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Multiple Representations and Meaningful Learning in Mathematics Education During the Transition to Higher Education

Representaciones múltiples y aprendizaje significativo en la enseñanza de la matemática durante la transición a la educación superior

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ABSTRACT

The transition from secondary education to higher education represents one of the major challenges in students' mathematical development. During this stage, many first-year university students experience difficulties in understanding fundamental mathematical concepts due to limited connections among different forms of mathematical representation and the predominance of procedural learning approaches. In this context, the present study aimed to analyze the contribution of multiple representations to meaningful learning of mathematical concepts among first-year university students. A mixed-methods approach with a quasi-experimental design was

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employed, involving students enrolled in introductory Mathematics and Precalculus courses. The instructional intervention was grounded in Duval's theory of semiotic representation registers and Ausubel's theory of meaningful learning, incorporating activities that promoted the integration of algebraic, graphical, numerical, tabular, and verbal representations. The findings revealed significant improvements in conceptual understanding, graphical interpretation, coordination among representation registers, and mathematical problem-solving skills. In addition, students reported positive perceptions of the instructional strategies, emphasizing that the use of multiple representations facilitated content comprehension and supported the construction of meaningful knowledge. The study concludes that multiple representations constitute an effective pedagogical strategy for enhancing meaningful learning in mathematics during the transition to higher education. Furthermore, they contribute to the development of mathematical reasoning, conceptual understanding, and the application of knowledge in diverse contexts. These findings provide relevant evidence for the design of educational practices aimed at improving mathematics teaching and learning in the early years of university education.
Keywords: Multiple representations; meaningful learning; higher education; mathematics education.

RESUMEN

La transición de la educación secundaria a la educación superior representa uno de los principales desafíos en la formación matemática de los estudiantes universitarios. Durante esta etapa, muchos estudiantes presentan dificultades para comprender conceptos fundamentales debido a la escasa conexión entre los diferentes registros de representación matemática y al predominio de aprendizajes centrados en procedimientos mecánicos. En este contexto, la presente investigación tuvo como objetivo analizar la contribución de las representaciones múltiples al aprendizaje significativo de conceptos matemáticos en estudiantes de primer ingreso universitario. Se desarrolló un estudio con enfoque mixto

y diseño cuasi experimental, en el que participaron estudiantes matriculados en asignaturas de Matemática Básica y Precálculo. La intervención didáctica se fundamentó en la teoría de los registros de representación semiótica de Duval y en la teoría del aprendizaje significativo de Ausubel, incorporando actividades que promovieron la articulación entre representaciones algebraicas, gráficas, numéricas, tabulares y verbales. Los resultados evidenciaron mejoras significativas en la comprensión conceptual, la interpretación gráfica, la coordinación entre registros de representación y la resolución de problemas matemáticos. Asimismo, los estudiantes manifestaron una valoración positiva de las estrategias implementadas, destacando que la integración de diferentes formas de representación facilitó la comprensión de los contenidos y favoreció la construcción de significados. Se concluye que las representaciones múltiples constituyen una estrategia didáctica efectiva para fortalecer el aprendizaje significativo de la matemática durante la transición a la educación superior, contribuyendo al desarrollo del razonamiento matemático, la comprensión conceptual y la aplicación de conocimientos en contextos diversos. Estos hallazgos aportan evidencia relevante para el diseño de propuestas pedagógicas orientadas a mejorar la enseñanza de la matemática en los primeros años universitarios.
Palabras clave: Representaciones múltiples; aprendizaje significativo; educación superior; enseñanza de la matemática.

INTRODUCTION

Teaching mathematics in the early years of higher education is one of the most significant challenges facing universities, especially in degree programs where this discipline serves as the foundation for the development of scientific, technological, and professional competencies. The transition from high school to college involves not only a change in educational level but also a profound transformation in the ways students study, reason, argue, and represent mathematical knowledge. During this process, many students struggle to understand fundamental concepts, interpret problems, establish connections between procedures and meanings, and apply what they have learned to new academic contexts. These difficulties often become evident in introductory courses such as Basic

Mathematics, Precalculus, Differential Calculus, Physics I, and Statistics, in which mastery of functions, graphs, equations, tables, and models is essential for academic progress.

Various studies have indicated that the transition from high school mathematics to college mathematics represents a critical moment in students' educational trajectories. Di Martino et al. (2023), in a systematic review of the secondary-to-tertiary transition in mathematics education, argue that this transition is marked by cognitive, institutional, and pedagogical discontinuities that affect how students engage with mathematical knowledge. In high school, learning is often organized around algorithmic procedures, repetitive exercises, and expected answers; in contrast, college requires greater intellectual autonomy, conceptual understanding, formalization, interpretation of models, and the ability to reason. This difference creates tensions, especially when students have developed a predominantly instrumental relationship with mathematics, based on the mechanical application of formulas rather than a deep understanding of concepts.

In this context, the concept of a function plays a central role. Functions allow us to model relationships between variables, interpret phenomena, analyze changes, and establish connections between different areas of knowledge. However, this concept is also often one of the most problematic for students entering college. Trujillo et al. (2023) state that the function can be considered a threshold concept in mathematics, since understanding it is essential for accessing more complex knowledge later on. Nevertheless, many students struggle to recognize a function in different forms of representation, interpret the meaning of its parameters, relate an algebraic expression to its graph, or verbally explain the behavior of a mathematical relationship. These limitations reveal that learning mathematics cannot be reduced to symbolic manipulation but rather requires the construction of meanings that are articulated across various forms of representation.

From this perspective, multiple representations constitute a highly valuable instructional strategy for promoting meaningful learning in mathematics. Ainsworth (1999) argues that multiple external representations can serve different functions in learning, such as supplementing information, limiting misinterpretations, and building deeper understandings. Subsequently, Ainsworth (2006) developed the DeFT framework, in which he argues that the effectiveness of multiple representations depends on three fundamental dimensions: the design of the representations, the functions they serve, and the cognitive tasks students must perform when interacting with them. This means that it is not enough to present an equation, a table, or a graph in isolation; it is necessary to design activities that require students to compare, translate, interpret, and coordinate these representations.

In mathematics education, multiple representations include algebraic, graphical, numerical, verbal, tabular, geometric, and contextual representations. For example, a linear function can be expressed as an equation, plotted on a Cartesian graph, organized in a table of values, described verbally as a relationship of constant change, or applied to a real-world situation involving proportionality. Each representation offers a particular

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perspective on the mathematical object, but none on its own guarantees understanding. Understanding emerges when students are able to establish connections among them, recognize their equivalences, interpret their differences, and use them flexibly to solve problems. In this sense, the use of multiple representations should not be understood as an accumulation of visual or symbolic resources, but rather as a cognitive mediation for constructing mathematical meaning.

Duval's theory of semiotic representation registers provides a key foundation for understanding this issue. Duval (2006) argues that access to mathematical objects is possible only through representations, since such objects are not directly observable. According to this theory, learning mathematics involves being able to perform operations within a single register and make conversions between different registers. Processing occurs, for example, when a student transforms an algebraic expression without leaving the symbolic language; conversion, on the other hand, occurs when the student moves from an equation to a graph, from a table to an algebraic expression, or from a verbal situation to a mathematical model. For Duval, conversion between registers constitutes one of the most complex—and, at the same time, most necessary—cognitive activities for mathematical understanding.

This idea is particularly relevant in the early years of college, where students must interpret concepts within a more formalized framework. Many errors are not solely due to a lack of procedural mastery but to an inability to coordinate registers. A student may solve an equation correctly yet fail to understand what the result represents graphically; may construct a table of values but fail to identify the trend of the function; or may observe a graph but be unable to explain the meaning of its slope, its intercepts, or its intervals of growth. These difficulties reflect a fragmented understanding, in which procedures are carried out without being integrated into a meaningful conceptual structure.

Meaningful learning, from Ausubel's perspective, implies that new knowledge is related in a substantive and non-arbitrary way to the student's prior cognitive structure. Although Ausubel's theory was initially formulated within a broader framework of educational psychology, its application to mathematics education helps us understand the importance of connecting new content to experiences, prior concepts, familiar representations, and contextualized problems. Koskinen and Pitkäniemi (2022), in a synthesis of research on meaningful learning in mathematics, emphasize that this type of learning is fostered when instruction promotes connections between ideas, active interaction, conceptual understanding, and student participation in the construction of meaning.

Consequently, the use of multiple representations can be considered a way to promote meaningful learning, provided that these representations are pedagogically linked to students' prior knowledge and cognitive needs. It is not merely a matter of showing various ways to represent a concept, but rather of creating conditions for students to understand why these representations are equivalent, what information each one provides, and how they can be strategically used to solve problems. Polman et al. (2021)

note that meaningful learning in mathematics involves students perceiving meaning, connection, and utility in what they learn. From this perspective, multiple representations can help shift the perception of mathematics from a set of isolated procedures to a language for interpreting relationships, phenomena, and situations.

The issue takes on greater importance when one considers that first-year college students come from diverse educational backgrounds. Some have had a school education focused on calculation and repetition; others have accumulated conceptual gaps; and many have not developed independent study habits or reasoning strategies appropriate for higher education. This diversity highlights the need to design instructional approaches that enable the assessment, support, and strengthening of mathematical understanding during the first semesters. In this regard, teaching based on multiple representations can serve as a transition strategy, as it helps bridge the gap between high school knowledge and university-level demands.

Furthermore, this strategy aligns with the current demands of higher education, which are oriented toward the development of competencies, problem-solving, critical thinking, and the application of knowledge in real-world contexts. University-level mathematics should not be limited to the transmission of techniques but should instead foster an understanding of structures, relationships, and models. To achieve this, it is necessary to move beyond approaches focused exclusively on lecture-based instruction and to promote learning experiences in which students interpret, argue, compare procedures, and justify their answers. Multiple representations offer a suitable framework for this purpose, as they require students to engage different modes of thinking and to recognize that a single mathematical object can be expressed in various ways.

Despite their importance, incorporating multiple representations into university-level instruction still presents challenges. In many cases, graphs are used only as visual aids, tables as a preliminary step to calculation, and equations as the dominant form of validation. This hierarchy often reinforces the idea that algebraic representation is the most important, while the others serve secondary functions. However, research in mathematics education has shown that deep understanding requires precisely the coordination among representations, not the subordination of one to another. Therefore, instruction centered on multiple representations must be intentionally planned, using activities that promote conversions, interpretations, and discussions about the meaning of mathematical objects.

From a research perspective, addressing this topic allows for an analysis not only of academic performance but also of the comprehension processes that students develop. A study on multiple representations and meaningful learning during the transition to higher education can provide evidence regarding students' initial difficulties, the ways in which they interpret mathematical concepts, and the effects of a teaching intervention focused on the coordination of representations. Furthermore, it can contribute to the design of pedagogical strategies for introductory courses, especially in institutions where failure or dropout rates in mathematics courses are a cause for academic concern.

Within this framework, this article aims to analyze the contribution of multiple representations to the meaningful learning of mathematical concepts among students transitioning to higher education. The study is based on the premise that mathematical understanding is strengthened when students are able to establish relationships between algebraic, graphical, numerical, verbal, and contextual representations. Furthermore, it is assumed that meaningful learning does not depend solely on exposure to content, but rather on the ability to relate that content to prior knowledge, academic experiences, and problem-solving situations that give meaning to learning.

Thus, this article seeks to address the need to strengthen mathematics instruction in the early years of college through teaching strategies that promote conceptual understanding, the integration of different representations, and problem-solving. The study's relevance lies in its focus on a recurring issue in higher education: the gap between the mathematical knowledge acquired in high school and the cognitive demands of college-level study. In light of this situation, multiple representations are presented as a pedagogical alternative capable of promoting deeper, more flexible, and transferable learning, thereby contributing to a more solid and meaningful academic transition.

The relevance of studying multiple representations in higher education is also grounded in the changes that contemporary approaches to the teaching and learning of mathematics have undergone. Over the past few decades, research in mathematics education has shifted from perspectives focused on the acquisition of procedures toward approaches that prioritize conceptual understanding, the construction of meaning, and the development of mathematical reasoning. In this context, the ability to interpret and coordinate different representations of the same mathematical object has become a fundamental indicator of understanding. Various studies have shown that students who are able to establish connections between algebraic, graphical, numerical, and verbal representations develop a deeper understanding of concepts and demonstrate a greater ability to transfer their knowledge to new situations (Lesh, Post & Behr, 1987; Kaput, 1989). This perspective recognizes that mathematical learning consists not only of mastering operational techniques, but also of constructing networks of meaning that enable students to interpret, model, and solve problems in different contexts.

The importance of multiple representations is particularly evident in the study of mathematical functions, which numerous authors consider one of the most relevant and complex concepts in school and college mathematics. Functions constitute the language through which phenomena of change, growth, motion, and dependence among variables are described; therefore, understanding them is essential in disciplines such as physics, chemistry, economics, and engineering. However, research conducted in various educational contexts has shown that many students have a fragmented understanding of the concept of a function, often limited to the symbolic manipulation of equations without adequate graphical or contextual interpretation (Carlson, Oehrtman & Engelke, 2010). This situation creates difficulties that persist throughout the early years of college and affect the learning of subsequent content related to differential and integral calculus.

From the perspective of the theory of semiotic representation registers, these difficulties can be explained by the inability to coordinate different forms of representation of the same mathematical object. Duval (2006) argues that authentic mathematical activity requires the simultaneous mobilization of several semiotic registers and that conceptual understanding emerges precisely from the ability to convert between them. Consequently, when students limit themselves to operating within a single register, their learning tends to be mechanical and superficial. Conversely, when students are able to relate an algebraic expression to a graph, interpret a table of values, or verbally describe the behavior of a function, they develop a more flexible and meaningful understanding. This idea has been supported by numerous studies that highlight the coordination of representations as an essential component of advanced mathematical thinking (Arcavi, 2003; Presmeg, 2006).

At the same time, technological advancements have expanded the possibilities for using multiple representations in the university classroom. Tools such as GeoGebra, Desmos, MATLAB, and various computer algebra systems allow for the dynamic visualization of mathematical concepts that were previously presented exclusively in symbolic form. The incorporation of these resources has fostered new ways of interacting with mathematical objects, allowing students to explore relationships, formulate conjectures, and verify results using different representations. According to Borba, Askar, Engelbrecht, Gadanidis, Llinares, and Aguilar (2016), digital technologies have transformed mathematics education by facilitating visualization and modeling processes that enrich conceptual understanding. However, the authors caution that the educational potential of these tools depends on instructional designs that promote reflection and connections between representations, preventing technology from becoming merely a calculation tool.

Another relevant aspect relates to the characteristics of students currently entering higher education. Contemporary university cohorts are characterized by increasing diversity in terms of prior academic background, educational experiences, learning styles, and mathematical competencies. This heterogeneity requires pedagogical strategies capable of addressing different levels of understanding and fostering inclusive learning processes. In this regard, multiple representations offer opportunities for students to access mathematical knowledge from different cognitive entry points. While some students may better understand a concept through a graphical representation, others may find greater meaning in a table of values or a contextualized situation. Integrating these representations broadens the possibilities for understanding and fosters the construction of shared meanings within the university classroom.

Likewise, the specialized literature has highlighted the close relationship between multiple representations and the development of higher-order mathematical competencies. These competencies include modeling, reasoning, mathematical communication, and complex problem-solving. Niss and Højgaard (2019) note that mathematical competence involves the ability to understand, use, and interpret mathematics in different situations, which necessarily requires the mobilization of various representational systems. From this perspective, multiple representations are

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not merely a teaching strategy but an inherent component of the development of mathematical thinking and the comprehensive education of college students.

The connection between multiple representations and meaningful learning takes on particular relevance when analyzed from the perspective of cognitive learning theory. Ausubel (2002) argues that the acquisition of new knowledge depends on the ability to relate it in a meaningful way to concepts already present in the student's cognitive structure. Consequently, meaningful learning requires that the content presented possess logical and psychological coherence, and that the student adopt a positive attitude toward understanding. Multiple representations contribute to this process because they facilitate the establishment of connections between different forms of knowledge, allowing students to relate abstract concepts to prior experiences, concrete situations, and contexts of application. In this way, representations act as cognitive bridges that promote the construction of more stable and lasting meanings.

The available empirical evidence supports this relationship. Various studies have reported significant improvements in conceptual understanding, problem-solving, and academic performance when teaching strategies based on multiple representations are implemented (Ainsworth, 2006; Rau, Aleven & Rummel, 2015). This research suggests that the coordination of representations fosters more elaborate reasoning processes, reduces reliance on rote memorization, and promotes a deeper understanding of mathematical concepts. Furthermore, it has been observed that students develop a greater ability to explain their procedures, justify their answers, and transfer knowledge to new situations—aspects closely linked to the principles of meaningful learning.

Despite the advances made in international research, there remains a need to further explore these relationships in Latin American contexts, particularly in the realm of higher education. Institutional conditions, curricula, educational trajectories, and the sociocultural characteristics of students can significantly influence how mathematical learning is constructed. Therefore, it is important to generate contextualized evidence that allows us to understand how multiple representations can help strengthen mathematics instruction during the first years of college and facilitate the transition from secondary to higher education. This interest is particularly relevant in science and technology programs, where difficulties in mathematics often constitute one of the main factors associated with low academic performance, course repetition, and student dropout.

Consequently, the study of multiple representations and their relationship to meaningful learning emerges as a relevant line of research for understanding and improving the processes of teaching and learning mathematics in higher education. Analyzing how students interpret, coordinate, and use different representations of mathematical concepts will make it possible to identify difficulties, design more effective teaching strategies, and contribute to the development of instructional models aimed at fostering deep conceptual understanding. From this perspective, this research posits that the connection between multiple representations and meaningful learning is a key element in strengthening university students' mathematical education and fostering a more successful academic transition to higher levels of study.

MATERIALS AND METHODS

This research was conducted using a mixed-methods approach, based on the premise that understanding mathematical learning processes requires both the objective measurement of academic outcomes and the analysis of students' experiences and perceptions during their educational journey. The combination of quantitative and qualitative methods provided a comprehensive view of the phenomenon under study, facilitating the identification of changes in learning and the understanding of the factors involved in the construction of mathematical meaning. This approach is grounded in the need to analyze not only students' performance but also the cognitive processes associated with the use of multiple representations in understanding mathematical concepts during the transition to higher education.

The research design was quasi-experimental with descriptive and explanatory scope. The study involved two groups of students enrolled in Basic Mathematics and Precalculus courses during their first semester of college. An experimental group participated in a instructional intervention based on the systematic use of multiple representations, while the comparison group engaged in the standard activities outlined in the course syllabus. Due to institutional conditions and the existing academic organization, it was not possible to randomly assign participants; for this reason, a quasi-experimental design was chosen to evaluate the effects of the intervention in real educational contexts.

The population consisted of first-year students enrolled in science, engineering, and education programs at a public university in Ecuador. The sample was selected using a non-probabilistic convenience sampling procedure, taking into account course availability and the participants' voluntary agreement to take part in the study. A total of 120 students participated, divided into two working groups. The selection of first-semester students stemmed from an interest in analyzing the learning processes that occur during the transition from secondary to higher education, a stage characterized by significant changes in cognitive, methodological, and academic demands.

The instructional intervention took place over eight weeks and focused on the study of fundamental concepts related to mathematical functions, variation, graphical interpretation, and the modeling of real-world situations. These topics were selected due to their relevance in introductory college mathematics courses and the evidence reported in the literature regarding the difficulties students face in understanding them. During the teaching process, activities were designed to promote coordination among different registers of semiotic representation, including algebraic, graphical, numerical, tabular, verbal, and contextualized representations.

The activities implemented in the experimental group were based on Duval's theoretical principles regarding registers of semiotic representation and on Ausubel's postulates of meaningful learning. Consequently, each topic was addressed through instructional sequences that required students to interpret, compare, and transform information across different registers of representation. For example, exercises were proposed in which students had to construct graphs from equations, derive algebraic expressions from data tables, verbally interpret the behavior of functions, and model contextualized situations using appropriate mathematical representations. These activities were designed to promote conceptual understanding and prevent learning from being limited to the mechanical application of procedures.

To support the intervention, technological resources were used to facilitate the dynamic visualization of mathematical concepts. Among these, the GeoGebra software was used to represent functions, analyze variations, and explore relationships between different representations. The incorporation of this tool allowed students to simultaneously observe changes in algebraic expressions, tables, and graphs, thereby promoting an understanding of the relationships between the different representations. Additionally, collaborative work was encouraged through group activities focused on discussing and justifying mathematical solutions.

Various instruments were used to collect data. First, a diagnostic test was administered before the intervention began to identify students' initial level of understanding of concepts related to functions and mathematical representations. This test included exercises in graphical interpretation, table analysis, the construction of algebraic models, and the solving of contextualized problems. Subsequently, at the end of the intervention, an equivalent test was administered to assess changes in learning and compare the results obtained by both groups.

In addition, a perception questionnaire consisting of Likert-scale items was designed to gather information about the students' experiences during the learning process. This instrument provided insight into the participants' assessments of the use of multiple representations, the usefulness of the resources employed, the level of understanding achieved, and the influence of the activities carried out on their mathematical learning. The internal consistency of the questionnaire was evaluated using Cronbach's alpha coefficient, yielding values above 0.80—considered adequate for educational research purposes.

To gain a deeper understanding of the quantitative results, semi-structured interviews were conducted with a group of students selected through purposive sampling. These interviews allowed us to explore the problem-solving strategies used, the difficulties encountered during the learning process, and perceptions regarding the relationship among the different mathematical representations. The information obtained helped identify patterns of conceptual understanding and provided complementary qualitative evidence for interpreting the research findings.

The quantitative data were analyzed using descriptive and inferential statistical techniques. Initially, frequencies, percentages, means, and standard deviations were calculated to characterize student performance. Subsequently, tests for comparing means were applied to determine whether there were statistically significant differences between the results obtained before and after the intervention, as well as between the experimental group and the comparison group. Additionally, effect size measures were calculated to estimate the magnitude of the changes observed in the participants' mathematical understanding.

Meanwhile, the qualitative data from the interviews were analyzed using a thematic coding process. The responses were organized into categories related to conceptual understanding, the use of multiple representations, learning difficulties, and perceptions regarding the usefulness of the implemented teaching strategies. Subsequently, an interpretive analysis was conducted to identify relationships between the students' discourses and the results obtained on the academic tests. This procedure allowed for the integration of quantitative and qualitative information, strengthening the validity of the conclusions reached.

To ensure the methodological quality of the study, widely accepted criteria for validity and reliability in educational research were applied. The instruments were reviewed by experts in mathematics education and research methodology, who assessed the relevance, clarity, and coherence of the items. In addition, a pilot study was conducted with students whose characteristics were similar to those of the final sample, allowing for adjustments to be made prior to the formal implementation of the study. The triangulation of data obtained through academic tests, questionnaires, and interviews further contributed to strengthening the credibility of the results.

From an ethical standpoint, the research adhered to the principles of voluntary participation, confidentiality, and responsible use of information. All participants were informed about the study's objectives and gave their consent to participate in the various phases of the research process. The data collected were used exclusively for academic and scientific purposes, ensuring the students' anonymity during the analysis and presentation of the results.

Overall, this methodology allowed for a rigorous examination of the influence of multiple representations on the meaningful learning of mathematical concepts among first-year college students. The integration of different sources of information and the combination of quantitative and qualitative approaches provided sufficient evidence to understand both the results obtained and the underlying learning processes, contributing to the generation of knowledge relevant to improving mathematics instruction in higher education.

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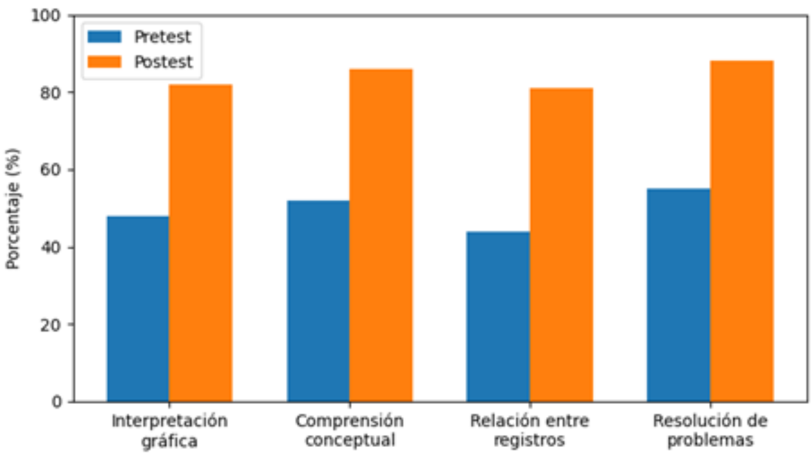
RESULTS

The results show a significant improvement in the performance of the students who participated in the instructional intervention based on multiple representations. A comparative analysis of the tests administered before and after the intervention revealed progress in conceptual understanding, graphical interpretation, the relationship between different modes of representation, and mathematical problem-solving.

In the initial diagnostic test, it was observed that students had greater difficulties with activities requiring them to establish connections between algebraic, graphical, and tabular representations. Most participants were able to apply basic algorithmic procedures but showed limitations in interpreting the meaning of mathematical expressions and relating them to contextualized situations. These difficulties were particularly evident in exercises related to functions, variation, and graphical analysis.

After implementing the instructional strategy, the results showed a general improvement across all assessed indicators. Graphical interpretation rose from an initial average of 48% to 82%, while conceptual understanding increased from 52% to 86%. Similarly, the ability to relate different forms of representation increased from 44% to 81%, representing one of the most significant improvements observed during the study. Finally, the ability to solve contextualized math problems improved from 55% to 88%, demonstrating students' greater capacity to apply the knowledge they acquired in diverse situations.

Figure 1. Comparison of pretest and posttest results for the evaluated indicators



The statistical analyses conducted revealed significant differences between the results obtained before and after the intervention ($p < 0.05$). These findings suggest that the systematic use of multiple representations fostered the construction of more solid mathematical meanings and a better understanding of the concepts addressed.

Furthermore, the effect size was high, indicating that the observed changes were not only statistically significant but also educationally relevant.

The results of the perception questionnaires showed a positive evaluation of the implemented strategy. Eighty-nine percent of the students stated that the simultaneous use of equations, graphs, tables, and contextualized situations facilitated their understanding of the mathematical content. Furthermore, 92% felt that the activities carried out allowed them to visualize more clearly the relationships between the concepts studied and their practical applications.

The interviews conducted complemented these findings. The students noted that previously they tended to solve problems mechanically, focusing solely on the application of formulas. However, during the intervention, they began to identify relationships between different forms of representation, which allowed them to better understand the meaning of the procedures they were performing. Several participants emphasized that graphical interpretation helped them verify results obtained algebraically and understand patterns of variation that they had previously perceived as abstract.

Overall, the results suggest that multiple representations constitute an effective teaching strategy for promoting meaningful learning of mathematics among first-year college students. The observed improvement in conceptual understanding, the coordination of representational registers, and problem-solving supports the idea that mathematical learning is strengthened when students have opportunities to establish connections between different ways of representing the same concept. These findings align with the theoretical approaches of Duval and Ainsworth, who argue that mathematical understanding emerges from the ability to coordinate and interpret multiple representational registers.

DISCUSSION

The results obtained in this study lead to the conclusion that the use of multiple representations is an effective teaching strategy for promoting meaningful learning of mathematics during the transition to higher education. The integration of algebraic, graphical, numerical, tabular, and verbal representations facilitated the understanding of fundamental mathematical concepts, allowing students to build stronger relationships between the different modes of representation and develop a deeper conceptual understanding of the content covered.

The study revealed that one of the main difficulties faced by first-year college students lies in their limited ability to establish connections between different ways of representing the same mathematical object. Although many participants demonstrated the ability to perform algebraic procedures, they struggled to interpret graphs, analyze

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data tables, or verbally explain the meaning of the results obtained. This situation confirms Duval's theoretical arguments that mathematical understanding depends largely on the ability to coordinate and transform different registers of semiotic representation.

Furthermore, the findings show that the implementation of activities aimed at promoting conversion between representations contributed significantly to strengthening conceptual understanding. Students not only improved their academic performance but also developed a greater ability to interpret mathematical phenomena, justify procedures, and apply knowledge in contextualized situations. These results support the idea that mathematical understanding goes beyond the memorization of formulas and procedures, requiring processes of active meaning-making.

Another relevant aspect identified during the study was the relationship between multiple representations and the principles of meaningful learning. The ability to establish connections between prior knowledge and new forms of representation allowed students to make greater sense of the mathematical content studied. In this regard, the research confirms Ausubel's postulates by demonstrating that the most enduring and transferable learning occurs when new information is substantially integrated into the student's cognitive structure.

The results also highlight the importance of incorporating active learning methodologies into introductory college mathematics courses. Activities based on the interpretation, comparison, and transformation of representations fostered more dynamic student participation in their learning process, promoting mathematical reasoning, argumentation, and problem-solving. This suggests the need to move beyond traditional approaches focused exclusively on lecture-based instruction and the mechanical completion of exercises, and to advance toward pedagogical models that prioritize conceptual understanding and the construction of meaning.

Similarly, the use of technological tools to support teaching helped strengthen the processes of mathematical visualization and interpretation. The ability to simultaneously observe different representations of the same concept facilitated the identification of relationships and patterns that, in many cases, are difficult to perceive using traditional methods. This demonstrates the potential of digital resources to enrich university-level mathematics education when they are integrated into pedagogically sound instructional approaches.

The observed improvement in problem-solving constitutes another significant finding of the research. The students who participated in the intervention demonstrated a greater ability to analyze situations, select appropriate strategies, and justify their answers using different representations. This result suggests that multiple representations not only promote conceptual understanding but also contribute to the development of higher-order mathematical competencies, which are fundamental to academic and professional performance in scientific and technological disciplines.

From an institutional perspective, the findings highlight the need to strengthen academic support strategies during the first years of college. The transition from secondary education to higher education represents a period of adaptation that requires methodologies capable of bridging the gaps between students' prior knowledge and the cognitive demands of the college level. In this context, multiple representations can serve as a valuable pedagogical tool to facilitate this process and improve retention rates and academic success.

Finally, it is concluded that mathematics instruction based on multiple representations fosters the construction of meaningful learning, strengthens conceptual understanding, and promotes more active student participation in their educational process. The results obtained provide empirical evidence supporting the systematic incorporation of this strategy into introductory higher education courses and suggest the need to continue conducting research that delves deeper into its impact on different mathematical content areas, educational contexts, and student populations. In this way, it will be possible to move toward teaching models that are more inclusive, comprehensive, and oriented toward the holistic development of the mathematical competencies required in contemporary university education.

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