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Transforming university education: a systematic review of mathematical modeling in learning

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ABSTRACT

This article is focused on analyzing the impact of mathematical modeling on the learning of university students. The starting point is the complexity of the learning process in technological careers, since cognitive, emotional, social and pedagogical elements are involved in this process, therefore, a multidisciplinary approach is required to allow a holistic understanding of educational phenomena. For this purpose, a systematic review was applied following the PRISMA guidelines and 30 research studies available in Scopus, PubMed, and Web of Science were selected. These studies highlight the importance of mathematical modeling in improving education. The results highlight a higher frequency of use for models with structural equations, models related to adaptive profiles and virtual mathematical models. It is concluded that mathematical modeling represents a valuable resource in higher education, which enriches the learning experience and prepares students to face academic and professional challenges. It is impact is manifested in the improvement of conceptual understanding, the strengthening of problem-solving skills and the close linkage between theory and practice.

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1. INTRODUCTION

In the field of higher education, the analysis and understanding of the students' learning process constitutes a fundamental challenge [1], [2]. The constant search for effective pedagogical strategies that promote academic success and the acquisition of relevant competencies has led to the exploration of various approaches, among which mathematical models emerge as tools of indisputable potential [3], [4]. Modeling, by al-lowing the quantitative representation of complex relationships between variables, has found fertile ground in educational research, offering an analytical perspective that goes beyond superficial observations [5], [6].

In the context of a constantly evolving university education, mathematical modeling presents itself as a promising alternative to address the diversity of factors that influence learning [7]. The complexity of this process, which involves cognitive, emotional, social and pedagogical elements, requires a multidisciplinary approach that allows a holistic understanding of educational phenomena [8]. In this sense, the proposed systematic review stands as an opportunity to examine and synthesize the existing scientific evidence regarding the use of mathematical models in the analysis of undergraduate learning.

Previous research has provided encouraging indications about the value of mathematical modeling in elucidating patterns and dynamics underlying the learning process [9], [10]. However, the diversity of approaches and results obtained raises the need for a comprehensive and systematic review that will allow an orderly synthesis of the progress achieved to date [11]. Such a review will not only contribute to consolidating existing knowledge but will also provide critical guidance for future research and pedagogical practices [12], [13].

The purpose of this study is to shed light on the current state of research in mathematical modeling for the study of learning in higher education. Through a systematic review of the literature, we analyze the trends, the methodological approaches used, and the most outstanding results of the studies that have addressed this topic. It also identifies the main findings derived from this research, about the effectiveness of mathematical models for the optimization of learning strategies and the improvement of the academic performance of university students. In short, this systematic review aims to contribute to the enrichment of the field of higher education and to provide a comprehensive and critical view of the application of mathematical models in university learning.

Mathematical modeling in higher education is an advanced pedagogical approach that relies on the application of mathematical concepts, techniques, and tools to address real-world problems within the academic context [14], [15]. This approach is characterized by the construction and manipulation of mathematical models, which are abstract and symbolic representations that capture essential aspects of phenomena, processes, or situations observed in various disciplines and interdisciplinary fields [16], [17]. Likewise, higher education involves a complex and multifaceted cognitive process that goes beyond the mere memorization of formulas and algorithms [18].

Students, in collaboration with expert instructors, embark on formulating problems, identifying relevant variables, deriving appropriate mathematical equations and relationships, and interpreting the results obtained [19]. This process requires critical and analytical thinking, as well as the ability to translate real-world situations into mathematical terms, and vice versa [20]. On the other hand, mathematical modeling in higher education is not limited to a single discipline, but finds applicability in a wide range of academic fields, including, but not limited to, physics, biology, economics, engineering, social sciences and health [21].

Mathematical models can be used to describe the evolution of biological populations, predict the behavior of financial markets, simulate complex physical processes, analyze epidemiological data, and solve interdisciplinary problems that require a deep understanding and quantitative approach [22]. This pedagogical approach not only drives the development of advanced mathematical skills, but also promotes the acquisition of transferable skills, such as problem solving, evidence-based decision making, effective communication, and interdisciplinary collaboration [23]. Students who participate in mathematical modeling experiences develop a deeper and more meaningful understanding of mathematics by observing how it is directly applied in real-world situations [24].

Mathematical modeling has become an essential component of pedagogy in higher education, as it prepares students to face complex and evolving challenges in their future careers and professional activities [25], [26]. In a world driven by technology and interdisciplinarity, the ability to address real-world problems quantitatively and mathematically is highly valued, and mathematical modeling stands as an invaluable tool for training capable and competent individuals to solve complex and multifaceted problems [27], [28].

The teaching of mathematics and the meaningful learning of its contents have given rise to a new concept called "neuro-mathematics" from a much more current perspective. This emerges as a proposal based on the relationship between neuroscience and mathematics didactics, which highlights the use of various structures, such as the Hodgkin-Huxley model, the Integrate-and-Fire model, neural networks, and synapses [29]. In this sense, modeling now extends to the design of innovative strategies. These should promote concatenated design actions between critical-reflective thinking and emotional charges that allow the design and development of models by students. In this sense, the research question formulated for this article is the following: What is the impact of mathematical modeling on the learning of university students?

In order to achieve the correct performance and development of students, the institution must consider different skills that will facilitate learning. In turn, university education is complemented with soft skills, which serve as adaptation tools for different educational spaces [30]. In the same way, the stimulation of research skills not only requires the adoption of technical and methodological skills, since it encompasses cognitive, affective and behavioral experiences [31], but also research strategies that allow continuous self-learning, since they have positive effects both in the academic and work environments [32].

As the years go by, the formative needs of students advance and expand, which drives the development of new evaluation methods that enrich the learning processes; on the other hand, higher education requires a critical and analytical approach that facilitates the application of theoretical concepts learned in class, as well as the connection between the traditional and the digital [33]. For the adequate academic process, it is necessary the incursion of formative strategies that help to achieve personal achievements and competencies that are beneficial for learning [34].

In higher education, these models are used to make an evaluation record of students, with the objective of following up on their performance; this allows identifying how improvements in student learning are developed through data review and elaboration of schemes [35]. These models attempt to translate a phenomenon or problem into a real scenario, and become essential for the generation of knowledge, since they help to replicate and understand various problems of reality [36]. Mathematical modeling, when used as a pedagogical approach, favors the understanding of the discipline to be studied, while offering an abstract relationship with reality that represents and simplifies it [35], [37].

Depending on the nature of each mathematical model and its application in the phenomena of reality, certain values are considered for their respective study, for example, variables, parameters, constraints, relationships between variables and simplified representations [38]. The latter, together with the activities generated from the incorporation of mathematical modeling, allows the intervention of realistic problems that consolidate different skills in the student when successful in practice [39].

Mathematical modeling incorporates levels of learning, where the cognitive, affective, and metacognitive are necessary for the development of competencies; thus, the development of tests and practical exercises promotes education under a holistic approach for the identification of strengths in academic competence [40]. From a research context, the study pursues the following objectives: i) to explain the impact of the application of mathematical models on student learning in higher education, to contribute to the consolidation of existing knowledge; ii) to describe how mathematical modeling improves the understanding of university students; iii) to detail the elements associated with the development of problem-solving skills; and iv) to analyze the connection between theory and practice of mathematical modeling in higher education. In this sense, the development of the established exploration will provide critical guidance for future research and pedagogical practices, based on the following research questions: i) What is the impact of mathematical modeling on university students' learning?; ii) How does mathematical modelling improve university students' understanding?; iii) What are the elements associated with the development of problem-solving skills?; and iv) What is the connection between the theory and practice of mathematical modeling in higher education?

2. METHOD

To achieve the established research objective, a qualitative approach methodology with an exploratory scope was adopted. To achieve the established research objective, a qualitative methodology with an exploratory approach was adopted. To carry out this task, the systematic review method supported by the principles of the PRISMA method was applied, addressing the basic stages of the method such as document identification, exhaustive review, eligibility, and inclusion [41], to investigate the use of mathematical modeling in the context of university learning. The choice of this methodological tool made it possible to carry out an exhaustive and organized search in the relevant academic literature, perform a critical analysis of the selected studies, and accurately and rigorously compile the available evidence [42].

This qualitative research approach and systematic review methodology provide a solid foundation for addressing the topic of mathematical modeling in the field of university learning. By systematically exploring the academic literature, a deeper and more comprehensive understanding of trends, approaches, and results in this specific field can be obtained. In addition, critical analysis of the selected studies will contribute to assessing the quality and relevance of the available evidence, which will ultimately enrich the research and its conclusions.

Consequently, the search for relevant academic literature and publications was carried out by accessing three prestigious electronic databases: PubMed, Scopus, and Web of Science. During this process, specific combinations of key terms, such as “mathematical modeling” AND “university learning” OR “higher education” were used to precisely identify those studies related to the implementation of mathematical modeling in the context of higher education. To further specify the search and focus on the efficacy of implementing mathematical modeling in college learning, terms such as “effectiveness” OR “outcomes” OR “impact” were included. These search equations and Boolean operators yielded a set of results relevant to the study of mathematical modeling in the field of university learning.

To boost the search in each of the databases or search engines, the configuration was applied: “mathematical modeling” AND “university learning” OR “higher education”, for Scopus. In the context of a systematic review on the importance of mathematical modeling in undergraduate learning, it was considered essential to establish inclusion and exclusion criteria in a robust and clear manner. These criteria played a key role in the careful selection of relevant studies, which, in turn, ensured the consistency and thoroughness of the review. A description of the inclusion criteria that were applied in the article search process is provided as:

– Thematic relevance: to be included in the review, each article had to be related, directly or indirectly, to the importance of mathematical modeling in the learning process of university students. This approach was specifically designed to ensure that the selected studies accurately addressed the central research question.

- Type of study: only empirical studies that focused on systematic research, either quantitative or qualitative, on the application of mathematical modeling in undergraduate learning were considered. This criterion encompassed a wide variety of research designs, including experimental studies, longitudinal research, case studies, surveys, and interviews. The rationale behind this choice was to ensure that the studies provided concrete and substantial data on the importance of mathematical modeling.
- Date of publication: the inclusion of articles was limited to a specific range of years, determined according to the needs and resources available to the reviewer. This temporal range, although variable, was established, for example, from the year 2018 to the year 2023, with the purpose of covering recent and relevant research. In this sense, it is intended to fulfill the purpose of selecting and including recent and relevant research on mathematical modeling.

An initial corpus composed of a total of 754 academic articles was examined as part of the systematic review of the literature, sectioned as: 254 from PubMed, 398 from Scopus and 332 from Web of Sciences. From this large sample, a rigorous selection process was carried out in four stages: identification, review, eligibility and inclusion. In the first shared review, 163 articles or duplicate documents were found, which were discarded, reducing the number of documents to 591. Next, a detailed observation of the structure of each article was carried out, from which 561 were discarded because they did not have a complete structure. This resulted in a select set of 30 studies relevant to the final analysis as shown in Figure 1. These studies were carefully selected and included based on their relevance and substantial contribution to the research topic, i.e., the importance of mathematical modeling in undergraduate learning.

It is imperative to note that this review was subject to certain limitations, such as publication bias and the restriction of studies available in languages other than English. Nevertheless, meticulous strategies were carried out with the aim of addressing and minimizing these potential biases. These strategies included an exhaustive search of the existing literature, in addition to the inclusion of studies in various languages. In this way, we sought to ensure that the systematic review covered as much relevant and reliable evidence as possible.

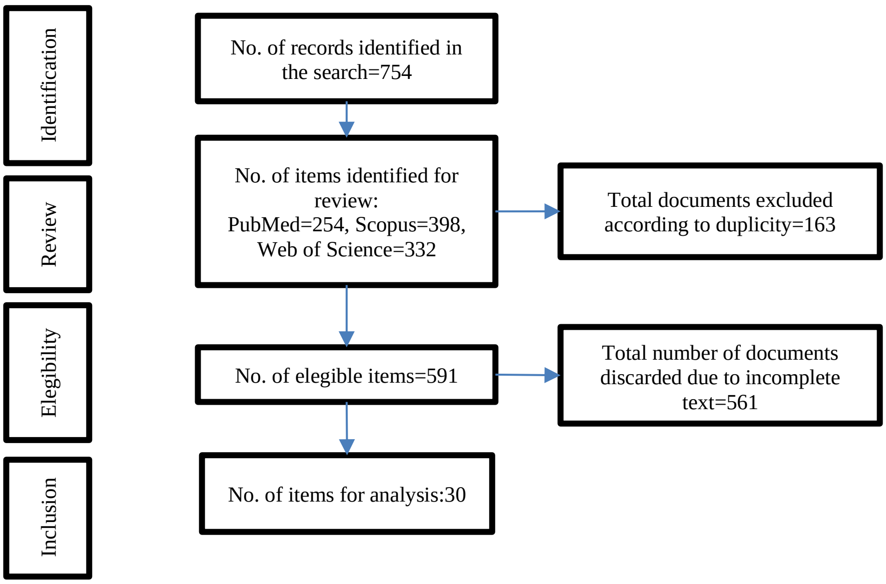

Figure 1. The algorithm designed to carry out the application of the PRISMA method in the research

3. RESULTS AND DISCUSSION

3.1. Results

These specific studies were chosen to present a focused and representative view of the intrinsic relationship between mathematical modeling and the improvement of the educational experience at the university level. Each of the selected papers provides significant insights that touch on various aspects of higher education, ranging from deepening conceptual understanding to optimizing academic performance, as well as adapting to the changing dynamics of digital environments. Table 1, by virtue of its selective and analytical approach, exposes the articles selected for the review, through a concise but representative synthesis of the findings that imply the importance of mathematical modeling in the university setting, presenting the qualitative aspects of each selection. Table 1, due to its selective and analytical approach, exposes the articles selected for the review through a concise but representative synthesis of the findings that imply the importance of mathematical modeling in the university setting, while presenting the qualitative aspects of each selection. The title of the article, authors and date of publication, methodology used and recommendations can be seen.

Table 1. List of articles selected for review

References	Findings
[43]	Cognitive and noncognitive predictors of performance on unified state tests in students with regular and advanced mathematics curricula are identified.
[44]	System accessibility, enjoyment, and result demonstrability have a positive influence on the perceived usefulness and ease of use of e-learning systems.
[45]	Predictive mathematical models are useful for identifying at-risk students in the context of higher education in South Africa, allowing for early interventions and personalized support.
[46]	Modeling reveals that undergraduate research impacts final certification outcomes. The use of multifactor linear regression methods and artificial neural networks stands out.
[47]	Fuzzy logic-based modeling software is a useful tool for the analysis of educational trajectories, as it provides valuable information for decision-making in academic planning.
[48]	The implementation of modeling tools in biorefinery education improves the understanding and application of chemical engineering concepts.
[49]	A mathematical model is developed based on set theory, indicated as MDE, which organizes instruction in professional education, facilitating the effective training of professionals in various fields.
[50]	The use of virtual design modules enhances learning and strengthens students' identity as engineers.
[51]	Mathematical modeling in hydrologic design case studies improves understanding and highlights the relevance of mathematical skills in engineering.
[52]	Mathematical modeling and data mining on large educational sets is valuable for curriculum planning and decision-making in education. Bag-of-words representations based on natural language processing were used.
[53]	Mathematical modeling improves conceptual understanding of differential equations in remote teaching.
[54]	The integration of mathematical modeling, visualization, and programming improves problem-solving and conceptual understanding in STEM.
[55]	Discussion participation modeling predicts performance in online mathematics courses. Multilevel modeling is highlighted for predicting student behavior over time.
[56]	Modeling contributes to the adaptation and stability of universities in digital environments, as it improves their ability to compete strategically. The mathematical model of the student's adaptive profile was proposed considering the learning scenario, their level of success, the adaptation mechanism, and the starting state.
[42]	The mathematical equation-based learning model of the statistical memory curve improves conceptual understanding and the connection between policy and academia.
[57]	The recommendation system based on performance modeling improves academic advising and curriculum planning.
[58]	The evidence-based mathematical pedagogical model improves understanding and skills in antenna design. The teaching and learning of antenna theory and design could be sectioned as a paper-based design domain and a summary realistic domain.
[59]	The use of artificial intelligence technologies in the organization of educational processes improves the efficiency and personalization of learning. For this purpose, a mathematical model of the generalized knowledge evaluation algorithm is proposed.
[60]	Structural modeling is applied to assess the impact of active learning methods in engineering education, demonstrating their success in enhancing learning outcomes.
[61]	Meaningful learning and mathematical modeling contribute to addressing business problem situations in higher education, promoting deep and applicable understanding.
[62]	A nonlinear mathematical model analyzes the impact of COVID-19 on higher education in developing countries, providing valuable information for crisis management in education.
[63]	The use of stochastic models in higher education is seen as a valuable pedagogical tool. It provides those responsible for the design and implementation of educational policies with predictive mechanisms on the exact parameters that must be considered by facilitators to improve the quality of their teaching. In this way, the general degree of student satisfaction can be raised in relation to the required competencies.
[64]	In the study, it was found that the incorporation of modeling and modeling in secondary technology and engineering education had a positive impact on the understanding of key concepts.
[65]	The results of this study suggest that interdisciplinary and multidisciplinary approaches in teaching applied mathematics at Lipetsk State Technical University had a positive effect on students' education.
[66]	The results indicate that mobile learning based on an appropriate teaching model has the potential to increase students' interest in learning and improve their academic achievement.
[67]	Results on artificial datasets show that this hybrid method is highly effective for classifying data samples, both when they fall into distinct regions and when significant overlap exists.
[68]	Understanding epidemiological and prognostic models is crucial to reduce the impact of this epidemic situation. SVM was found to be the most effective, used in 23% of the studies, followed by DT at 17% and boosting at 15%.
[69]	With mathematical models, students generate practical knowledge, independently explore mathematical theories, foster critical thinking, and improve their metacognitive and communication skills. Competence in mathematical modeling is often assessed through formative assessments.
[70]	Machine learning and mathematical modeling techniques have come a long way in predicting changes in groundwater levels. However, machine learning has prevailed, with random forest methods being the most common, followed by support vector machine and artificial neural network approaches.
[71]	The simultaneous development of mathematical models and experimental/imaging techniques remains rare but offers substantial potential. Open-source sharing of complete, annotated datasets and models encourages collaboration across different fields and fosters the creation of innovative techniques.

In relation to the quantitative results, it was possible to appreciate the use of various mathematical models in the selected publications, with a greater participation of models with structural equations, models related to adaptive profiles and virtual mathematical models. In the first place, with the same level of frequency and percentage distribution, the use of structural equations, adaptive profile mathematical models and virtual models stand out with 10% each. In a second group with a lower frequency are predictive models, linear regression and multilevel models with 6.66% each. Finally, neural networks, dynamic simulation models, models based on set theory, and physico-mathematical models, were found with 3.33% each.

The number of annual studies clearly shows an evolution over six years. An increasing trend in research activity is observed for 2020, which remained constant until 2021; however, a significant upturn is observed for 2022, as well as a small decrease in 2023, indicating a growth in the production of studies in this area in recent years as presented in Figure 2. This is mainly because technological advances may facilitate the development of research in certain areas, which could lead to an increase in the production of studies in these fields.

The selected articles also demonstrate the existence of positive and negative findings in relation to the year of publication as shown in Figure 3. This analysis facilitates a retrospective view on the distribution and trend of positive and negative findings in academic research. An overall predominance of positive findings is observed in the years 2019, 2020, 2021, and 2022, in contrast to 2023; however, positive findings (n=18) predominate over negative findings (n=12). This overview contributes to the understanding of the evolution of research findings in the examined field over a six-year period.

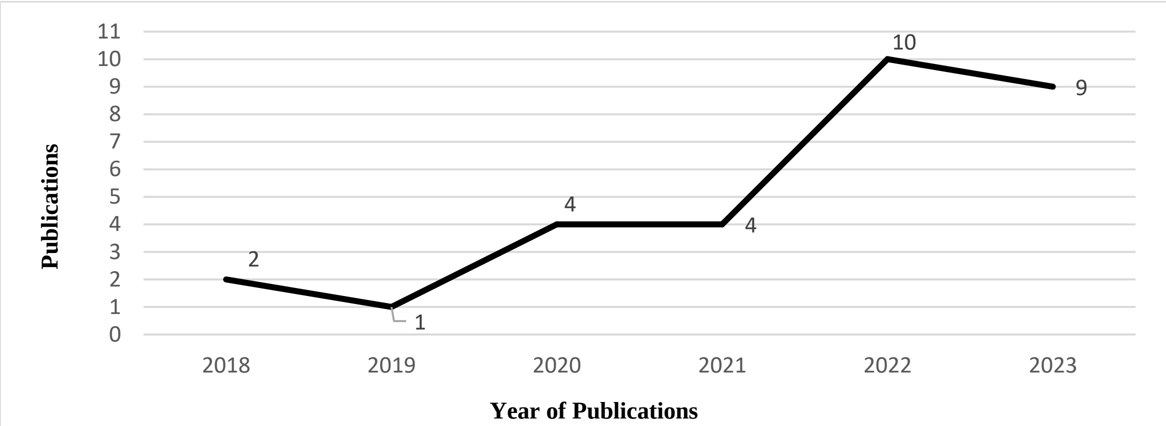

Figure 2. Number of research per year study

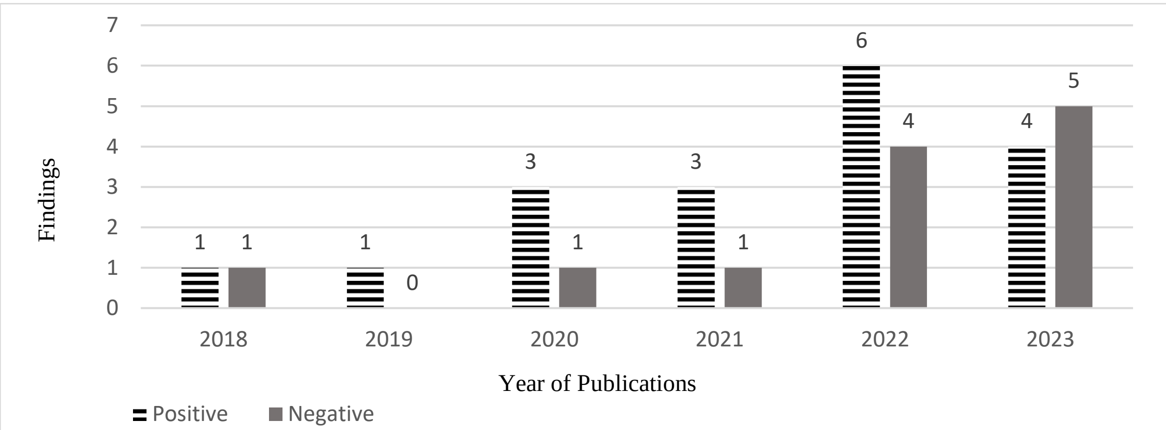

Figure 3. Ratio of positive and negative findings by year of publication

On the other hand, selected research findings from 2018 to 2023 reveal remarkable developments in the relationship between mathematical modeling and education, particularly in crucial areas of pedagogy and educational technology. Key findings highlight trends, key patterns, and conceptual connections. Earlier in the series, a focus on identifying cognitive and non-cognitive predictors of student achievement stands out. Studies such as Voronin *et al.* [43] lay the groundwork by exploring the influence of these predictors in the context of unified state exams and advanced mathematics curricula. Simultaneously, student adoption of e-learning systems, as studied by Hanif *et al.* [44], becomes a critical topic of interest; educational technology can be a valuable resource for addressing the application of mathematical models with structural equations.

The years 2020, 2021, 2022, and 2023 mark a period of deepening the role of mathematical research and modeling in higher education. These studies highlight the positive influence of student research on academic outcomes, emphasizing the importance of early immersion of students in research activities [46]. In addition, the usefulness of mathematical modeling in professional education planning and management offers a valuable perspective for addressing the adaptation of academic programs to the ever-changing demands of the labor market [50].

Subsequently, in the years 2022 and 2023, innovation and evaluation of higher education is presented, where mathematical modeling emerges as an effective tool to improve conceptual understanding in technical disciplines in engineering and physics; as well as the application of theoretical concepts in a deep way [53]. In this sense, the use of these models can facilitate the teaching and evaluation of online learning; an example of this can be the use of an online learning algorithm using fuzzy neural networks. Collectively, this series of research traces an evolution at the intersection of mathematical modeling and education. From understanding factors that drive student success to implementing educational technologies and promoting student research in higher education, these investigations contribute significantly to the improvement of pedagogical practice.

This analysis highlights the need for more interdisciplinary and collaborative research, as well as the application of modeling approaches in pedagogical decision making. It also underscores the relevance of continuous adaptation to the changing demands of the educational environment and the importance of rigorous assessment to ensure the quality of teaching at all levels. These findings provide a solid foundation for future research, as well as for driving educational innovation in the 21st century.

3.2. Discussion

The research question guiding this analysis focuses on the impact of mathematical modeling on college students' learning. To address this question, after examining the contributions of the 30 publications selected and shown in the previous section, the information was synthesized in order to present the discussion in an orderly and articulated manner. In this context, three main axes have been established for the discussion, starting with the improvement of conceptual understanding, then the development of problem-solving skills and, finally, the connection between theory and practice.

3.2.1. Improved conceptual understanding

The improvement of conceptual understanding in the university context is a topic of great relevance in higher education. In this sense, previous research [52], [53] highlighted that the incorporation of mathematical modeling in the remote teaching of differential equations leads to a significant improvement in the conceptual understanding of university students. Their focus was on a deeper understanding of the concepts and an enhanced ability to apply them in various contexts. Complementarily, Peng e*t al.* [42] proposed a mathematical equation-based learning model of the statistical memory curve; this strengthened the connection between political ideology and academic disciplines in university education and also knowledge retention and understanding of political criteria.

In a precise context, Saleem *et al*. [68] highlighted the importance of predictive models in studies related to public health problems, such as those generated by epidemics and decision-making, while Wei et *al*. [69] emphasized that with these, elementary school students can take advantage of their application to model environments and cases on everyday problems and improve both cognitive and creative skills. Similarly, Afrifa *et al*. [70] confirmed through referential exploration that predictive models can contribute to the understanding of phenomena already evidenced, by simulating similar situations in the future, complementing automatic learning in students. On the other hand, Berg *et al*. [71] shared their experience with the use of in vivo images within mathematical modeling, which represents a way to improve the understanding of specific contents such as blood flow behavior and conditions.

On the other hand, Ziatdinov and Valles [54] highlighted that the application of mathematical modeling in university STEM education, boosted in conceptual understanding and as well as problem-solving skills. This increased academic performance in students. In the case of Merck *et al*. [51], they proposed a mathematical model in the context of hydrological design and demonstrated an increase in conceptual understanding, which underlines the relevance of mathematical modeling to contextualize theory in practice and improve understanding in particular fields. In the case of Tarasyev *et al*. [47], they took the discussion beyond pure mathematical modeling by developing fuzzy logic-based modeling software to analyze educational trajectories. Their research highlighted the importance of personalization in higher education, suggesting that tailoring instruction to students' individual preferences and needs can improve conceptual understanding and academic performance.

Taken together, the findings of these eleven publications consistently indicate that mathematical modeling is of great importance for the conceptual understanding of college students. This is in direct agreement with previous studies [3], [4] which point out that modeling facilitates the acquisition of relevant skills, by knowing its nature, applications, and benefits to refine the handling of mathematical functions and operations and other related disciplines. Similarly, the retention of knowledge and the ability to apply concepts in practical situations support the usefulness of mathematical modeling as an effective tool for meaningful learning in higher education, aspects that are in direct agreement with the contributions generated by the studies [5], [6], who emphasize the potential for understanding and analysis of various areas of knowledge, such as biology, physics, economics, and engineering. This enriches the educational experience of students to face academic and professional challenges more effectively.

3.2.2. Development of problem-solving skills

Contemporary higher education faces a growing demand to prepare students not only with a deep understanding of concepts, but also with the ability to apply that knowledge in challenging contexts and solve problems effectively. In this context, mathematical modeling has emerged as a prominent pedagogical strategy that seeks not only to enhance conceptual understanding, but also to cultivate critical problem-solving skills. In this regard, Ziatdinov and Valles [54] stated that mathematical modeling not only improves conceptual understanding, but also promotes substantial development of problem-solving skills. Their research indicates that the integration of mathematical modeling, visualization, and programming through GeoGebra in undergraduate STEM education lead to improved academic performance, a phenomenon that can be attributed to the acquisition of stronger problem-solving skills.

On the other hand, other research [65], [66] added a critical dimension by highlighting the importance of study and research tracks in university teacher education. Their study highlights that these tracks not only promote the effective connection between theory and practice, but also enable students to acquire a deeper understanding of their future profession and improve their pedagogical skills, which include problem-solving skills. The work of Fasinu *et al*. [58] facilitates visualization of how a mathematical pedagogical model based on empirical evidence can positively impact the development of specific skills required for antenna design. The students who participated in this study provided information to denote an improved conceptual understanding, but more significantly, they were able to effectively apply this knowledge in practical projects, reflecting the tangible development of problem-solving skills.

In turn, Atalla *et al*. [57] explored how mathematical modeling can personalize academic advising and curriculum planning in college. Their research highlights that student who benefited from an intelligent recommendation system based on performance modeling received more personalized recommendations and experienced greater academic success, implying significant development of problem-solving skills in their academic pathway. The contribution of Lee and Recker [55] focuses on the importance of active participation and online interaction in undergraduate academic achievement. Their focus on mathematical modeling to predict student achievement highlights how problem solving is enriched when students actively participate in asynchronous discussions in online mathematics courses.

The study by Melnykov *et al*. [46] provides an additional argument, as it shows that research conducted by university students, as a form of modeling the real world, translates into higher grades in final certifications. This result highlights the relationship between student research and the development of problem-solving skills, which is crucial in the university context. In another vein, Karyy *et al*. [59] and Guimarães and Lima [60] explored how artificial intelligence and modeling can further personalize the educational process. Their developed model illustrates how artificial intelligence can adapt learning to the individual needs of students, improving the efficiency of the educational process and strengthening the development of problem-solving skills.

Barker [50] adds evidence by demonstrating that modeling using structural equations can improve conceptual understanding and knowledge retention compared to more passive approaches in engineering education. This finding supports the hypothesis that mathematical modeling fosters more effective learning and the development of problem-solving skills. In this regard, Fontana and Groenwald [61] further explore the application of mathematical modeling in addressing business problems in higher education. Their results indicate that this approach promotes a deep and applicable understanding that helps students deal with problem situations in business contexts, which further reinforces the relevance of modeling in the development of problem-solving skills.

Several research [63], [64] develop a mathematical model to assess the quality of stochastic skills training in higher education, demonstrating its usefulness in measuring acquired skills and facilitating the evaluation and improvement of education in this specific field, which supports the importance of modeling in the development of problem-solving skills. Finally, Abidemi *et al*. [62] presents a nonlinear mathematical model that analyzes the impact of COVID-19 on higher education in developing countries. The results help to understand the implications of the pandemic on education and to plan appropriate response strategies, highlighting the relevance of modeling in crisis situations and its ability to address complex problems.

Thus, as mentioned by several studies [14], [15], [20], mathematical modeling in higher education is a mechanism of great importance for the development of problem-solving skills in university students, using critical and reflective thinking. Likewise, this is supported by previous studies [16], [17], who emphasize the goodness of representing in a simplified form a large-scale phenomenon to be analyzed and interpreted using objective functions, variables, constraints, and other specifications, and thus obtain a conditional optimal solution. On the other hand, Rodríguez-Nieto *et al*. [21] argue that mathematical modeling emerges as a fundamental educational strategy that can positively transform the university learning experience. All this allows categorically supporting mathematical modeling in university curricula to boost undergraduate decision-making.

3.2.3. Connection between theory and practice

This subsection details the strategies employed to merge, compare, or triangulate both quantitative and qualitative data sets. It explains how the synthesis of these diverse data sources contributes to a comprehensive understanding of the research problem. The convergence between theory and practice in the field of higher education has been meticulously examined throughout several investigations, which have been focused on deciphering the transcendental influence of mathematical modeling on the learning process of university students. Through a more detailed analysis of the contributions of these studies, it is possible to deepen the richness and scope of the relationship between mathematical modeling and higher education.

Studies by Fu *et al*. [66] bring up the relevance of study and research paths as vehicles of integration between theory and practice. This research reveals that these trajectories play a critical role in the training of university teachers, in which mathematical modeling becomes an effective pedagogical tool to foster a deeper understanding of their future profession. Thus, the relationship between theory and practice becomes more explicit as students embark on research and apply theoretical concepts to real situations in an educational setting.

In the work of Sherstobitova *et al*. [56], they focus on the adaptation and stability of educational institutions in the changing digital environment, and conclude that mathematical modeling is a tool that allows competition between universities to implement pedagogical theory and digital reality, increasing efficiency in their administrative procedures. In the same way, according to Barker [50], the use of virtual design modules in engineering courses strengthens the professional identity of students, thus mathematical modeling becomes a bridge between academic theory and professional training.

On the other hand, Pinevich *et al*. [10] add an ethical dimension, by exploring how modeling can be employed to address humanitarian problems, it is noted that it is implemented as a catalyst for ethical and social problem solving. This is evidenced in the work Kenger and Ozceylan [67], who provide a mixed integer linear programming (MILP) model and an improved online learning algorithm for general fuzzy min-max neural networks, which become a bridge connecting pedagogical theories with teaching strategies tailored to the changing needs of learners. The approach of Tarasyev *et al*. [47], prioritizes personalization in education through the use of fuzzy logic-based modeling software, which allows its conversion to individual student needs, reinforcing the intertwining of education theory and personalized application. In turn, student safety can also be ensured through predictive mathematical models, according to Appel and Durandt [45], facilitates early intervention in student well-being and support.

In this sense, mathematical modeling emerges as a vital and multifaceted link between theory and practice in higher education. The aforementioned studies, by delving deeper into their results and applications, reveal how mathematical modeling not only enriches theoretical understanding, but also directly influences the training of professionals, institutional decision making, humanitarian problem solving, effective teaching and student care. Ultimately, mathematical modeling is consolidated as an essential tool in the continuous improvement of higher education and in the construction of a solid bridge between theory and practice in this academic context.

In a precise direction, the connection between theory and practice in the case of mathematical modeling presents the fundamental foundations for the gradual development of emerging technologies. An example of this is the study developed by Finotelli and Eustache [29], who delve into the modeling of human memory to represent the motivational state of the learner and its effect on the learning process. This is perceived when quantitatively exposing the rate of change of learning that is associated with variation in motivation, as well as an initial factor in the gain equation, e.g., the change in motivation at the beginning of a learning task.

In addition, several researches [35]–[37], [42] through the results of their respective research, showed the convergence between the theory and practice of mathematical modeling. This is detected by explicitly highlighting effective and sustainable innovations, as well as the creation of systematized responses that bring a positive impact of mathematical methods and models in the treatment of memory during the learning process. In this way, one can emphasize the optimization of processes of a social nature such as engineering projects, medicine, as well as manufacturing systems, the expansion of AI through advanced algorithms, and the reengineering of nanotechnology.

Finally, Martín-Lara and Ronda [48] presented a way to bridge the gap between theory and practice in the use of mathematical models in the educational field. In this context, in developing the study, they compared the results obtained after the lessons that were traditionally performed, with those obtained after the implementation of several computer activities with modeling and simulation of bioreactors to teach biorefinery concepts focused on bioethanol production. This is a living example in which mathematical modeling provides the practical information to corroborate the theoretical aspects learned.

4. CONCLUSION

It is found that the integration of mathematical modeling in the teaching and learning processes at the university level promotes a substantial improvement in conceptual understanding. This improvement is not limited only to a superficial assimilation of concepts, but translates into a deeper understanding and the ability to apply these concepts in a variety of academic contexts. The evidence presented in the studies analyzed consistently supports this claim, highlighting the value and high importance of mathematical modeling as a pedagogical resource to enrich the conceptual understanding of college students.

Mathematical modeling is found to be an effective tool for fostering the development of problem-solving skills. Research findings suggest that students exposed to mathematical modeling acquire strong skills to tackle complex problems and to effectively apply mathematical principles in practical situations. This problem-solving ability emerges as a crucial competency in higher education and in preparing students to face academic and professional challenges, thus, it is concluded that mathematical modeling has a high level of importance for university learning.

It is also established that mathematical modeling facilitates the connection between theory and practice in higher education. The studies analyzed highlight how mathematical modeling allows students to experience the concrete application of theoretical knowledge in real-world situations. This connection between theory and practice not only enriches academic training, but also strengthens students' professional identity by providing them with meaningful and applicable experiences in their fields of study.

Taken together, these findings provide a solid basis for understanding and appreciating mathematical modeling as a valuable educational resource in higher education, as well as for appreciating its importance in facilitating student learning. The integrated and sustained reinforcement of mathematical modeling in university curricula, as well as in teaching strategies, can significantly enrich students' learning experience and prepare them more effectively to address the academic and professional challenges they will face in their educational and career paths. In addition, mathematical modeling is positioned as a tool that not only improves academic training, but also influences institutional decision-making, the resolution of socially relevant problems and the continuous improvement of the quality of teaching in higher education.

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C : **C**onceptualization
M : **M**ethodology
So : **So**ftware
Va : **Va**lidation
Fo : **Fo**rmal analysis
I : **I**nvestigation
R : **R**esources
D : **D**ata Curation
O : Writing - **O**riginal Draft
E : Writing - Review & **E**diting
Vi : **Vi**sualization
Su : **Su**pervision
P : **P**roject administration
Fu : **Fu**nding acquisition

CONFLICT OF INTEREST STATEMENT

Authors state no conflict of interest.

DATA AVAILABILITY

Data availability is not applicable to this paper as no new data were created or analyzed in this study.

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