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To cite this article:

Niño-Rojas, F., Lancheros-Cuesta, D., & Jiménez-Valderrama M.T.P., Mestre, G., & Gómez, S. (2024). Systematic review: Trends in intelligent tutoring systems in mathematics teaching and learning. *International Journal of Education in Mathematics, Science, and Technology (IJEMST)*, *12*(1), 203-229. https://doi.org/10.46328/ijemst.3189

International Journal of Education in Mathematics, Science and Technology

2024, Vol. 12, No. 1, 203-229 https://doi.org/10.46328/ijemst.3189

Systematic Review: Trends in Intelligent Tutoring Systems in Mathematics Teaching and Learning

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Article Info

Article History

Received:
13 January 2023
Accepted:
24 August 2023

Keywords

Intelligent tutoring system
Virtual environment
Adaptive learning
Mathematics
Higher education

Abstract

The use of intelligent tutoring systems (ITSs) is growing rapidly in the field of education. In mathematics, adaptive and personalized scenarios mediated by these systems have been implemented to aid concept comprehension and skill development. This study presents a systematic review on the current status of the use of ITSs in mathematics education in higher education institutions (HEI). More specifically, it inquires about elements rarely addressed in reviews, such as the purposes, advantages, effectiveness, limitations, characteristics, and development and research methodologies in ITSs used for mathematics education. We analyzed 43 documents in 15 specialized and indexed journals in the years 2012-2022. In addition to providing a global overview of the implementation of ITSs in mathematics teaching and learning, we also present trends and opportunities for future research on building educational environments guided by these technologies.

Introduction

The use of intelligent tutoring systems (ITS) is becoming increasingly common in the field of education. These systems are part of the emerging technologies that are currently being incorporated as a means of supporting students and teachers in teaching and learning scenarios. Educational institutions are choosing to provide students with additional learning materials and services that contribute to the construction of knowledge. These include contents, tools, suggestions, and recommendations presented to students according to their needs. This trend is called adaptive learning (Brusilovsky et al., 1995).

Mathematics is one of the areas where this trend has become involved at all levels of education. Due to difficulties in comprehension, representation, conceptualization, and analysis in subjects related to arithmetic, algebra, geometry, and calculus, students are presented with an alternative that fits their cognitive (Cung et al., 2019; Phillips et al., 2020) and affective needs (Ascari et al., 2021). To this end, ITSs are categorized as an efficient tool for learning mathematics due to the functionality and advantages that intelligent and adaptive technologies hold (Mojarad et al., 2018; Lopes, et al., 2019).

On the other hand, there are currently few studies related to mathematics education using ITSs that report trends, purposes, advantages, and limitations, among other characteristics necessary for identifying their current state in this field. Thus, the relevance of this study lies in the systematic review of the use of ITSs for teaching and learning mathematics in secondary school and the first semesters at higher education institutions (HEI), which is where students face the above-mentioned subjects. For our methodology, we adapted the ideas proposed by Kitchenham (2004) for systematic reviews (planning, conducting the review, and reporting the review). Likewise, the selection of journals and scientific documentation in the field of educational technology was completed in two phases: (1) a review of the Web of Science (WoS) database following the ideas proposed by Bacca et al. (2014) and followed by Niño and Gómez (2022), and (2) a review in Scopus considering the rigorous evaluation process for the documentation presented in this database.

This paper starts by posing research questions related to identifying the trends, purposes, advantages, effectiveness, limitations, and characteristics of the use of ITSs in secondary schools and HEIs. We also inquire about the inclusion of user modeling and adaptive processes in ITS applications, and for the final question, we examine the research methodology elements used for applying ITSs in mathematics teaching and learning at HEIs. After this, we describe our methodology, where we present the categories of analysis, the exclusion and inclusion criteria, the selection and analysis of scientific documentation, our descriptive and bibliometric analysis, and the trends and conclusions.

Related Works

In mathematics learning, understanding, applying concepts, carrying out procedures and solving problems, has been a challenge for researchers due to the difficulties presented by students in their assimilation and internalization. In this sense, these difficulties are frequently addressed through the incorporation of information and communication technologies in a large part of the educational settings and levels. One of the technologies with the greatest projection to address this problem is artificial intelligence (AI), since it facilitates teaching and learning at all educational levels due to the benefits it offers such as: identifying shortcomings in students, addressing their difficulties, helping in decision making, providing plans and improvements through adaptive and personalized paths (Chen et al., 2020; Hwang et al., 2020;).

Several studies show the potential and impact of AI in education, for example, Chen et al. (2020), show in their review that the incorporation of humanoid robots and chatbots as teachers or instructors have improved the effectiveness and efficiency of teachers, which has contributed to educational quality. Likewise, Xie et al. (2019) study the trends and developments of adaptive and personalized learning between 2007 and 2017. In that work, the authors show the importance of introducing tools that contribute to these adaptable processes to students, such as devices intelligent or systems based on artificial intelligence. Another study shows the interest in promoting adaptive and personalized processes through web-based online learning in order to promote learning paths in an adaptive way, promoting individual student performance (Chen, 2008). Moreover, according to Gallagher et al. (2022), adaptive teaching is essential to ensure that all students have the same educational opportunities.

Reviews on the influence of the services or tools provided by AI are developed at all educational levels. However, little research focuses on a particular level of education. Zawacki-Richter et al. (2019) develop a review on the implementation of these services in higher education. This review studies 146 investigations between 2007 and 2018, where it highlights that the most used disciplines are STEM and computer science. In addition, they share that the four areas of greatest application are: profiling and prediction, assessment and evaluation, adaptive systems and personalization, and intelligent tutoring systems (ITS).

In the particular context of mathematics education, bin Mohamed, et al. (2022), carried out a systematic review and meta-analysis between 2017 and 2021 where they studied 20 documents that present a detailed description of the importance of AI in academics. Mathematics teaching and learning processes at all educational levels. The tools that were most used for mathematics education are robotics, agent teaching, autonomous agent and comprehensive approach, and the countries with the most research carried out are the USA and Mexico.

On the other hand, Hwang and Tu (2021), carry out a bibliometric mapping analysis and a systematic review between 1996 and 2020, where the research trends of AI in mathematics education are explored through 43 documents. The authors highlight in their review: the application domains, the participants, the research methods, the technologies adopted, among others.Additionally, and due to the COVID 19 pandemic that affected the world, AI-based systems were notoriously considered in mathematics education. Despite the fact that the use of these technologies during confinement yielded undesirable results, mediating scenarios are expected to be built by AI-based tools that impact the teaching and learning of mathematics. For example, del Olmo-Muñoz et al. (2022) proposes a study that illustrates the efficiency of ITS aimed at learning mathematics, particularly the teaching of solving verbal problems.

In this order of ideas, for this research a particular review of the use of ITS in the teaching and learning of mathematics in secondary and higher education is proposed. It is necessary to inquire about the impact of ITS, emphasizing the purposes, advantages, limitations, effectiveness, research methodologies, temporal dimension, type of adaptation process, type of user modeling, articulated teaching or learning strategy, ITS used and areas of mathematics most intervened. In addition, this research provides a look into the future and trends on the implementation of these systems in mathematics education at a higher level.

ITS Applications in HELs

The use of ITSs for teaching and learning mathematics has been growing in recent years. Joaquim et al. (2022) conducted a study that aimed to identify good and bad pedagogical practices based on teaching and learning processes using a gamified ITS in basic education. As an advantage, they found that gamified ITSs are important for improving learning and promoting greater participation. This study also sheds light on the importance of using gamified ITSs aligned with the school curriculum and having a clear intervention proposal instead of relying on voluntary use.

Similarly, Jaques et al. (2013) present the expert system of the PAT2Math algebra tutor. PAT2Math is an ITS that teaches students how to solve linear and quadratic equations. It is a web-based system implemented in Java, which allows students to use it on any computer or platform with Internet access. PAT2Math consists of an algebra editor (PATequation) which helps students solve equations. In this same area, Arnau et al. (2013) build an ITS for tracking user actions with the ability to provide adequate supervision during arithmetic and algebraic problem solving. Jaques et al. (2013) developed an ITS that could personalize the process of learning mathematics by using case-based reasoning such as with big data technology and discussing the potential of implementing IoT technology in the architecture of ITS development.

O'Rourke et al. (2015), Hybrid Learning Environment, n.d., Deo et al. (2020), and Lopes et al. (2019) have shown that step-by-step tutorials are effective as instructional tools, especially when they provide interactive elements such as templates, videos that track learner progress, and user-friendly interfaces.Regarding the definitions of an "intelligent tutoring system" Gonzalez et al. (2014) define an (ITS) as a system capable of guiding students along a particular field of knowledge through solving tasks tailored to the learner's needs. This paper proposes an architecture concept for ITS implementations of game-based learning, which is then used for designing a system for teaching and learning mathematics.Similarly, when mentioning the design of this type of system, Krichen (2020) determines that learning environments made up of a virtual environment and a tutor must exist and must be designed following a cognitive geometry paradigm similar to the practices observed in classrooms. Such systems are advantageous when working with struggling learners (Aleven et al., 2010; Ascari et al., 2021; Ciolacu & Beer, 2016; Mamoun et al., 2018; Work in progress: Online resource platform for mathematics education (IEEE Conference Publication, n.d.).One feature that is present in most of these systems is student tracking. Xiong et al. (2013), Huang et al. (2013), Mojarad et al. (2018), and Ford and Allali (2022) proposed a system that allows ITSs to strive for students to hold long-term mastery over what they learn.

Paneque, et al. (2017) conducted a study that revealed that tutor-teacher-student interactions produced a considerable number of mathematics learning opportunities of the "thinking strategically" type, establishing figurative inference conjectures and promoting the transition from empirical to deductive argumentation. ITSs that use predictive models and artificial intelligence are being implemented to perform this tracking (Craig et al., 2013; Kautzmann & Jaques, 2019; MacLellan & Koedinger, 2022; Nye et al., 2018; Zheng et al., 2019). Including user models in the adaptation process is indispensable. The selection of the technique used in the adaptation process will depend on this (Brusilovsky, 2001). Numerous studies have given a descriptive definition of these models relevant to student profiles for teaching mathematical concepts (Bush, 2021; Cung et al., 2019; Gil Vera, 2017; Lei et al., 2021; Liu et al., 2017; Nguyen et al., 2020; Phillips et al., 2020; Shin, 2021; Singh et al., 2022; Wang et al., 2020).

ITSs are also developed as gamification strategies in order to improve student attention processes. Rai and Beck (2012) present an approach to make a tutor increasingly game-like, with an assessment to estimate the effect of game-like elements in terms of their benefits, such as improving engagement and learning, as well as their costs, such as distractibility and working memory overload. Blanca-Estela and Josefina (2017) conducted a study proposing a semi-automatic tool that implements different modules of a cognitive tutor, following an instructional design for solving algebra problems by handling gamification and game strategies based on tangible user interface computational theory techniques. Recent studies show adaptive processes that consider predictive mathematical models and artificial intelligence techniques, with expert systems being the most widely used (Johnson et al., 2022; Liu et al., 2020; Lu et al., 2021; Online Practical Deep Learning Education: Using Collective Intelligence from a Resource Sharing Perspective, n.d.).

Method

We considered the following research questions for the systematic review:

1. What are the purposes, advantages, and limitations of applying ITSs in the teaching and learning of mathematics in HEIs?
2. Does the study consider the inclusion of user modeling and adaptive processes for applying ITSs?
3. What were research methodology elements used in the application of ITSs for teaching and learning mathematics at HEIs?

For this review, we followed the phases proposed by Kitchenham (2004), as described below (see Figure 1)

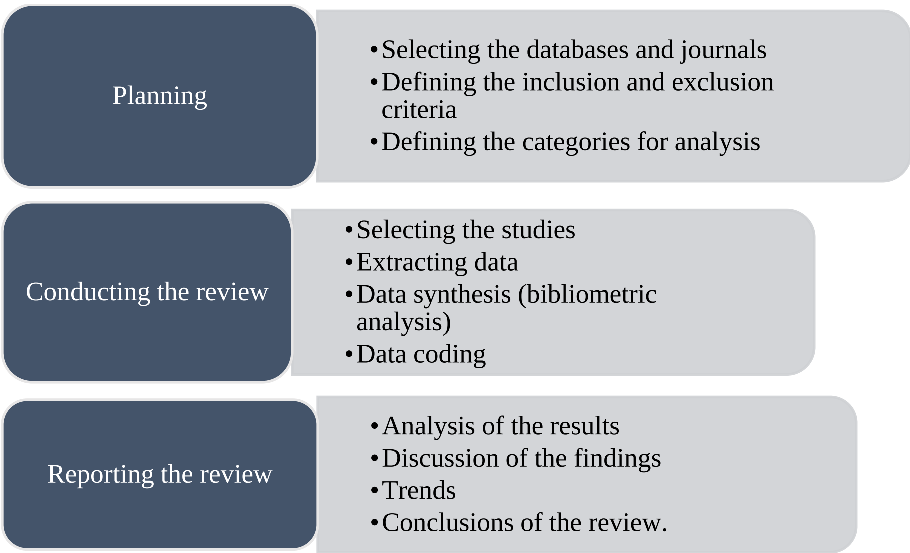

Figure 1. Method. Adapted from Kitchenham (2004)

Planning

Selecting the Databases and Journals

First, we reviewed the Web of Science (WoS) database to identify the journals with the highest JCR impact factor in the field of educational technology and then, in the second stage, we reviewed the documentation in journals or conferences indexed on Scopus. We chose these two databases for the scientific rigor shown in their demanding evaluation parameters for publishing papers.For the journal selection process in WoS, we initially considered the top five journals with the highest h5-index in Google Scholar's educational technology category. We used Google Scholar because WoS does not have an exclusive category for educational technology, which made it necessary to search for the selected journals in this database's social science category. The five most influential journals in the educational technology category are presented in Table 1.

Table 1. Google Scholar Educational Technology Journals

Journal	**H5**
Computer & Education	109
British Journal of Education Technology	62
The internet and Higher Education	59
Journal of Educational Technology & Society	54
Education and information Technologies	52

Each journal generated five journal groups (G1, G2, G3, G4, G5) classified based on citations as described by Bacca et al. (2014). This generated a broader group of journals, among the most representative of educational technology, according to verifications in SJR and the JCR impact factor (see Table 2). Another group of selected journals derived from the comparison between citations with the journals in the previous table (see Table 2) that are not part of the educational technology category but are indexed in the Journal Citation Reports Science Citation Index Expanded (JCR SCIE). This generates a new list of journals considered in this review (see Table 3).

Table 2. Educational Technology Journals

Journal	**Impact Factor (JCR)**
Computer & Education	8.538
Internet and Higher Education	7.178
International Journal of Computer-supported Collaborative Learning	5.108
International Journal of Educational Technology in Higher Education	4.944
British Journal of Education Technology	4.924
Interactive Learning Environments	3.928
ETR&D-Educational Technology Research and Development	3.565
Educational Technology & Society	5.522
Australasian Journal of Educational Technology	3.067
Education and information Technologies	2.917

Table 3. JCR SCIE Journals

Journal	**JCR**
Knowledge-based systems	8.038
Expert systems with applications	6.954
International Journal of STEM Education	5.789
IEEE Intelligent Systems	3.405
IEEE ACCESS	3.367
IEEE Transactions on Education	2.116

Defining the Study Inclusion and Exclusion Criteria

Inclusion Criteria

General Criteria

- Studies published between 2012 and 2022.
- Studies that describe uses of ITSs in mathematics education in secondary education or HEIs.

Specific Criteria

- Studies that report the advantages, disadvantages, possibilities, limitations, characteristics, uses, challenges, and effectiveness of ITSs in the teaching and learning of mathematics in HEIs.
- Studies that describe applications that consider a user model and/or adaptive process combined with the ITSs.
- Studies that describe applications of ITSs in mathematics education in HEIs or in the teaching and learning of subjects related to basic mathematics.
- Studies that describe methods for evaluating the implementation of ITSs in mathematics teaching and learning scenarios in HEIs.

Exclusion Criteria

- Studies not classified as “articles” or “conferences” in the selected journals (e.g., book reviews, books, editorial publication information, book chapters, etc.).
- Studies that mention ITS applications at other levels of education (e.g., preschool, primary school).
- Studies that mention ITS applications in teaching and learning in areas other than mathematics.

Defining the Categories for Analysis

We defined the categories for analysis based on the proposed research questions.

1. ***What are the purposes, advantages, and limitations of applying ITSs in the teaching and learning of mathematics in HEIs?***

Subcategories

- Reported purposes of ITS use
- Reported advantages of ITS use
- Reported limitations of ITS use
- Reported effectiveness of ITS use (effectiveness evaluation)
- Type of ITS used

2. ***Does the study consider inclusion of user modeling and adaptive processes for applying ITSs?***

Subcategories

- Type of adaptation process
- Type of user modeling

3. ***What research methodology elements were used in the application of ITSs for teaching and learning mathematics at HEIs?***

Subcategories

- Research sample
- Research method
- Time
- Data collection method

Conducting the Review

Selecting the Studies

In order to select the scientific documentation and conduct the bibliometric analysis, we standardized the keywords in the ERIC and UNESCO thesauri. The following equation was generated based on this (Table 4):

Table 4. Search Equation

Connector	Keyword
	"Intelligent Tutorial System" OR "Expert Systems" OR "artificial intelligence" OR ctat OR "adaptive learning"
AND	Math OR maths OR mathematics OR mathematical OR "math education" OR "mathematics education" OR "mathematical sciences" OR "learning of mathematics" OR "Mathematics teaching"
AND	"higher level education" OR "higher education" OR "university studies" OR "University education" OR "Upper level" OR "Third stage education"

Considering the inclusion and exclusion criteria, we selected 43 articles and conferences from the chosen WoS journals and the Scopus database (see Table 5). The documents that were in both databases were counted as part of the WoS selection. A total of 22 articles were registered here, while 21 were registered in Scopus.

Table 5. Number of Articles per Journal and Database

Journal	**Number of documents**
JCR – SSCI	Total 10
Computer & Education	2
Internet and Higher Education	0
International Journal of Computer-supported Collaborative Learning	0
International Journal of Educational Technology in Higher Education	0
British Journal of Educational Technology	1
Interactive Learning Environments	1
ETR&D-Educational Technology Research and Development	2
Educational Technology & Society	2
Australasian Journal of Educational Technology	0
Education and Information Technologies	2
JCR – SCIE - ESCI	Total 12
Knowledge-based systems	0
Expert systems with applications	1
IEEE Intelligent Systems	0
IEEE ACCESS	3
IEEE Transactions on Education	1
International Journal of Artificial Intelligence in Education	2
International Journal of STEM Education	1
International Journal of Science and Mathematics Education	1
Lecture Notes in Artificial Intelligence	1
American Journal of Distance Education	1
International Journal of Mathematical Education in Science and Technology	1
Documents in Scopus	Total 21
Journals	9
Conferences	12

Data Extraction, Synthesis, and Coding

From the selected documents, the United States of America (USA) was the country with the highest number of publications on the subject, with a total of 16 articles, equivalent to 37%. This was followed by China with 12% and Brazil with 9%. Colombia represents 2% of publications in this field. These results are shown in Figure 2. On the other hand, 50 articles were found in WoS that matched the search criteria. 2021 was the year with the highest production, which is the year after the beginning of the pandemic. We can speculate that this explains the volume of information on autonomous and adaptive learning tools. As shown in Figure 3, there has been an increased interest in publishing in this area in recent years.

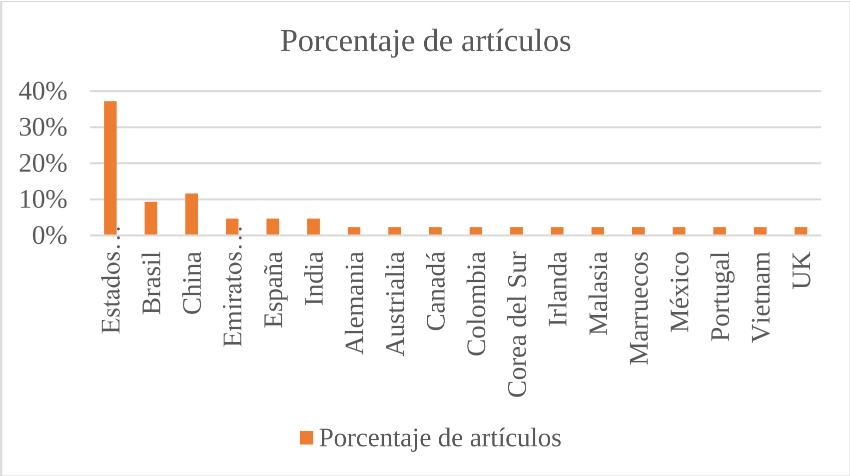

Figure 2. Statistics of Articles per Country

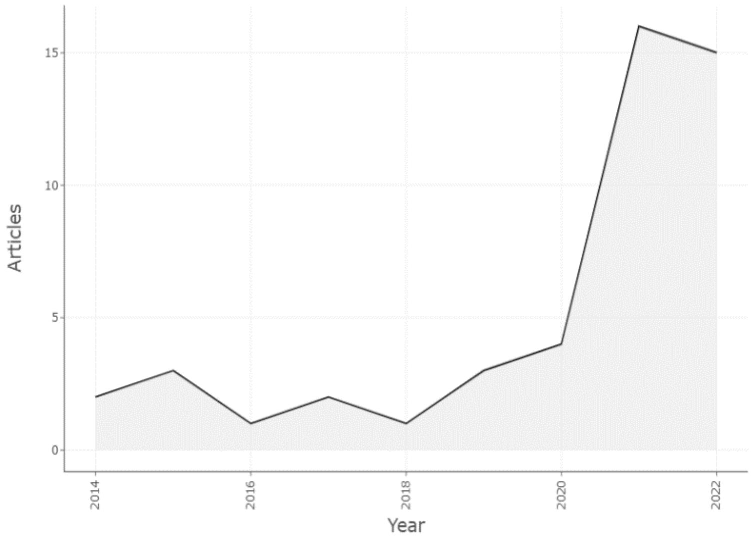

Figure 3. Frequency of Publication (on ITSs) in Recent Years — Web of Science

Figure 4 shows the relationship between the number of articles found and the keywords used in the search.

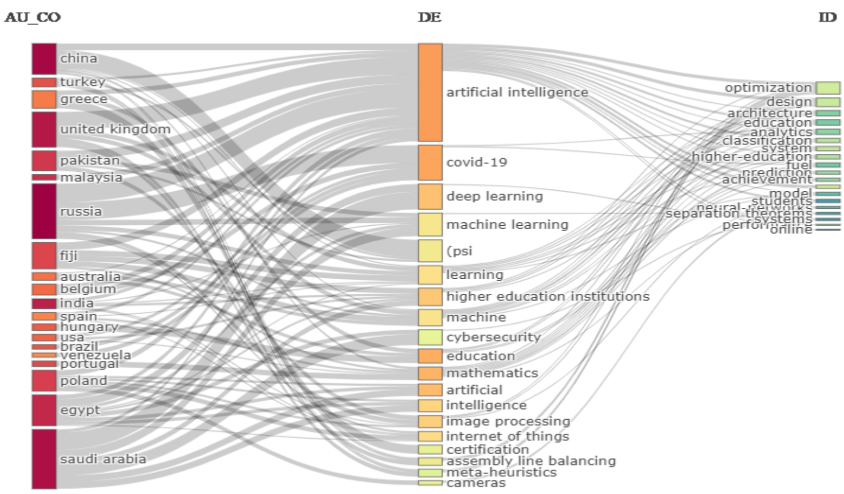

Figure 4. Relationship between Articles and Search Criteria — Web of Science

Regarding the Scopus bibliometric analysis, Figure 5 below shows an increase in publications in the area, especially during 2021.

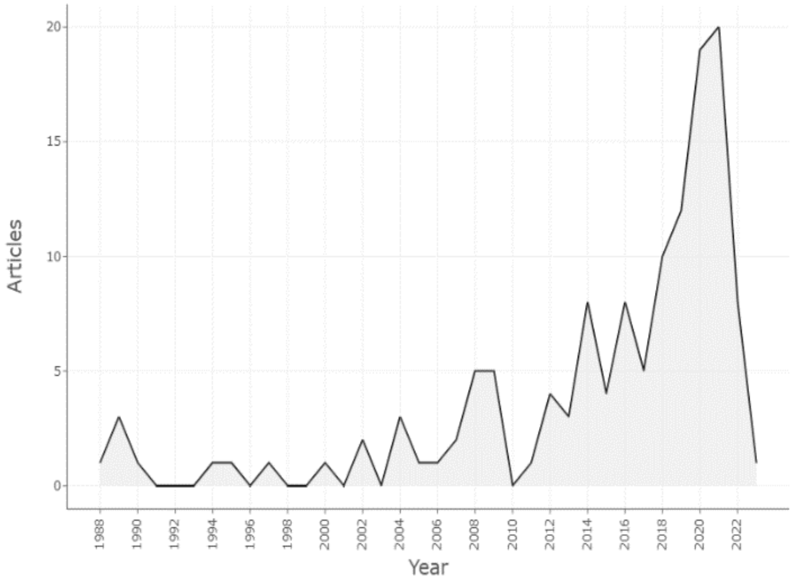

Figure 5. Frequency of Publication (on ITSs) in Recent Years — Scopus

Likewise, Figure 6 shows the relationship between the number of articles, keywords, and secondary keywords used for this review.

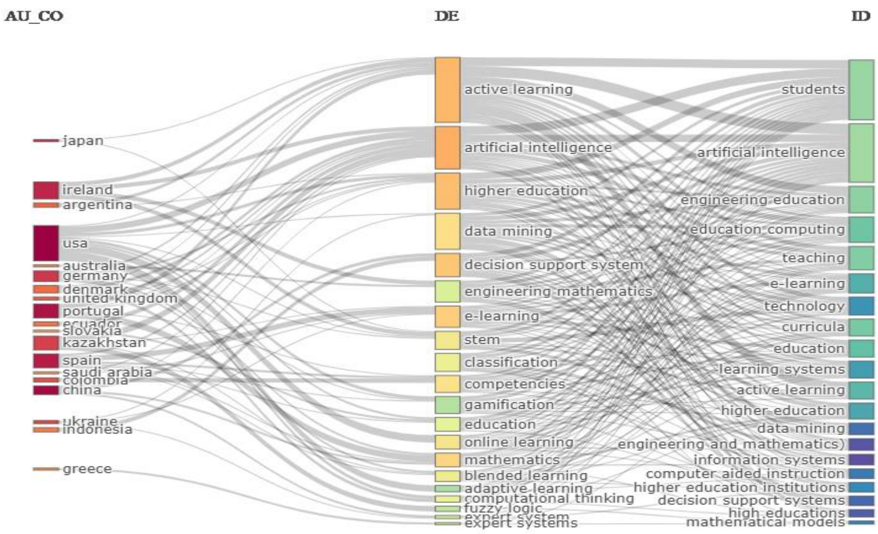

Figure 6. Relationship between Articles and Search Criteria — Scopus

Results

To answer the question "What are the purposes, advantages, and limitations of applying ITSs in the teaching and learning of mathematics in HEIs?" we listed the purposes, advantages, limitations, reported effectiveness, and the ITSs that were used.

Reported Purposes of ITS Use

11.62% of the reviewed documents use ITSs to explain a specific topic and provide instruction on the process of solving mathematical problems. This shows that few studies have the goal of explaining a topic and specifically of teaching problem solving. From this, further study is expected on the teaching and learning of solving mathematical problems through ITSs in HEIs, especially in the first semesters of university.

Most of the studies (41.86%) show an interest in the personalization and adaptation of learning. Some of these systems are designed for solving questions and providing feedback on the procedures and answers given by students (intelligent tutoring). Based on the identified shortcomings and particular needs of each student at a cognitive and affective level, the systems define a personalized and adaptive study plan that contributes to overcoming the perceived difficulties and improving academic performance (Gallimore & Stewart, 2014; González, Mora & Toledo, 2014). Other noteworthy purposes are the reinforcement or supplementation of a topic (16.27%), the assessment of a subject (23.25%), or the development of skills or learning outcomes (16.27%). Table 6 describes the purposes identified in the reviewed studies.

Table 6. Purposes of ITS Use

Subcategory	**Number of studies**	**Percentage (%)**
Explanation of a topic	5	11.62
Reinforcement or complement of a topic	7	16.27
Evaluation of a topic	10	23.25
Educational game	4	9.3
Solve problems	5	11.62
Personalization or adaptation of learning	18	41.86
Development of competencies or learning outcomes	7	16.27
Improve participation	3	6.97
Exploration	2	4.65
Other purposes	4	9.30

Other purposes are described at the end of the table. These include maintaining student motivation for mathematics (Llorens et al., 2014) and using the benefits offered by educational technologies to improve the capacity and working memory of students in the process of learning mathematics online (Mamoun et al., 2018). In that order of ideas, another study highlights that designing and producing teaching materials is an essential purpose, fundamental in providing the student with a wide variety of procedures and activities according to their needs, facilitating learning, and improving their working memory (O'Rourke et al., 2015). Finally, student perception regarding the use of ITSs in mathematics teaching and learning processes are also discussed (Nye et al., 2018).

Reported Advantages of ITS Use

The use of ITSs in mathematics teaching and learning offers significant advantages such as the improvement of learning, the promotion of participation, interaction and collaborative work, among others. However, the advantages that were most reported in the studies were personalized learning (27.9%) and the immediate feedback offered to students when solving exercises and problems or when facing difficulties (23.25%). Regarding the interventions offered by ITSs, some studies show an improvement in problem solving (18.6%), and others provide details on the step-by-step of the suggested procedures (11.6%). Table 7 describes the advantages identified in the reviewed studies.

Table 7. Advantages of ITS Use

Subcategory	**Number of studies**	**Percentage (%)**
Improve learning	11	25.58
Promotes participation	4	9.30
Improve Solve problems	8	18.60
Favors interaction	4	9.30
Facilitates collaborative work	1	2.32
Increases motivation	5	11.62
Improve skill development	5	11.62
Personalize learning	12	27.9
Improves student performance	4	9.30
Provide immediate feedback	10	23.25
Provides step-by-step procedures	5	11.62
Facilitates the evaluation or monitoring process	7	16.27
Promotes navigability	2	4.65
Other advantages	0	0

Several of these systems start their teaching and learning processes with an assessment that allows inquiring about the students' current knowledge and then place them in previously defined profiles. These assessments are reported as an advantage offered by ITSs (16.27%). This allows creation of an environment of formative assessment when carrying out activities, in which, unlike traditional methodologies, the information is immediately available. This offers teachers a more detailed diagnosis of difficulties and mistakes, and thus can guide an assertive instructional process (Haridas et al., 2020; Zheng et al., 2019).

For example, the ALEKS ITS guides the process and shows an individualized learning sequence, which presents differentiated problems through questions. Here, participation is encouraged and it helps students with diverse levels of performance, requiring less supervision and assistance from teachers in their established plans (Craig et al., 2013; Huang et al., 2013; Raju et al., 2018).

Reported Limitations of ITS Use

53.48% of the reviewed studies reported limitations. The most frequent were related to sample size (21%), limited time (9.3%), and network connection (9.3%). The sample used for these studies was relatively small, which affected the overall findings. Some studies state that the time for conducting the study was limited and that the student was not given enough time to prepare, which could have contributed to the lack of success (Liu et al., 2017).

Technical failures were also reported for the used systems (4.65%), such as issues in wireless connectivity. Failures in system design were also noted regarding the lack of rigor in the provided feedback (4.65%). Technical problems occurred due to non-updated versions of browsers in the rooms used for carrying out the activities (Nye, et al., 2018), which could have delayed their completion. Another study claims to have had problems with the server, since this resulted in the loss of several student data, which hindered the assessment of a sizable number of participants (O'Rourke et al., 2015).

The type of assessment was another reported limitation. One study reported using only short questions and highlighted the need to involve other types of questions, such as multiple-choice, closed questions, among others (Lu et al., 2021). This could improve the formative and personalized process; however, it is important to explore and design assessments with questions that also inquire about the students' collaborative skills (Walker et al., 2014). Table 8 summarizes the identified limitations.

Table 8. Limitations of ITS Use

Subcategory	**Number of studies**	**Percentage (%)**
Sample	9	21
Connectivity	4	9.3
Limited time	4	9.3
Technical problems	2	4.65
Lack of compromise	2	4.65
Evaluation	2	4.65
Feedback	2	4.65
Personalized learning	2	4.65
Design	1	2,32
Others	4	9.3
Does not specify the study	20	46.51

2.32% of the studies report three concurrent limitations (one study), 18.6% show two concurrent limitations, and 32.55% report only one. Other reported limitations (9.3%) are related to inadequate use of the system (2.32%), poor understanding of the contents (2.32%), failure to consider affective states (2.32%), and the inclusion of technology (2.32%).

Reported Effectiveness of ITS Use

ITS effectiveness was analyzed based on system functionality and the teaching and learning of topics related to algebra, equations, problem solving, fractions, to mention the most common. It was found that most ITSs in the reviewed studies improved academic performance (37.2%) and student learning (18.6%). In addition, there was a clear improvement in teaching practices articulated with the implementation of these systems (4.65 %). Furthermore, it can be inferred that mathematics education integrated into these technologies favors teaching practices and profoundly impacts student learning (Shin, 2021).

Improvements in student academic performance were reported as a result of accessibility to additional learning materials such as workshops, assignments, and summative and follow-up assessments (Lei et al., 2021; Zheng, 2019). Other reported signs of effectiveness are shown in Table 9.

Table 9. Effectiveness of ITS Use

Subcategory	**Number of studies**	**Percentage (%)**
Improvement in academic performance	16	37.2
Improve learning	8	18.6
Increases motivation	5	11.62
Encourages personalized and adaptive learning	5	11.62
Effectiveness in design or system	5	11.62
Positive perception	4	9.3
It favors the evaluation	4	9.3
Improve teaching practice	2	4.65
Increase in participation	2	4.65
Promotes long-term retention	1	2.32
Does not specify the study	8	18.6

As shown in Table 10, other studies reveal that ITSs increase motivation towards learning (11.62%) and promote more adaptive and personalized learning (11.62%). These findings show that the adaptive and personalized support offered by ITSs improve learning and level of acceptance in students (Ciolacu & Beer, 2016; Singh et al., 2022; Walker et al., 2014), aid in solving mathematical problems (Nguyen, et al., 2020), and increase participation (Paiva et al., 2017).

Regarding the effectiveness of the system used, 11.62% of the studies showed positive results with the use of the algorithms used in the design phases. For example, Masood and Mokmin (2017) conclude that including case-based reasoning, such as big data algorithms, is effective for presenting solutions to various problems. Another study uses the extreme learning machines (ELM) model for performance evaluation, showing noteworthy results for this intelligent algorithm in terms of efficacy and speed of response (Deo et al., 2020).

Type of ITS used

The use of ITSs as an aid for academic performance and mathematics learning stands out in the studies we reviewed. Some were designed for the studies and others were already built. Table 10 lists a few of the systems involved in the reviewed studies related to the field of mathematics as well as the description of each ITS.

Table 10. Type of ITS

ITS	Area or topic addressed	ITS Description
The platform MeuTutor	problem solving	It is a gamified ITS, launched by the company MeuTutor Soluções Educacionais.
PAT2Math	Algebra	It is an intelligent tutor system that teaches students how to solve linear and quadratic equations.
CRISTAL (Case-based Reasoning)	Algebra	It is an intelligent case-based tutoring system.
EMATIC	Math problem solving	Game-based learning ITS.
GeoGebraTUTOR GGBT	Geometry and problem solving	Geometric workspace that is supported by the works of a tutorial system for the definition of a means of reasoning for the student.
ASSISTments	Long-term skill retention	The ASSISTments is a web-based tutoring project.
Game tutor Monkey's Revenge	Geometry and problem solving	Game based coordinate geometry tutor.
MATHia	Formative and summative assessments	It is a smart tutoring system that is part of Carnegie Learning's blended middle and high school math curriculum. Based on Cognitive Tutor technology
MAFint	Fractions	Affective Model of Tutorial Intervention for ITS.
Platform MITO	Mathematics in HEIs	It consists of small self-paced modular units of educational content that include video tutorials, notes, and formative assessments with personalized feedback.
ALEKS (Assessment	Mathematics and	It is a blended-learning model. Intelligent

ITS	Area or topic addressed	ITS Description
and LEarning in Knowledge Spaces)	problem solving	tutoring system for mathematics designed to integrate with the study plans.
LEIA (LEarnIng Algebra)	Algebra	It is a web-based application that helps users learn algebra through the solution of single variable algebraic equations.
APA (Agente Pedagógico Animado)	Algebra	The APA has facial expressions related to speech and other expressions such as feeling and blinking.
Adaptive collaborative learning support (ACLS) The Adaptive Peer Tutoring Assistant (APTA).	Algebra	Adaptive collaborative learning support. Adaptive peer tutoring assistant.
Woot Math Adaptive Learning (WMAL)	Rational numbers	It is a digital tutor that incorporates dynamic digital manipulatives, video tutorials and automatic feedback to students and teachers.
MapOnLearn	Structure of data	Method of organizing and displaying maps for online learning systems.
AmritaITS	Algebra	Program that applies automatic learning models (machine learning) that predict reading and writing difficulties.
Hybrid-AQG	Programming	Combined question generation system based on semantics and syntax: hybrid automatic question generation
IPS	Analytic geometry, algebra and problem solving	Model for the intelligent solution of problems in mathematics

ITS	Area or topic addressed	ITS Description
Cyber - Math,	Basic math	Oriented to the teaching and learning of basic and operational mathematics.

The most commonly used ITS in the studies we reviewed is the ALEKS platform (18.6%). This is followed by PAT2Math (4.6%), used to support algebra learning; GeoGebra TUTOR (4.6%), used to strengthen students' reasoning through geometric problem solving (Tessier-Baillargeon et al., 2014); and MATHia (4.6%), implemented to support formative and summative assessment processes. Regarding the research question, "Does the study consider inclusion of user modeling and adaptive processes for applying ITSs?"**,** although most of the articles do not include information about this, the use of artificial intelligence methodologies in the adaptation process is evident.

We considered the following to answer this question:

The type of adaptation process is the model that enables content adaptation or enables processes of deployment to intelligent tutoring systems. In this regard, we could observe that most of the analyzed documents do not detail the adaptation model or process (42%). However, the most used technique is expert systems (32%). An expert system is a rule-based model or technique that considers the learner's profile, the domain model, and the history of use in order to define conditions and restrictions that allow adaptation. To a lesser extent, we identified adaptation process models based on Bayesian networks, predictive models, fuzzy logic, machine learning, and neural networks. Artificial intelligence techniques are clearly the most used in adaptation processes for this type of system. The adaptation processes and the number of studies involved are detailed below (see Table 11).

Table 11. Adaptation Processes

Subcategory	Number of studies	Percentage (%)
Bayesian networks	1	2
Expert system	14	32
Predictive model	5	12
Not detailed	18	42
Diffuse logic	1	2
Neural network	2	5
Machine Learning	2	5

Regarding the user model subcategory, a higher percentage of articles (47%) do not describe how the student model is configured. 23% of the documents show a student model that considers psychological aspects and the skills that are being developed in the intelligent tutor. In 21% of the documents, the student model includes a profile with information on the student's performance in the intelligent tutoring system, as well as usage history. Only 9% of the documents mention that the student model is made up of basic data, which correlates with systems that did not provide information on their adaptation system (see Table 12).

Table 12. Student Model

Subcategory	Number of studies	Percentage (%)
Student profile with information on successes and failures in the evaluation activities. Usage history.	9	21
Student profile includes basic data	4	9
Student profile includes psychological aspects and skills information	10	23
Not detailed	20	47

The development of intelligent tutoring systems in mathematics involves the inclusion of models and/or techniques based on artificial intelligence. Expert systems are one of the most widely used. However, in terms of personalization, other adaptive processes must be adopted, requiring the system to learn from the student's performance, achievements, and the difficulties they may face during their learning process. Regarding the research question "What research methodology elements were used in the application of ITSs for teaching and learning mathematics at HEIs?" we found the following methodological aspects used for collecting, organizing, and analyzing the quantitative data. There is no specific trend towards a qualitative or quantitative approach (see Table 13) in the reviewed studies. Additionally, one third of the articles present the designs without implementing them. This prevents us from collecting evidence of the effectiveness or the changes in learning that the ITS represents for students.

Table 13. Types of Research

Subcategory	Number of studies	Percentage (%)
There is no information	14	33
Qualitative	13	30
Quantitative	12	28
Mixed methods	4	9

In addition, the main types of research design we identified were quasi-experiments, case studies, and descriptive studies (see Table 14). This shows that they are localized studies, aimed at a specific population. Attempts for generalization are seen in very few cases when implementing these learning systems.

Table 14. Type of Design

Subcategory	Number of studies	Percentage (%)
There is no information	19	44
Quasi-experimental	6	14
Descriptive	5	12
Case study	5	12
Pre-experimental	3	7
Ethnography	2	5
Experimental	1	2
Longitudinal	1	2
Not specific	1	2

The above is supported by the fact that convenience non-probabilistic sampling is used in all the studies we reviewed (see 15). On the other hand, when reviewing the number of participants in the studies, it can be perceived that this type of research requires a team of teachers to guide the same subject. In order for the sample size to range between 30 and 300, more than one group per subject is needed.

Table 15. Sample Size

Subcategory	**Number of studies**	**Percentage (%)**
30 or less than 30	4	9
Between 30 and 100	9	21
Between 100 and 300	9	21
Between 300 and 500	2	5
More than 500	6	14
There is no information	12	28
They don't implement it	1	2

Another interesting aspect of the review was the follow-up time in the implementation of the strategy, as it continues to support the idea that this type of learning process guided by tutoring systems is limited to specific situations and contexts. The length of the studies does not exceed (for the most part) one year (see Table 16).

Table 16. Follow-up Time

Subcategory	**Number of studies**	**Percentage (%)**
Less than a week	6	14
Between 1 and 4 weeks	2	5
Between 1 and 6 months	4	9
Between 6 and 12 months	9	21
More than 1 year	6	14
There is no information	16	37

In order to present their results and conclusions, the reviewed articles focus on the data collected through the different platforms used for implementing the tutoring system. In general, they used questionnaires and pre and post surveys to show the differences (see Table 17).

Table 17. Data Collection Instruments

Subcategory	**Number of studies**	**Percentage (%)**
Records on different platforms	29	67
Pre-post questionnaire	7	16
Binnacle	2	5
Video	2	5
Interviews	1	2
There is no information	6	14

The above shows that ITSs are becoming a potential data collection and time and resource optimization instrument for assessment and follow-up processes.

Trends and Future Research

In this research, a systematic review is carried out on the use of ITS in the teaching and learning of mathematics in secondary and higher education. This search is carried out in the most representative educational technology journals (Web of Science) and in journals indexed in Scopus. The main findings show that the use of ITS in mathematics education provides benefits in terms of teaching and learning mathematics, particularly arithmetic, algebra, differential calculus and related topics with problem solving. This is due to the advantages that STIs offer such as: optimization of the evaluation, monitoring and assignment of activities processes according to the difficulties encountered by the teachers, and in the students, it favors the personalization of learning and the adaptability of the processes.

The development of ITSs in mathematics involves the inclusion of models and/or techniques based on artificial intelligence. Expert systems are one of the most widely used. However, in terms of personalization, other adaptive processes must be adopted, requiring the system to learn from the student's performance, achievements, and the difficulties they may face during their learning process.It is pertinent to confront and articulate the use of ITS with teaching and learning strategies or methods such as flipped classroom, STEM, deep learning, collaborative learning and experiential learning, and inquire about the level of effectiveness of the articulation of these methods in scenarios mediated by the ITS, since these alternatives can offer greater effectiveness and appropriation of the concepts involved in mathematics education at a higher level. Finally, more qualitative and longitudinal research is expected, which investigates and shows the impact of the use of ITS in the teaching of mathematics in higher education for long periods of time, since currently there is more quantitative and mixed research and most transverse type.

Conclusions

In this paper, we conducted an analysis of scientific documentation regarding the use of ITSs for teaching and learning mathematics topics that are addressed in the first semesters in HEIs. For this analysis, we followed a rigorous method for selecting journals and articles in important databases such as Web of Science and Scopus. We analyzed 43 articles with findings on the purposes, advantages, and limitations of applying ITSs in mathematics teaching and learning, of including user modeling and adaptive processes in ITS applications, and of the research methodology elements used in each study.

Regarding the purposes, advantages, and limitations of ITS use, the importance of incorporating these systems in the learning of mathematics was evident. They promote the personalization and adaptation of learning, the development of competencies and learning outcomes, and facilitate processes for providing student feedback and formative and summative evaluation. However, more attention should be paid to limitations such as network problems, limited time to carry out the activities, and inadequate technical support for the systems.

An analysis of the methodological elements leads to the conclusion that the pattern for reporting results in this type of research is characterized by them being opportunity studies, where the main resources are the students that are active at the time of the implementing the tutoring system and the teachers assigned to guiding the subjects in the specific period of implementation. It is rare to find a longitudinal (quantitative) or ethnographic (qualitative) study that shows the impact caused by the use of the proposed strategy. In the quantitative studies, the use of statistical data analysis was limited to descriptive statistics. No type of inferential or correlation analysis was proposed that would allow conclusions to be drawn beyond the specific group under follow-up. This study was limited to scientific documentation in English published in the last decade. Further research analyzing other types of documentation, such as book chapters, books, and articles in other languages and in years prior to 2012, is expected.

Acknowledgements

The work of Francisco Niño Rojas, Diana Lancheros Cuesta, Tatiana Jiménez Valderrama, Gelys Mestre Carrillo and Sergio Eduardo Gomez Ardila has been supported by the Entorno virtual de aprendizaje inteligente para la enseñanza y aprendizaje de las matemáticas Project (DCBS212-188) that is funded by the Universidad de La Salle, Bogotá, Colombia. On the other hand, the work is also supported by the research groups MATESTASIS (COL0022647) in which Francisco and Tatiana are active members; group Automatización, visión artificial y robótica - AVARC (COL0017431), in which Sergio and Diana are active members and group Bioprospección y conservación biológica (COL0023161) in which Gelys is an active members.
Moreover, we declare that our work does not present any conflict of interest.

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