organizations, which advocate pedagogies based on interaction, active engagement, and self-directed construction of knowledge (OECD, 2023).

According to UNESCO (2021), the rapid development of AI is having a major impact on education; as advances in AI-driven solutions carry enormous potential for social good and the achievement of the Sustainable Development Goals; becoming the catalyst for instructional processes, as it provides digital means and materials capable of personalizing learning, automating didactic processes and generating predictive analysis of student learning; this technological revolution poses substantive challenges for teachers, as it requires the development of specific digital skills such as the use of AI platforms, the interpretation of data and the ethical integration of algorithms in curriculum design; that is, a sustained update in digital competence and culture.

In the field of education, artificial intelligence (AI) has established itself as one of the tools most used by students to interact with content, obtain explanations and solve academic activities. However, its integration into the teaching of mathematics in secondary education, especially to promote problem solving and the understanding of abstract concepts, is still limited. In this context, it is essential to ensure an adequate and effective pedagogical use of digital technologies in the classroom (Moreno-Mediavilla et al., 2023). However, the various AI tools have a high potential to optimize teaching, learning, and assessment processes, contributing to the strengthening of the didactic process.

However, in secondary education institutions there is a significant lack in the use and understanding of these technologies; a lack caused by the limited mastery of digital skills or by their lack of knowledge, which hinders the implementation of AI-based resources, slows down pedagogical innovation and compromises the effectiveness of teaching-learning processes (Sánchez, 2025). However, AI cannot easily replicate functions of the human brain, such as critical thinking, creativity, or ethical problem-solving. This merits assuming it as a tool to enhance human capacities and not to replace them, given that its greatest value lies in personalizing learning without losing the human dimension, strengthening the relationship between students and teachers, promoting continuous training, technical support and the development of educational policies that facilitate their responsible and effective incorporation into the classroom.

To complement the above, Flores & Núñez (2024), based on the review of 32 articles published in recent years on the application of artificial intelligence in education, identify various limitations, including insufficient teacher training and deficient technological infrastructure; It is worth mentioning that most of the studies included in the study are limited to higher education, leaving aside the primary and secondary education levels. On the other hand, Jiménez & Ramírez (2024) analyse the adoption of artificial intelligence in teachers by applying surveys to 299 educators, which made it possible to identify several limitations, such as unequal access to technology, poor teacher training, and fear of excessive use of this tool.

In the corpus of recent studies on artificial intelligence (AI), Nie et al. (2020) identified a positive and significant association between smartphone use and subjective well-being in rural farmers in China. For their part, Chang et al. (2021) noted that the implementation of a mobile chatbot for learning has the potential to improve both academic performance and self-efficacy in university students in northern Taiwan. Similarly, Lee et al. (2022), through an experimental study, demonstrated that the application of AI contributes to improving student performance, self-efficacy, and motivation. Likewise, Yilmaz & Karaoglan (2023) evidenced, in the context of programming, that the use of AI significantly increases students' self-efficacy and motivation. Finally, research carried out in Jordan reported positive attitudes towards the use of AI as an educational tool; along these lines, Ajlouni et al. (2023) concluded, based on a quantitative study, that AI is a valuable tool for learning, as it favours the development of primary counselling skills and contributes effectively in therapeutic contexts.

As can be seen, the aforementioned studies emphasize the well-being and academic success of students and their dependence on the learning environment and cultural context, as well as the educational advantages associated with the use of AI to support students' self-efficacy, motivation, and meaningful learning, which are determining factors for a comprehensive academic education. However, no studies could be found that measure the intensity of learning through the use of AI tools in the development of mathematical competences in secondary school students.

From this perspective, this research was aimed at answering the question: What is the level of relationship between AI-assisted teaching based on Khanmigo and the development of mathematical competences in secondary school students? Therefore, the objective of the research was: to determine the level of *influence of the use of artificial intelligence based on khanmigo on the development of mathematical competences in secondary school students;* in this framework, specific objectives were set regarding the level of incidence of the use of AI on problem-solving skills, reasoning, modelling and mathematical communication. The main hypothesis of the study is: The use of educational AI based on Khanmigo significantly influences the development of problem-solving, reasoning, communication and mathematical modelling skills in secondary school students.

2. LITERATURE REVIEW

2.1. *Artificial Intelligence and Education*

Artificial intelligence (AI) comprises computer programs that facilitate communication using natural language in text, image, or voice formats, simulating human activities. Its development has transformed various aspects of daily life, allowing tasks to be carried out more efficiently and quickly, simplifying processes that were previously complex and marking a before and after with the arrival of this technology (Tumbaco et al., 2025). In the field of education, it facilitates access to knowledge, optimises resources and encourages the development of fundamental digital skills in teachers and students (Jin et al., 2024); Its incorporation into the educational process implies pedagogical and didactic benefits aimed at optimizing learning. This technology enables the integration of algorithmic systems, digital interfaces, and augmented environments that actively structure the processes of meaning construction (González-González, 2023). In this context, mediation plays a key role in the interpretation, production, analysis and personalisation of content (Williamson & Eynon, 2020). Personalization allows for an effective learning experience, where students can advance at their own pace, reinforcing topics where they have difficulties and accelerating learning in topics they master (Gualsaqui et al., 2025).

In the field of education, AI tools are integrated with other strategies aimed at addressing current challenges, such as strengthening digital skills and creativity in secondary school students. In this context, AI contributes to shaping a new educational landscape focused on the development of creative thinking and problem-solving (Dawson et al., 2023). Likewise, these resources act as catalysts for educational activity by promoting personalized learning experiences adapted to the individual rhythms of students (Biswas, 2023), promoting flexible learning environments that enhance self-motivation and the achievement of meaningful learning.

The integration of AI in the pedagogical process must be accompanied by spaces for discussion, critical reflection and monitoring, as well as knowledge of its effects in the educational field. This technology opens up opportunities and requires a rethinking of education to respond to the challenges of access, quality, relevance, equity, and efficiency of education systems (Murra, 2025). Its use favours the generation of ideas for teaching, instructional design and the diversification of didactic resources through the adaptation of content and the presentation of information in different formats. Its main applications include intelligent tutoring systems, personalized learning, data analysis, and generative AI for class preparation (García-Peñalvo et al., 2024).

In the area of school mathematics, AI tools make it possible to carry out interactive activities, similar to those developed by students with teachers, and play an important role in strengthening mathematical skills. These tools facilitate the explanation of concepts, the resolution of exercises showing reasoning, the creation of problems adapted to the student's level and the detection and correction of common errors. They also allow for the proposal of activities, evaluations and rubrics; on the other hand, it offers tutoring, personalized support and interactive assistance in research activities, which strengthens motivation and vocation for learning; being of great help for the teaching of the teacher and the learning of the students.

2.2. Khanmigo-Based Artificial Intelligence

Khanmigo is an educational artificial intelligence system developed by Khan Academy, based on advanced language models and supported by AI-assisted learning. It works as a personalized tutor who guides the student through questions, progressive feedback, and step-by-step reasoning. Unlike other AI applications that offer direct answers, Khanmigo is designed under pedagogical principles such as Socratic learning, which encourages the student to discover the answer for themselves; cognitive scaffolding, which adjusts the level of help according to their progress; and active learning, which encourages reflection, critical thinking and problem-solving. This approach is based on the principle that knowledge is best built when the student actively participates and receives personalized guidance in real time.

From a pedagogical perspective, Khanmigo's educational innovation aligns with the principles of constructivism and the sociocultural theory of learning. From a constructivist perspective, learning mathematics is conceived as an active process in which students construct their own knowledge. In this sense, the tool guides students through orienting questions, helps them identify errors, and promotes understanding of mathematical procedures. It also connects with sociocultural theory by offering progressive support or scaffolding tailored to the student's level of understanding, thus facilitating the gradual assimilation of concepts. Similarly, it fosters Socratic learning through questions such as: What information does the problem provide? What formula could you apply? or why doesn't this result match the previous one? strengthening logical-mathematical reasoning and metacognition. Finally, it incorporates principles of adaptive learning, as it analyzes student responses to adjust the difficulty, type of help, and pace of interaction, allowing for more personalized teaching, especially in classrooms with a large number of students.

In mathematics education, Khanmigo is part of Intelligent Tutoring Systems (ITS), which are characterized by providing cognitive scaffolding, immediate feedback, and personalized learning pathways, fostering the development of mathematical skills and greater student participation (Son, 2024). Its application to arithmetic, algebra, and geometry content facilitates conceptual understanding, reasoning, communication, modelling, and problem-solving. Furthermore, AI-based tutoring systems represent a promising strategy for improving mathematical learning through personalized instruction and continuous support; however, their implementation must be complemented by the teacher's pedagogical guidance to ensure meaningful and ethically responsible learning experiences (Létourneau et al., 2024).

As part of the ITS, Khanmigo functions as an intelligent tutor that guides students through the problem-solving process without providing immediate answers. It offers constant support, reducing learning gaps, and reinforces the development of critical thinking and reasoning skills. As a support tool for teachers, it guides them toward more complex pedagogical tasks. It promotes the ethical use of AI, prioritizing responsible learning and preventing plagiarism or excessive reliance on other technologies. In this vein, AI-based tutoring systems can significantly contribute to personalized learning and the strengthening of mathematical competencies when implemented using relevant pedagogical approaches (Chudziak & Kostka, 2025). Khanmigo also stands out for functioning as an AI-based Socratic tutor that guides students through leading questions, fostering conceptual understanding, mathematical reasoning, and the development of problem-solving and argumentation skills; furthermore, it personalizes learning by adapting explanations and providing immediate personalized feedback according to the needs of the students, which contributes to differentiated teaching, particularly in classrooms of students with heterogeneous levels of mathematical knowledge (Khan Academy, 2024).

Addressing the diverse learning paces and levels of mathematical assimilation, Khanmigo allows for: reinforcing basic concepts for those who need it, and proposing additional challenges for more advanced students, significantly reducing frustration and the likelihood of students dropping out of math classes.

It also shifts the focus from using mistakes as punishment to using them as learning opportunities or starting points for analysis; this feature is key to reducing math anxiety and building student confidence. Another fundamental aspect is the support it provides teachers in reinforcing explanations covered in class and assisting with independent practice, allowing teachers to dedicate more time to reasoning, discussion, and solving complex problems.

In short, Khanmigo-based AI prepares students for responsible use of technology and to face future academic challenges, where deep understanding and reasoning ability will be more important than simply memorizing formulas; It emphasizes the process, rather than the results, helping the student to understand the meaning of the procedures, justify the answers and to relate mathematical concepts to each other for the different topics of mathematics.

2.3. Mathematic Competence in Second Education

Competence is the faculty that the person has to act consciously in the resolution of a problem; competencies is a complex learning, it involves the transfer and appropriate combination of very diverse capacities to modify a circumstance and achieve a purpose (MINEDU, 2020). In the educational field in general in secondary education, competence is conceived as contextualized and creative know-how, its learning is longitudinal, since it is reiterated throughout their schooling, in order to reach increasingly higher levels of performance; and they are constituted by the integration of knowledge, skills, values and attitudes, which enable students to act wisely in different contexts; developing in an integral way the three types of knowledge: doing, thinking and acting in the face of problematic situations that arise.

Within the framework of the Education 2030 Agenda, studies at the secondary level consider as a central axis the formative processes towards the acquisition of applicable knowledge, critical thinking and skills transferable to various contexts, preparing students to function effectively in complex contexts and permanent changes. In this way, UNESCO (2015) considers that it is necessary to "guarantee inclusive and equitable quality education and promote lifelong learning opportunities for all" (p. 7). Declaration indicating the prioritization of content acquisition and the development of transferable and meaningful skills in education systems in the global context.

Therefore, it is essential to rethink the strategies to carry out the learning process aimed at achieving and strengthening students' competencies, based on learning strategies based on the use of technology to enhance the learning of mathematics (Suyo et al., 2019). Thus, the achievement of mathematical competence implies building mathematical knowledge based on situations where it makes sense to relate concepts and conjecture, complying with three basic transversal principles: contextualization, globalization, and personalization of mathematical practice (Niss, 2002).

According to UNESCO (2017), the development of mathematical competence consists of the integration of knowledge, skills, attitudes and values that enable students to interpret, model and solve problems in multiple contexts. Consequently, mathematical competencies encompass the skills necessary to use mathematical concepts, procedures and tools in problem solving; which include numerical reasoning, mathematical modelling, and the effective communication of mathematical ideas. The development of these competencies is essential for the development of logical-mathematical thinking, as it allows students to apply their knowledge in a practical and contextualized way in various scenarios (Carriazo-Regino et al., 2024).

Problem solving: it is a fundamental competence of mathematics education. It is limited to the ability to identify, formulate and solve problematic situations in the context through mathematical tools, using varied strategies and evaluating the relevance of the results obtained. From UNESCO's perspective (2015), problem-solving promotes intellectual autonomy and strengthens higher cognitive skills, such as critical analysis and informed decision-making; from the application of what has been learned in real situations. The development of this competence by the student implies that he or she is able to interpret problematic situations, select appropriate strategies, execute procedures and critically evaluate the results obtained; It focuses on the execution of algorithmic processes aimed at the deep understanding of a topic and the transfer of knowledge.

Mathematical reasoning and argumentation: represents an essential mathematical thinking competence aimed at the comprehensive training of the student and is aimed at promoting critical thinking as a key skill of the 21st century. This is manifested in the ability to establish logical relationships, formulate conjectures, justify procedures and communicate demonstrations according to the educational level. Mathematical reasoning favours logical-deductive thinking and contributes to the development of a mathematical culture based on evidence and conceptual coherence, strengthening intellectual autonomy and the ability to base decisions based on evidence. This competence makes it possible to link abstract knowledge with real phenomena, promotes learning applicable to concrete situations, aimed at ensuring relevant and effective results.

Mathematical communication and representation: consists of the student's ability to express, interpret and argue mathematical ideas in a clear, coherent and grounded way, using mathematical language and appropriate representations in different contexts. This competence implies that the student not only solves exercises, but also can explain how he thinks, justify procedures, interpret information and dialogue mathematically with other people. Mathematical communication is the ability to express and interpret mathematical ideas clearly through various systems of representation, such as oral and written language, algebraic symbols and expressions, graphs, tables, diagrams, and numerical and geometric representations. It also allows you to understand and analyse mathematical information present in different contexts and situations of daily life.

Mathematical modelling: consists of the student's ability to represent, interpret, analyse and solve situations in the real context through the use of mathematical concepts, procedures and language; that is, to make the connection of mathematics with problems of everyday life, scientific, economic, social or technological. This competence is aimed at the student applying formulas, and understanding how mathematics helps to explain phenomena and make informed decisions. Its effectiveness includes a cyclical process in which students: Identify a problem in the real context, recognising situations in their environment that can be analysed mathematically; select relevant variables, data and relationships; use algebraic expressions, tables, graphs, functions, equations, proportions, statistics or other mathematical resources; apply mathematical procedures and strategies to obtain results; interprets and validates the results that make sense in reality; and explains the process and supports the decisions made.

Based on the three topics developed in the literature review section, AI can be established as an essential ally for the strengthening of the three fundamental competencies in the area of mathematics developed in this study, since the relevant application of digital technology tools allows the optimization of teaching-learning processes; through a number of pedagogical resources. Thus, the relevant and responsible integration of artificial intelligence transforms teaching practices and supports the integral growth of students, as it enhances critical thinking, the resolution of real problems and the formation of citizens capable of facing the challenges of the digital age. Where, instruction, pedagogy, assessment practices and the integration of innovative technologies in educational institutions are already part of the potential that learning environments have in the twenty-first century.

The potential of AI as a tool adaptable to the teaching-learning process of mathematics lies in its ability to promote motivation towards learning and the level of development of mathematical skills of students. In this sense, its implementation favours various dimensions of the educational process, including the development of research skills, the personalization of learning, the strengthening of student autonomy, as well as the increase of motivation and academic commitment. Likewise, its use in the educational field contributes to the dynamic, sequential and efficient learning of mathematical content and to the promotion of positive attitudes towards this discipline in secondary education.

3. METODOLOGY

3.1. Research Approach

This research is developed under a quantitative approach, since it seeks to objectively measure the relationship between the frequency of use of Khanmigo-based AI in the learning of mathematics in secondary school students. According to Hernández-Sampiere & Mendoza (2018), "*the quantitative approach uses data collection and analysis to test hypotheses based on numerical measurement and statistical analysis*" (p. 5). This approach makes it possible to establish causal relationships between variables, as well as to compare results obtained before and after the application of the pedagogical intervention using the AI tool based on Khanmigo.

3.2. Type And Design of Research

The research is of an applied type, since it tried to measure the efficiency of the technological mediation in the teaching-learning process, prioritizing the analysis of data, the subject-technology interaction and mediated learning experiences. It seeks to generate knowledge aimed at solving a specific educational problem, specifically improving the learning of mathematics through the use of AI tools. It is also framed at an explanatory level, since it aims to determine the influence of the use of AI on the learning of Mathematics, establishing cause-effect relationships between the independent variable and the dependent variable. The design of the research was experimental in its pre-experimental variant, since the intervention work was carried out in a single group, with measurement before and after the experimental intervention of the behaviour of the study variable, in order to investigate in a factual way, the consequences of the insertion of AI in the instruction process.

3.3. Study Variables and Participants

The variables identified for the study were: Use of AI tools in the teaching-learning of mathematics, at the nominal level; and development of mathematical competencies in secondary education students, at interval level. The variables were operationalized into measurable dimensions and indicators, and then analysed using descriptive and inferential statistical techniques.

The population was made up of students in the last year of secondary education from the province of Huánuco enrolled in the academic year 2025, whose ages fluctuate between 16 and 18 years old; The work was carried out with the participation of 38 students representing 10% of the population, chosen through random sampling by clusters. The sample was made up of students in the last year of studies to whom the data collection instruments were applied both before and after the pre-experimental process.

3.4. Research Techniques and Instrument

The research technique used was the survey, due to its effectiveness in collecting intangible information, such as perceptions and reasoning of the participants, aimed at the collection and rigorous analysis of data (Stantcheva, 2023). In this research, two questionnaires were applied, whose items are distributed in four dimensions and in 20 items for each variable; Both instruments were designed to measure and evaluate the study variables according to the objectives set for the study. Likewise, both questionnaires aim to measure the study variables at two times (before the intervention and after the experimental process to measure the effect of the integration of the AI tool on the process of acquiring mathematical knowledge. These instruments were developed in line with the objectives of the study and adapted to the academic context of the research environment. To guarantee their quality, the instruments went through validation and reliability procedures.

The questionnaire designed for the collection of data for the variable use of AI, was aimed at measuring the level of pedagogical, technological, cognitive and motivational importance perceived by secondary education students, each dimension of study contains 5 items, adding a total of 20 items. The items are aimed at the students' assessment of the contribution provided by the AI tools for the learning of mathematics at four levels (1 = deficient, 2 = regular, 3 = good, 4 = excellent), table 1. The wording of the items is based on the everyday teaching-learning contexts in school classrooms, where the participants in the study were asked to respond based on real experiences. Prior to being administered, to ensure that the items are clear and understandable, the questionnaire was validated by expert judgments and a reliability test.

Table 1: Dimensions And Items for Assessing the Usefulness of AI In the Mathematics Classroom.

Dimension	Items	Rating
Pedagogical	The AI adapts the content to my level of learning. The AI provides immediate feedback on my answers. The AI adjusts the pace of learning according to my needs. The use of AI promotes my participation in learning. AI makes it easier to understand complex topics.	Deficient Regular Good Excellent
Technology	The AI platform is easy to use. I can access the AI from different devices without difficulty. The interaction with AI is clear and understandable. AI integrates properly with other digital tools. AI works stably during use.	Deficient Regular Good Excellent
Cognitive	The use of AI strengthens my critical thinking. AI helps me solve problems more efficiently. AI improves my logical reasoning. AI favours my understanding of concepts. I can apply what I learned with AI in new situations.	Deficient Regular Good Excellent
Motivational	The use of artificial intelligence increases my interest in learning. I feel more motivated by using AI in my studies. Artificial intelligence fosters my autonomy in learning. Using AI reduces my anxiety about academic tasks. I persist more in difficult activities when I use AI.	Deficient Regular Good Excellent

To measure the mathematical competence developed by the students, a test of 20 items was used, five for each of the four dimensions and one item for each indicator (20 items, valued from 0 to 4 points), the same to be evaluated with a qualification in the vigesimal system (00 to 20), by dimension. The objective of the test was to measure the level of mathematical competencies developed by the participants before and after implementing the mathematics teaching-learning strategy; whose items were built aligned with the content scheduled for the second semester of the 2025 school year. The test items are circumscribed in the indicators of the dimensions of: problem solving, mathematical reasoning, communication, and mathematical modelling (Table 2).

Table 2: Dimensions, Indicators and Rating System for the Development of Mathematical Competencies.

Dimension	Indicators	Qualifier
Troubleshooting	Identify relevant data in mathematical problems. Select strategies to solve a problem. Execute step-by-step procedures with feedback. Verify results using explanations. Adjust problem-solving strategies.	From 0 to 20
Reasoning and argumentation	Formulate conjectures based on guiding questions. Justifies procedures with the support of explanations. Contrast their answers with those suggested by the AI. Identifies errors in their reasoning and feeds back on themselves. Use examples and counterexamples provided by AI to make an argument.	From 0 to 20
Mathematical Communication	Explains mathematical procedures performed. Use symbolic language correctly. Interpret graphs and representations. Translate everyday problems into mathematical language. Reformulate answers based on feedback.	From 0 to 20
Mathematical modelling	Identifies relevant variables of a mathematical expression. Build and use mathematical models. Represents relationships using equations or graphs. Interpret solutions with contextualized explanations. Evaluate the validity of the model with the help of simulations.	From 0 to 20

The content validity of the instruments was established through expert judgment, made up of teachers with extensive experience in mathematics education and pedagogical use of digital technology; the chosen experts evaluated the relevance, clarity and coherence of the items. Likewise, internal validity was examined using correlations between the total of items. On the other hand, in the measurement of reliability, a high reliability was obtained (Cronbach's Alpha Coefficient: 0.87 and 0.93, for each instrument).

3.5. Investigative Procedure

The research process begins with the choice of the population and study sample; then, a pre-test is applied to the study group before implementing the AI tool in the teaching-learning process, which allowed establishing the level of knowledge and mathematical skills of the students foreseen in the curricular design, considering aspects such as basic algebraic operations, the solution of first-degree equations, the interpretation of the graph of functions, the fundamental concepts of geometry and the statistical analysis of data from everyday situations. This diagnostic stage allowed establishing a baseline, to proceed with the pedagogical intervention mediated by AI, aimed at strengthening the mathematical competences of the students.

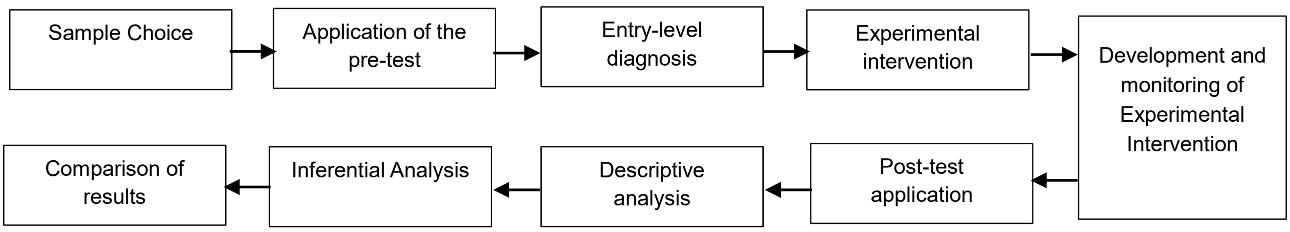

Figure 1: Route Followed in the Research Process.

The mediation phase consisted of the systematic implementation of AI tools to support the teaching-learning process of mathematics, actively integrating them into the process of planning and achieving classes. During a two-month period, the students participated in activities designed to strengthen the weaknesses detected in the diagnostic phase. Each teaching-learning session was carried out through the combination of a conceptual introduction of the topic addressed and the use of AI tools in practical activities, aimed at promoting participation and constant interaction among participants. The students carried out their learning activities individually and collaboratively, making use of AI tools, reinforced with the use of software and mathematical simulators that motivate and facilitate the development of learning activities.

The measurement of competencies was carried out through a multiple-choice test and direct resolution exercises, whose items were oriented to the analysis of the three competencies established for this study. The test was graded in the vigesimal system, distributed proportionally according to the dimensions and indicators of each competency. Also, an observational rubric was used during the initial class sessions to record aspects related to class participation, accuracy in problem solving and argumentation of mathematical procedures. The data collected through the questionnaire were analysed using statistical software (Excel and Minitab). For this process, descriptive statistical techniques (mean, coefficient of variation and range) were used to present attitudes towards AI and the scores obtained in the evaluation rubric administered to the study sample; and, Student's t-test for paired data with a significance level of $\alpha = 0.05$.

The intervention process was accompanied by continuous monitoring through participation records and formative or process evaluations, with the purpose of guiding the progress of the students, both individually and in groups. Some metacognitive reflections were also promoted based on brief discussions at the end of each activity, where the participants mentioned, the strategies used, their difficulties and their achievements with the use of AI. This methodology facilitated the reinforcement of academic content and stimulated the development of mathematical skills and critical thinking, autonomy in learning and familiarization with the use of digital tools for educational purposes, preparing students to face the educational challenges of the twenty-first century with greater competencies.

4. RESULTS

The results focus on the use of AI in the context of mathematics classes with students in the fifth grade of secondary education. First, the self-rating of the value of Khanmigo-based AI by the participants before and after the experimental intervention in the teaching-learning process of mathematics was analysed; then, the impact of AI on learning and the development of mathematical skills in the four dimensions consigned for this study is evaluated.

4.1. Value Of AI Tools Before and After the Experimental Interventions

As a global result of the answers obtained from the participants and from the 20 items considered in the assessment survey, on the usefulness of AI at the pedagogical, cognitive, technological, and motivational level in the teaching-learning process of mathematics, applied before and after the experimental intervention. The results showed significant changes in the students' perception of the usefulness of this technological resource. Before the intervention, 23.68% of the students rated as deficient; after the experience, this percentage decreased to 4.61%; In the same orientation, the qualification of fair decreased from 43.29% to 30.92%. In contrast, the good rating increased from 27.50% to 37.50%, while the excellent category increased from 5.53% to 26.97% (Figure 2). These results show that the application of AI based on Khanmigo had a positive effect on the teaching-learning process of mathematics, by significantly reducing performance levels with poor and regular ratings, and increasing good and excellent ratings.

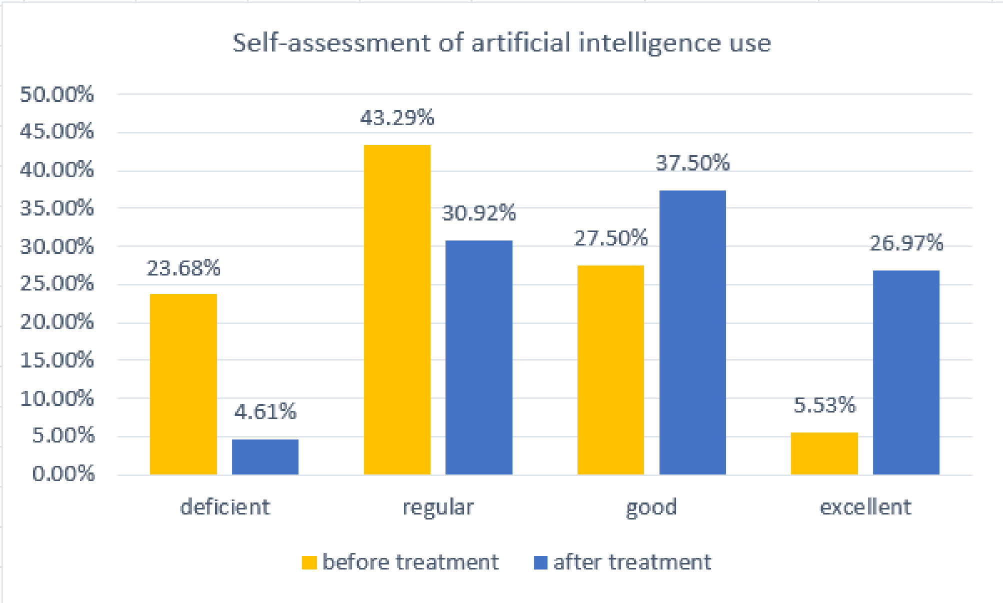

Figure 2: Qualification Of the Pedagogical, Technological, Cognitive and Motivational Use Before and After the Experimental Treatment.

Also, the results shown in Figure 2 indicate that students in the last year of secondary education have a positive attitude towards the use of AI tools, however, their application in the performance of academic activities is still in the process of consolidation. Despite the fact that most of the participants, after the experimental intervention, rate the use of Khanmigo-based AI tools as good or excellent, with respect to its influence on the development of problem-solving, reasoning, communication and mathematical modelling skills, there are limitations in its full integration of this tool in the classroom by mathematics teachers. being a latent task to overcome the limitations in its academic use and in its full integration into the learning process.

4.2. Development Of Mathematics Competence Before and After Experimental Action

Regarding the comparative descriptive analysis based on four descriptive statistical measures of central tendency and dispersion based on the results of the evaluation of the development of mathematical competence developed by the students, before and after the experimental process, in the four dimensions in the present study.

In the *problem-solving* dimension, the mean increased from 11,711 to 14,184, while the coefficient of variation of the scores obtained in the pre-test had a variability of 23.98%, while in the post-test only 14.73%; likewise, the interquartile range and range decreased significantly (Table 3). These results indicate that after the use of Khanmigo-based AI, the problem-solving skills of secondary school students have improved significantly.

Table 3: Means, Ranges and Coefficients of Variation of the Capacities Of: Problem Solving and Mathematical Reasoning Before and After the Experimental Intervention.

Troubleshooting				
Variable	Media	CoefVar	Range	IQR
Pre-test	11.711	23.98	11.000	4.250
Post-test	14.526	14.73	7.000	3.000
Mathematical reasoning				
Pre-test	10.921	24.77	11.000	4.000
Post-test	14.395	14.31	8.000	3.000

Also, in the second section of Table 3, it is shown that the development of mathematical *reasoning ability*, with respect to the mean, has evolved from 10.921 to 14.395; while the coefficient of variation has decreased from 24.77% to only 14.31%, this indicates that the results obtained by the students became homogeneous in the qualifications obtained; similarly, the range and interquartile range also decreased. by 2 and 1 points, respectively. These results indicate that after the integration of AI tools based on the Khanmigo, the level of mathematical reasoning and argumentation of the students has improved significantly after the experimental treatment.

In the dimension of *mathematical communication*, the mean of the qualifiers obtained by the participants increased from 11,605 to 14,368, in terms of the measures of dispersion, before the intervention the coefficient of variation, range and interquartile range were obtained: 25.03%, 11 and 4.250, respectively; while after the experiment the values of these statistics were: 14.42%, 8.00 and 3.00, respectively (Table 4). These results indicate that the experimental intervention in the teaching-learning process of mathematics mediated with AI based on the Khanmigo, significantly influenced the mathematical communication skills in secondary school students.

Table 4: Means, Ranges and Coefficients of Variation of the Capacities Of: Communication and Mathematical Modelling Before and After the Experimental Intervention.

Mathematical Communication				
Variable	Media	CoefVar	Range	IQR
Pre-test	11.605	21.81	9.000	4.250
Post-test	14.368	14.42	8.000	3.000
Mathematical modelling				
Pre-test	11.395	25.03	11.000	3.500
Post-test	14.474	17.06	9.000	2.250

In the mathematical *modelling dimension*, the mean before the experimental treatment was 11,395 and after the treatment 14,474, increasing by more than 3 points; while in the dispersion measures the range decreased from 11 to 9, similarly the interquartile range from 3,500 to 2.25 and the coefficient of variation decreased from 25.03% to 17.06 (Table 4). These results show that, after the use of AI based on the Khanmigo, the ability of secondary school students to identify and use mathematical models has improved significantly.

In general, from the results summarized in tables 3 and 4, a substantial increase in the mean grades can be perceived in four dimensions considered for this study; Likewise, with respect to the dispersion measures, a significant decrease can be evidenced, both in the range, coefficient of variation, and in the interquartile range, which indicates that after the experimental intervention the data were more homogeneous with respect to before the intervention. These results showed that, in general, students had fragmented knowledge and difficulties in the study and learning of mathematics, which justified the need to implement an intervention through the use of AI to strengthen their mathematical skills and consequently a development of mathematical competencies in secondary education students.

It should also be noted that these achievements were favoured by the development of autonomous and interactive mathematical activities that the students carried out during their learning activities. As a result, the use of AI through Khanmigo not only facilitated the acquisition of mathematical knowledge, but also strengthened the analytical skills, logical reasoning and decision-making of secondary school students. Overall, the results confirm that the integration of digital technologies in the classroom is a relevant factor to strengthen the learning of mathematics in secondary education, by favouring motivation, participation and the development of academic skills.

4.3. Inferential Analysis of Results

Before proceeding with the hypothesis test, the Shapiro-Wilk normality tests were applied to the data obtained in the pre-test and post-test on the level of development of mathematical competencies. For both cases, the significance values (p-value) were 0.291 and 0.253, respectively, both higher than the significance level (0.05). These results indicate that the null hypothesis of normality is not rejected, therefore, the data (scores) of both tests fit an approximately normal distribution, so the t-test was applied for paired samples. This statistical test was selected because the study was based on a single group of students, to whom measurements of the mathematical competence developed were applied, before (protest) and after (post-test) of the intervention, generating data dependent on each other. The objective was to determine if there was a significant difference in the development of students' mathematical skills after the integration of AI tools in the teaching-learning process.

The null hypothesis to contrast with the results obtained in the protest and post-test for the four dimensions considered at a significance level of 0.05 was: The use of educational AI based on Khanmigo does not significantly improve problem-solving skills, reasoning, communication and mathematical modelling in secondary school students. For the process of testing the null hypothesis, the theoretical critical value for the rejection of this null hypothesis (t = 1.687 and p-value = 0.05) was taken as a degree of freedom of 37.

The results of the t-test for the problem-solving dimension (Table 5) indicate a t-value of 9.27 and a p-value of 0.000, evidencing a significant difference between the means of the two measurements of the measurements before and after the experimental intervention. Similarly, in this same table, for the mathematical reasoning dimension, the calculated value of t is 10.45 and the p-value is 0.000; both indicate the rejection of the null hypothesis, that is, the mathematical reasoning capacity developed by the students with the implementation of AI tools was significant. In short, the use of educational AI based on Khanmigo significantly improves problem-solving and mathematical reasoning abilities to 95% confidence.

Table 5: Paired T-Test for Dimensions: Problem Solving, And Mathematical Reasoning.

Hypothesis Testing: Problem Solving	
Null hypothesis	H_0 : difference = 0
Alternate hypothesis	H_1 : difference > 0
T-Value	P value
9.27	0.000
Hypothesis Testing: Mathematical Reasoning	
Null hypothesis	H_0 : difference = 0
Alternate hypothesis	H_1 : difference > 0
T-Value	P value
10.45	0.000

According to Table 6, as a result of the paired t-test for the *mathematical communication* dimension, the value of *t* = 9.67 and a p-value of 0.000 were obtained, results that show a significant difference between the means obtained in this dimension before and after the experimental intervention. On the other hand, for the mathematical *modelling dimension*, the calculated value of *t* was 8.94 and the p-value of 0.000; both indicate the rejection of the null hypothesis, that is, the ability to identify and use mathematical models in students had a significant improvement since the implementation of AI tools. The use of educational AI based on Khanmigo significantly improves *communication* and *mathematical modelling* skills in secondary school students with a confidence level of 95%.

Table 6: Paired T-Test for Dimensions: Communication and Mathematical Modelling.

Hypothesis Testing: Mathematical Communication	
Null hypothesis	H_0 : difference = 0
Alternate hypothesis	H_1 : difference > 0
T-Value	P value
9.67	0.000
Hypothesis Testing: Mathematical Modelling	
Null hypothesis	H_0 : difference = 0
Alternate hypothesis	H_1 : difference > 0
T-Value	P value
8.94	0.000

From the four tests analysed (Tables 5 and 6), it can be concluded that AI tools applied in a pertinent way strengthen the teaching of mathematics by offering motivating strategies that enhance students' abilities, their effectiveness directly depending on adequate teaching planning. Significantly benefiting the teaching-learning process of mathematics in secondary education, as long as teachers and students have the necessary skills in the use and management of the tools provided by digital technologies.

5. DISCUSSION

In digital education, the decisive factor is not access to technological resources or technical mastery of platforms, but rather the teacher's ability to transform technology into a meaningful pedagogical tool (Revuelta et al., 2022). Furthermore, digital technology fosters the development of logical-mathematical thinking by enabling the practical and contextualized application of knowledge in diverse scenarios (Carriazo-Regino et al., 2024). It also facilitates continuous monitoring, timely feedback, diversification of learning evidence, and the strengthening of student self-regulation. However, this study identified problems related to the inappropriate use of AI in academic activities, technological dependence, and a decline in students' critical thinking skills, primarily associated with technical limitations and insufficient teacher training in digital technology applied to mathematics education.

In a correlational study, Ihsani (2024) demonstrated that ChatGPT use is positively associated with solution quality, self-efficacy, and metacognitive engagement, suggesting that the intensity of its use could predict perceived problem-solving skills in mathematics learning. This explanatory study, using pre- and post-tests, reported encouraging results, based on students' self-assessments of the role of AI in their learning process and development of mathematical skills. The study revealed a significant improvement in secondary school students' perceptions of Khanmigo as a tool for self-study and deep learning of mathematics.

According to Ajlouni (2025), AI-based and technology-enhanced learning environments can support students' emotional well-being, where ChatGPT functions both as a cognitive support tool and an affective resource in mathematics learning, helping to explain its significant associations with students perceived mathematical problem-solving skills. Reinforcing this position, the study focused on implementing teaching strategies aimed at promoting active learning and critical, contextualized digital competence among teachers, geared towards innovating the teaching-learning process. It explored and leveraged the potential of these tools, which fostered significant changes in the value and use of technology in secondary education.

The teaching of mathematics in secondary school aims to promote the development of logical, critical and creative thinking in students, aimed at solving everyday problems, interpreting information and making informed decisions. In this framework, it is essential that students understand and apply concepts of arithmetic, algebra, geometry and statistics in situated contexts. From a teaching perspective, digital resources such as AI serve as support from the personalization of learning to the creation of more interactive and adaptive teaching environments (Aparicio-Gómez, 2023). Aimed at the optimization of educational processes, particularly in planning, didactic mediation, formative assessment and student participation (Tondeur et al., 2008). In line with the above, the results of this study show a direct and statistically significant influence of the use of AI on the quality of the teaching-learning process and the development of mathematical competences in secondary education students.

Salinas et al. (2024) concluded that AI can enrich hands-on learning and authentic assessment when students understand its operation, limitations, and academic applications. Furthermore, its educational impact is favourable when complemented by training in information validation, ethical criteria, and strategies for critically integrating the generated content (Pham et al., 2025). In accordance with these findings, the present study demonstrated that the integration of AI transcends the technical aspects and involves cognitive, metacognitive, and ethical dimensions to achieve effective educational benefits, as evidenced by the ratings given by the majority of participants, who rated the experience as good or excellent after the experimental intervention.

Therefore, for an efficient integration of AI in the educational process, it is essential to prepare teachers in the selection and relevant use of this technological tool for the study of mathematical content, ensuring, in turn, that students develop critical awareness and the ability to evaluate both content and technology in a reflective way. This approach aligns with contemporary demands for human-centred approaches to educational technology, which seek to balance innovation with pedagogical accountability (Holmes et al., 2024). In this sense, the sustained and regulated use of AI tools can optimize the learning of mathematics; however, it is important to consider that an excessive reliance on these technologies could weaken critical skills, erode confidence in one's own abilities, and affect the student's autonomy.

In today's education, it is essential to carry out the learning process based on the interaction between students and intelligent systems to ensure effective pedagogical mediation, promoting automated decision-making and the responsible use of these tools for academic and training purposes (Flores-Vivar & García-Peñalvo, 2023). In this context, artificial intelligence favours the personalisation of student learning and the academic support of teachers, adapted to the specific needs of each educational context (Mejía-Janampa et al., 2025), consolidating itself as a tool for guiding, structuring and evaluating the learning process in a coherent way. These findings coincide with studies that highlight the contribution of AI in the design of more organized learning experiences. (Caicedo et al., 2025). Consequently, the results show a positive impact of AI on the teaching-learning process of mathematics, promoting pedagogical, didactic and ethical advances for its effective integration in the classroom. Likewise, the high level of satisfaction of the participants regarding the use of Khanmigo reveals the potential of this tool to strengthen the mathematical skills of secondary school students.

On the other hand, the development of

mathematical competencies requires constant practice, a positive attitude towards learning, and evaluation processes aimed at demonstrating practical skills beyond the theoretical domain (Acosta et al., 2025). In this context, the teacher plays a fundamental role in promoting student motivation and concentration through the use of innovative digital tools, such as AI, as well as by designing activities that strategically integrate these technologies to strengthen learning and mathematical skills in secondary school students. To capture this purpose, in this study, AI was conceived as a complementary tool that favours instructional planning and access to knowledge, without replacing teaching work, recognizing both its educational potential and the risks associated with its indiscriminate use, which could encourage technophilic behaviours in students.

The tools provided by digital technology are considered crucial to overcome difficulties in mathematics and promote meaningful learning, but they require adequate mastery of their use by the teacher (Mora, 2003). It is necessary to maximize their impact to strengthen teacher training and improve the availability of teaching materials, considering that the effectiveness of digital tools depends on their constant use and integration into real learning contexts (Vélez & Rivadineira, 2023). This prerogative was also evidenced in the study, where the descriptive analysis of the results evidenced a significant improvement in the development of mathematical competencies in the four dimensions, increasing the grades obtained by more than 3 points between the pre-test and the post-test administered.

The effective integration of technology in education depends on the articulation between the technological, pedagogical and disciplinary knowledge of teachers (Runge et al., 2023). After the experimental work, a significant advance was envisioned in the management of AI tools in the didactic and pedagogical management of teachers. As teachers' knowledge and use of AI is strengthened, the didactic and pedagogical conditions of the classroom have improved. The impact of the use of AI with didactic intentionality on learning and the development of mathematical skills in secondary school students is empirically confirmed. Thus, interactive activities emerge as pedagogical catalysts that transform teaching practices and learning dynamics, highlighting the need for equitable and sustainable digital integration aimed at the comprehensive training of students (Ajlouni et al., 2025).

Regarding AI-assisted tutoring, Son (2024) argues that it offers new opportunities to enrich the teaching and learning of mathematics, noting that its effectiveness depends on the alignment between its functionalities, the educational context, and the teacher's role in designing learning activities. In line with this perspective, during the experimental intervention, students solved mathematical problems through guided practice, solution analysis, and problem-solving by analogy. Students also assumed peer tutoring roles, providing feedback on their classmates' problem-solving processes while simultaneously receiving automated feedback on their own reflective practice.

Like any study, this research had some limitations, both in the methodology employed and in the experimental intervention. Methodologically, the use of a pre-experimental design, characterized by a small sample, the absence of a control group, and limited control of external variables, meant that the improvements observed in students' mathematical skills are attributed with some restrictions, since factors such as student maturity, concurrent educational experiences, or the effect of prior assessments could have influenced the results. Therefore, the findings were interpreted with caution regarding the effectiveness of the intervention. Indeed, "Pre-experimental designs constitute a viable alternative in the face of institutional or logistical constraints, but they present some limitations that affect the internal and external validity of the results" (Hernández et al., 2018).

Several limitations were identified during the experimental intervention. First, the cross-sectional design only allowed for establishing relationships between variables through self-perception questionnaires, which are susceptible to social desirability bias and subjectivity, without considering their evolution over time (Ghomi & Redecker, 2019). Furthermore, teachers and students reported institutional barriers to integrating AI in the classroom, including insufficient technological infrastructure, limited connectivity, inadequate training in emerging digital resources, time constraints, and a lack of ethical guidelines—factors that can affect the effectiveness and equity of its educational use (Esteves-Fajardo et al., 2024). In addition, limitations in teachers' digital skills continue to hinder the effective incorporation of these technologies into teaching and learning processes (Vargas et al., 2024). Therefore, it is essential that educational institutions strengthen digital accessibility and promote ongoing teacher training for the pedagogical use of AI tools in specific subjects.

As a recommendation, future research could expand the analysis by adopting longitudinal designs that allow assessing not only the immediate satisfaction of students, but fundamentally the long-term impact on academic performance and the development of competencies (Granda et al., 2024). It would also be plausible to incorporate mixed methodologies that combine quantitative data with classroom observations, interviews, or analysis of pedagogical practices, in order to obtain a deeper understanding of the subject under study (Harris et al., 2009). It would also be necessary to compare the effects of the use of AI in the different areas of instruction in secondary education and at other educational levels that make it possible to identify common patterns and particularities in the relationship between the use of AI tools and the development of mathematical skills.

6. CONCLUSIONS

This study contributes empirical evidence on the knowledge and pedagogical use of artificial intelligence (AI), identifying some limitations of teachers and secondary school students, who use it sporadically due to a still basic knowledge of its educational potentialities and applications. However, secondary school students positively valued the usefulness of AI tools for learning mathematics. Likewise, significant differences were found in the perception and assessment of AI in the four dimensions analysed, highlighting the need to strengthen the didactic and pedagogical mechanisms that guide a pertinent use of digital resources in the teaching-learning process. In this context, the integration of Khanmigo in the teaching of mathematics in secondary education made it possible to design, implement and analyse educational strategies supported by AI to optimize teaching practice and student learning.

Firstly, the results show that the appropriate use of artificial intelligence (AI) tools has a positive influence on the attitude of secondary school students towards learning mathematics. Likewise, a greater inclination of students for the sciences was observed compared to the areas of social sciences and humanities. In addition, differences in the responsible academic use of AI were more noticeable in the later years of schooling, suggesting a greater awareness of the importance of technology for their personal and academic development. In line with this, most of the participants rated the contribution of AI tools to their learning and the development of their mathematical skills as good or excellent.

Regarding the development of mathematical skills mediated by artificial intelligence tools based on Khanmigo. First, this technological tool promoted intellectual autonomy and strengthens higher cognitive skills, such as critical analysis and informed decision-making; from the application of what has been learned in real situations; making students interpret problematic situations, select solution strategies, carry out procedures and evaluate the results obtained; likewise, execute algorithmic processes aimed at the deep understanding of a topic and the transfer of the mathematical knowledge acquired.

Secondly, the students significantly developed their capacity for reasoning and mathematical argumentation, as they show the ability to establish logical relationships, formulate conjectures, justify procedures and communicate appropriate demonstrations; externalizing the developed logical-deductive thinking; linking abstract knowledge with real phenomena, evidenced in learning applicable to concrete situations, aimed at ensuring relevant and effective results.

Thirdly, the students made significant progress in the use of representation systems (numerical, algebraic, graphic and verbal), as well as interpreting information presented in different formats; significantly improving their ability to verbally explain how they solved an equation or interpret a graph of a mathematical function, having this as a tool for informed decision-making. Students also made significant progress in their ability to represent, interpret, analyse and solve situations in the real context through the use of mathematical concepts, procedures and language; that is, to make the connection between mathematics and everyday life, scientific, economic, social or technological problems. This competence is aimed at the student applying formulas, and understanding how mathematics helps to explain phenomena and make informed decisions.

The results, described and analysed from a logical and critical perspective, suggest that the integration of AI tools should not be conceived as an isolated complement to the didactic process, but as a structural transformation of educational practices, aimed at training autonomous, critical and competent students in the face of the challenges of an increasingly technological and connected society. In this sense, it is recommended to develop high-impact longitudinal studies, explore scalable models in various educational contexts, and strengthen teacher professional development programs that promote the design of innovative learning experiences. Likewise, the need to guarantee equitable and sustained access to technologies is emphasized, as well as to promote the pedagogical use of AI tools in the learning of mathematics and the continuous training of teachers in digital resources.

In summary, this study contributes to a deeper understanding of how the pedagogical mediation of artificial intelligence tools can enhance the use of emerging technologies in mathematics learning. It also shows that teacher-led interaction favours processes of abstraction, critical analysis, and synthesis, contributing to the achievement of significant learning. In this sense, the research constitutes a relevant basis for the design of future pedagogical strategies. However, the integration of AI in mathematics education must be progressively consolidated and improved, addressing challenges such as reducing technological gaps and improving automated interactions, in order to ensure effective, equitable and sustainable implementation in secondary education.

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