

AI-Based Tools in Mathematics Education: A Systematic Review of Characteristics, Applications, and Evaluation Methods

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Abstract

Artificial intelligence has been utilized for enhancement of education. The paper describes the gradual influences of Natural language processing, ChatGPT and Intelligent Tutoring Systems in mathematical education in particular. A systematic review and briefing is targeted for budding researchers in the field of AI based education. A comparison of research with a brief summary is provided along with the analysis of the search. Future scope for the clear understanding and easy implementation of mathematics is aimed with development of the intelligent system with customized solutions to the difficulties faced by the learners of mathematics. The impact of Artificial Intelligence (AI) on the applications in education has been evolving since the past 50+ years. The advent of Intelligent Tutoring Systems has emerged as a rich and important natural environment that deploys and improves AI algorithms. The review carried out shows ITS as an ever growing field for education comes with positive impact on education outcomes, effective increase in learning rates, increase in the learning levels of students and many such benefits. It also has its own challenges in creating authoring environments, making collaborative learning possible, world wide web deployment and creation of virtual reality environments to name a few. In this review paper we focus on the impact of applications that have been developed using NLP, ChatGPT and ITS as education technology.

Keywords: Artificial Intelligence; ChatGPT; Computers and Education; Intelligent Tutoring System; Natural Language Processing.

1. Introduction

The study of learning experience has always been fascinating since its inception. Various approaches have been experimented and analyzed in detail for the purpose of value addition. The dynamics in learning has evolved mainly due to the online availability of content. The patterns have evolved due to the experiences faced during the pandemic times by learners, they got the inclination to learn online. A sudden boom to use the resources remotely and a decline in face-to-face teaching learning was observed. The language used in academic text is interconnected and delivered to motivate the understanding and communication to enhance in-depth knowledge transfer, it deals with linguistics and psychology. It covers cognitive abilities, self-concepts, conceptual skills, accuracy, sentence processing, grammatical skills and so on. A sudden boom to use the resources remotely and a decline in face-to-face teaching

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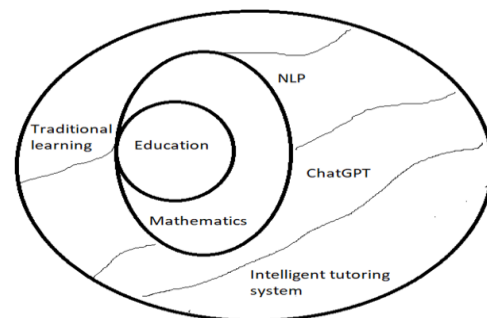


Figure 1 Various Methodologies Implemented for Education

Figure 1 gives the methodologies utilized in imparting knowledge such as traditional learning, natural language processing, ChatGPT, and Intelligent tutoring systems (ITS) with education in its core and closely analyzing the implementation of methods in mathematical education in specific. Natural language processing (NLP) in mathematics provides interactive tutorials, concept summarization, language-based problem solving, automated feedback and analysis, language-assisted data analysis and virtual laboratories. By utilizing the capabilities of NLP for mathematics education, a more customized, personalized, interactive and accessible to learners with different abilities could be targeted. Integrating it to our classrooms could empower students with a more innovative, practical concept clarity to improve the deep learning and mastering of mathematical skills. NLP combines linguistics and computer science. ChatGPT has been used since its inception and has been used in the education system widely by the students' community. A thorough analysis is needed to build trust in its adaptivity. It is to be validated even though a deep study reveals the gaps for its improvement in mathematical education in particular. Intelligent Tutoring Systems, Expert Systems, Knowledge Based Systems, ChatGPT, Assistive Technologies to name a few are already using the smart efforts of AI. The COVID-19 and post COVID-19 was the era where education of the children and students who wanted to pursue higher education had seen a drastic change in the way education was imparted. The classroom teaching was confined to four walls of homes. This was the period when different platforms came up with various online teaching learning solutions. Google Meet, Zoom, Webex, Skype, Pexip and many such. Although they were able to do quite a good job during the pandemic, students and teachers did miss the charm of offline teaching. Post pandemic, with things being almost settled, computer scientists and researchers are still in the mode of making education highly efficient for students. Many technologies old and new are trying to make learning more efficient and interesting through tools such as Expert Systems, Assistive Technologies, and Intelligent

Tutoring Systems to name a few with various algorithms running in the background that use Natural Language Processing, Machine Learning, and Artificial Intelligence to name a few.

2. Motivation

Since early times, as early as the 1960s, Computers have been used to solve various educational problems. A couple of tasks to name are automated testing, providing educational instructions by engaging students in challenging tasks, training the students through practice and many such. During the early 70s computer scientists and researchers dreamt of an ambitious goal to develop computer based educational instruction in terms of Intelligent Tutoring Systems to mimic personal human tutors who provide highly efficient learning environments [1-7]. According to Wikipedia, an ITS is An intelligent tutoring system (ITS) is a computer system that imitates human tutors and aims to provide immediate and customized instruction or feedback to learners, usually without requiring intervention from a human teacher. The ITS basically comprises of four major components [8-11]

1. The Domain model also called a cognitive model or expert model is generally built on a learning theory.
2. The Student model
3. The Tutoring model, and
4. The User interface model

The challenge lies in the development of the above four major components to achieve the goal of teaching and learning. Since ITS mimics human tutors, it should be devised in such a way that motivates the learners to learn. Much research is involved in the creation of the modules. It is also important that these modules have hand-shaking among themselves to get accurate results in terms of teaching learning process.

3. Research Questions

3.1 NLP and ChatGPT

- a. Comparison of NLP architecture
- b. Addressing the learning experience of the students using ChatGPT
- c. Analysis of the accuracy of ChatGPT in regards to mathematical word problems

- d. What is the current state of research in the NLP, ChatGPT for education purposes in mathematics?

3.2 Intelligent Tutoring System ITS:

- Who is the major audience during the research carried out
- What area of Mathematics is used while developing of any application or tool
- What is the accuracy of the application or tool used during the research?
- What is the underlying mechanism used for the implementation of ITS in the case of quantitative research?

4. Mind Map

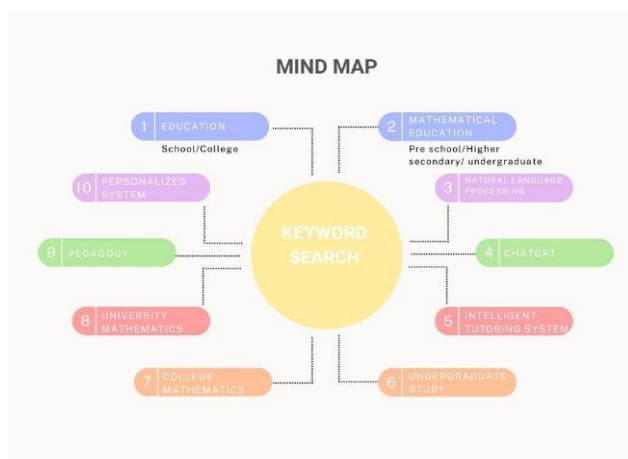


Figure 2 Keyword Search Criteria to Screen the Articles

The above Mind Map gives an overview of the keywords searched. It helps in narrowing down and selection of research papers that contributes in the identification of the AI based educational tools from Education in general to Mathematical Education in particular.

5. Review Analysis

Jia Tracy Shen, Michiharu Yamashita, Ethan Prihar, Neil Heffernan, Xintao Wu, Ben Graf, Dongwon Lee (2021) [12], developed a MathBERT for prekindergarten to undergraduate mathematics users. Evaluation was performed using corpus from paper abstracts, college syllabus, K12 topics to analyze the credibility of the process. Comparison was performed with task adaptive pretrained model TAPT, BASE BERT

and MathBERT+TAPT. (Jinhyuk Lee, 2020) [13]. Nguyen, Hien D, Herrera Viedma, Enrique et al. (2020) [14] proposed a model called Rela-Ops which includes foundational concepts such as relations, operators and inference rules. It was constructed on the concept of Ontology and Object oriented approach. Knowledge bases of 2D Analytical Geometry taught in high-school and Linear Algebra taught in the University were prepared using multiple knowledge domains. The solutions provided by the model were similar to problems that could be solved by humans. Nguyen, Hien D., et al. (2021) [15] proposed a knowledge model that integrated the knowledge of operators and functions. The model was used to organize the knowledge base for the subject of Discrete Mathematics as an Intelligent Problem Solver. The system could automatically solve basic human-readable problems using reasoning. The results were quite encouraging. Nadine Cruz Neri, Jan Retelsdorf (Nadine Cruz Neri, 2021) [16] investigated the role of linguistic features in mathematics education. A comprehensive review, covering the impact of linguistic features (LF) on comprehension and performance in science and math was performed on 40 articles, it covers the analysis of the language complexity and understanding inferences drawn from them. Also suggesting the future questions to be addressed such as a detailed discussion on the usage of German language in education is raised. Ascari, Soelaine Rodrigues, Andrey Ricardo Pimentel, and Ernani Gottardo (2021) [17] in their research proposed that errors made by learners while solving exercises can also be considered as one potential area that helps an ITS to adapt to the learner's requirement. A model was presented that allowed automatic intervention to the ITS whenever the learner committed an error. This mechanism helps in greater engagement of the learner and motivates the learner to improve its learning engagements. Deborah Ferreira (Ferreira, 2022) [18] describes mathematical language processing to express variables with meaningful statements, compared SciBERT and MathBERT and showed SciBERT performed better. Peng, Shuai, et al, (2021) [19] Fine tuning of the model was also

performed. De Menezes, Matheus Freitas, José Francisco De M. Netto, and Arcanjo Miguel Mota Lopes (2022) [11] used the application of Educational Data Mining techniques to teach fundamental concepts of algebra. A web-based ITS was developed that not only taught mathematics to the students but by using the steps of knowledge discovery methodology like: cleaning, integration, selection, transformation, mining, evaluation and presentation of information, but also made a comparative study of the level of difficulty of the proposed algebraic questions asked by the system. The EDM also helped the teachers in making decisions and enhanced their teaching processes. It also provided the feedback on the academic performance of the students which helped the decision makers in finding out the problems that the students face as an individual as well as a collective group. The analysis for 30 4th semester Mathematics Education students from a university in Pekanbaru, Riau Province, Indonesia, and employed a non-test instrument with five categories. (Zafrullah, 2023) [20]. The results showed the learning experience using ChatGPT had 80.33% interest level. (Marchy, 2022) [21]. The tool can fetch information and help learners in an increased level of motivation to complete the task and be engaged in the process. (Sabtu, 2019) [22]. The implementation of natural language processing to help students learn word problems in mathematics (Mingyu Zong, 2023) [23] have analyzed the performance of GPT 3, 3.5, GPT 4 models Built upon the Transformer architecture, GPT models leverage the self-attention mechanism to capture contextual dependencies in input data, generate and continue writing coherent texts. (Brown, 2020) [24] These models are pre-trained on large-scale corpora, allowing them to learn rich representations of English language and capture various semantic patterns. (Griffith, 2021) [25] Efforts are to be made for providing a more personalized training to the students for an enhanced learning experience. Xuan-Quy Dao, Ngoc-Bich Le (Le, 2023) [26] had worked on a National High School Graduation examination mathematics paper with 250 questions to analyze the ChatGPT mathematical ability to solve

questionnaires. It could achieve 83% accuracy, which supports the thought of its ability to be an effective educator. In their extensive and systematic research study, Olmo-Muñoz, Javier, et al. (2023) [9] found that mathematics education in technology based situations without the intervention of teachers is challenging and almost non-existent. They also researched the factors that affected the learning of the students during COVID-19 and how socio-economic factors are more prominent in the learning process of the students. The study concludes with the fact that the time has come to include technology as a part of education in learning mathematics. Yousef Wardat, Mohammad A. Tashtoush, Rommel AlAli, Adeeb M. Jarrah (Yousef Wardat, 2023) [27] studied content analysis of interviews and investigation of user experience. It discusses the drawbacks due to the premature corpus of mathematics in ChatGPT. Also future enhancements such as the integration of chatbots to improve the solution capacity of the system. Shih, SC., Chang, CC., Kuo, BC. et al (2023) [10] developed a Mathematics ITS which made the students learn multiplication and division of fractions. It was an adaptive, response-driven and to one dialogue based ITS that was evaluated for 66 students of sixth grade from central Taiwan. The students were divided into a group of two of 35 and 31 students as the experimental group and control group respectively. A pre-test was conducted to get the know-how of the performance of the students before the teaching process was taken. After the pre-test, the experimental group was taught using the one-to-one instruction through the math ITS whereas the control group was taught using the conventional method with the same teaching material. After the teaching process was completed, a test was conducted for all the 66 students. Results revealed students who had taken lessons from the math ITS, even those performing lower than fellow students previously, could perform better after taking sessions from the math ITS. Furthermore, the students were interested and willing to take up more lessons through math ITS. This adaptive dialogue based, response driven math ITS model was quite popular and liked among the

students. Niño-Rojas, Francisco, et al. (2024) [8] carried out a review on how ITS impacts the teaching and learning process for Mathematics at various levels, right from the school level to the University level. The review was done by considering various parameters such as: (i) selection of appropriate databases and Journals, (ii) deciding on factors for selection of papers, and (iii) type of research done: qualitative and quantitative. The analysis was done for the period 2012 to 2022 on the implementation of ITS in mathematics teaching and learning. It also researched the trends and opportunities for future advancements on building educational environments driven by technology.

6. Overview of Analysis

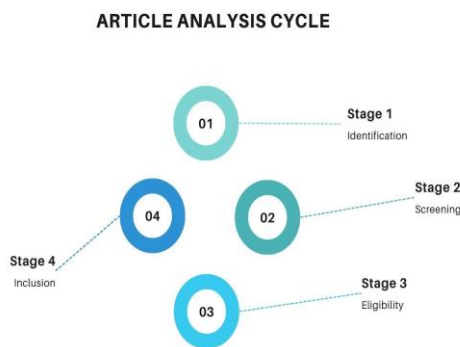


Figure 3 Stages of Analysis

Stages encountered during the identification, screening, eligibility and inclusion of the articles referred is depicted in the diagram above.

Identification: The connectors such as “AND”, “OR”, were used with all combinations of keywords. Screening: Abstracts were intensively referred and on the basis of their contents relative to our search of mathematical tools were identified.

Eligibility: After the screening was carried out, those closely connected articles in Intelligent Tutoring Systems, Natural Language Processing and ChatGPT were only considered for further inclusion.

Inclusion: The eligible articles were included and recent research was highlighted. Qualitative search gave direction to address research gaps to be addressed in the near future. The Screening started with papers with applications of NLP, ChatGPT,

and ITS with educational applications, it was later narrowed down to only mathematical education, A Keyword search was performed on Google scholar, and Google patent and relevant papers were shortlisted. The abstract was studied and the decision for inclusion was taken based on the content relevance to the syllabus followed by pre-school, higher secondary and undergraduate courses. It includes work from 2019 to 2024 and care is taken to the best of knowledge of the authors to include the latest and precise data keyword search included the following: education, mathematical education, school mathematics, natural language processing, ChatGPT, Intelligent tutor system, undergraduate studies, K12. Based on the keyword search the below table represents the list of articles included in the search and specification of the research domain, country of origin, and category of students targeted along with a brief description of the exploration is curated. pictorial representation of article-analysis cycle, mind map of keyword search, summarizes the flow of review done. The pie chart depicts the country-wise advancements between 2020-2024. The introduction of teaching aid in school and col-lege level requires precision and accuracy which is lacking in ChatGPT. The security and legitimacy of usage is to be addressed. The future scope is aimed at advancing the experience to specific course content with experiment and fine tuning to deliver a marketable product with easy to acquire cost. A quantitative analysis and improvement for the approach is intended.

7. Acknowledgment

We are gratefully thankful for the exceptional research support by our research mentor Dr. Priti Sajja. We are also grateful to our colleague Dr. Rupam Gupta who gave us the direction for the research carried out. We are also grateful to the management of our Institute Sardar Vallabhbhai Patel Institute of Technology, Vasad – Anand, Gujarat for constantly motivating us to pursue research and funding our work. A special thanks to our Mr. Sunny Shah our lab technician who helped us with the editing of the paper. Lastly, the errors opinions and omissions done in the paper remain with us. The responsibility for the content.

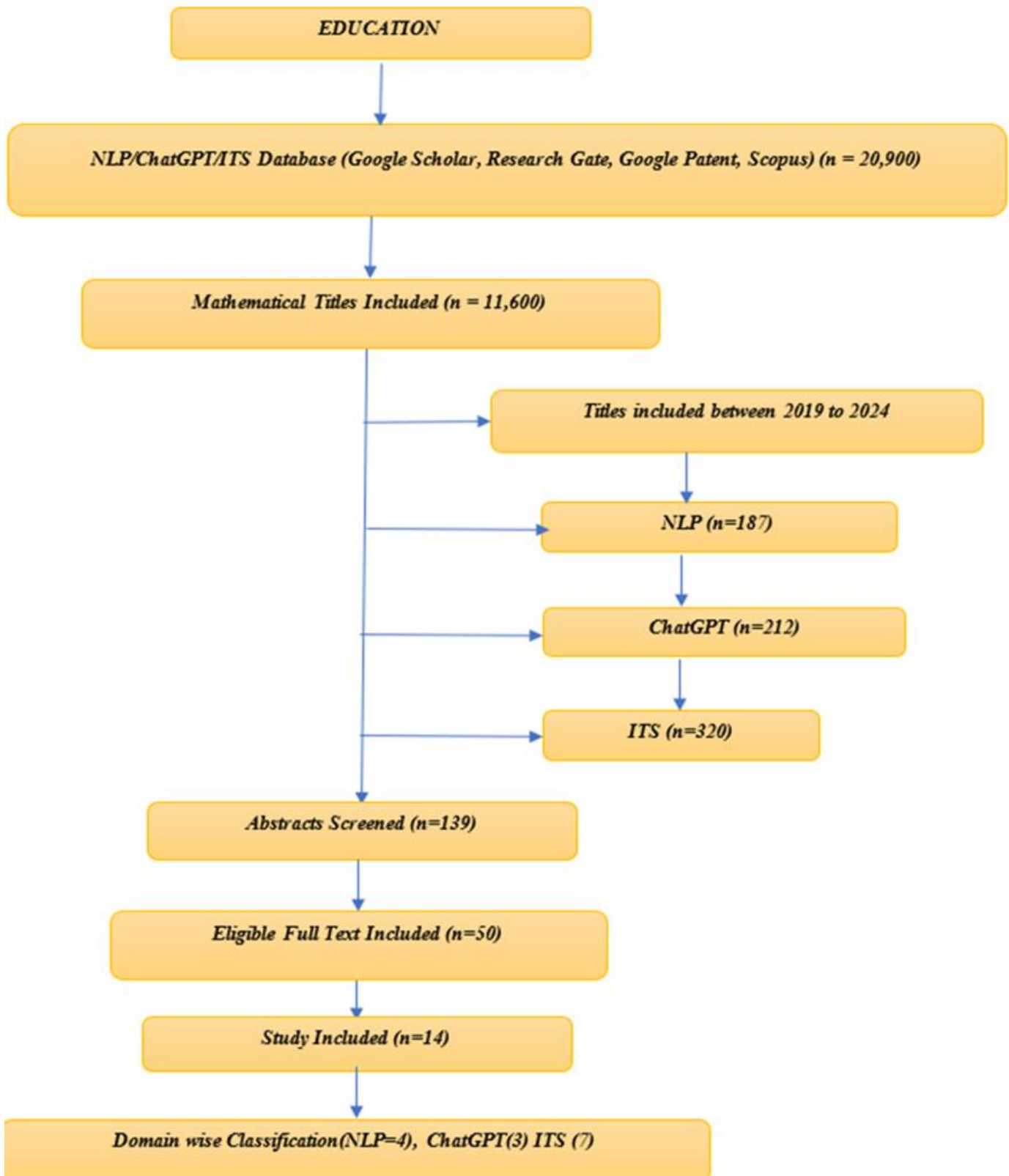


Figure 4 Flow Chart for Identification, Screening and Inclusion of Eligible Titles

Table 1 Survey of AI Tools (NLP, ChatGPT and ITS) in Mathematical Education

Sr No	Journal	Research Domain	Country	Focus on students	Year	Analysis used
1	IEEE Access Special Section on Intelligent Information Services	Intelligent Tutoring System	Vietnam	2D-Analytical Geometry in high-school and Linear Algebra in university	2020	A model called Rela-Ops which was proposed to include foundational concepts such as relations, operators and inference rules. Concept of Ontology and Object oriented approaches.
2	13th International Conference on Knowledge and Systems Engineering (KSE)	Intelligent Tutoring System	Vietnam	Engineering students	2021	An Intelligent Problem solver was proposed, where a knowledge model that integrated the knowledge of operators and functions was presented.
3	International Conference on Intelligent Tutoring Systems	Intelligent Tutoring System	Brazil	N/A	2021	MAFint, ITS can be made adaptive through errors committed by learners, and through this learners can be kept motivated towards learning
4	Deborah Ferreira, Mathematical language processing: Deep Learning representation and inference over Mathematical text	NLP	USA	Basic mathematics	2022	NLP suggests the most likely help to prove a statement, and express variables meaningfully, a deep learning approach is used to address the issue.
5	Nadine Cruz Neri, J. R. (2021). The role of linguistic features in science and math comprehension, A systematic review and desiderata for future research. Educational Research Review.	NLP	Germany	School textbook contents,	2022	NLP contribution with how LF contributes in comprehension and performance of the subject
6	ZDM – Mathematics Education (2023) 55:35–48 https://doi.org/10.1007/s11858-022-01396-w	Intelligent Tutoring System	Spain	Word Problems in Maths	2022	Comparison of various technology based mathematics education, where ITS was researched to have more potential than one-to-one human tutoring during the COVID-19 pandemic era.
7	IEEE Frontiers in Education Conference (FIE). IEEE	Intelligent Tutoring System	Brazil	20 students of a Public school used this Web based ITS for learning algebra	2022	Educational Data Mining Teach mathematics (algebra) and also carry out a comparative study between the level of difficulty of the proposed algebraic questions
8	Mingyu Zong, B. K. (2023). Solving math word problems concerning systems of equations with GPT. Machine Learning with Applications Elsevier.	Natural language processing (NLP)	United States	School children	2023	the use of GPT-3, GPT-3.5, and GPT-4, in models released by OpenAI, for three related challenges pertaining to math word problems corresponding to systems of two linear equations. classifying word problems, extracting equations from word problems, and generating word problems were performed. Analysis of performance was compared
9	Zafrullah, M. L. (2023).	ChatGPT		Fourth-	2023	Comparing the learning experiences of students

	ChatGPT Open AI: Analysis of Mathematics Education Students . Journal of Technology Global			semester Mathematics Education students		with ChatGPT
10	Le, X.-Q. D.-B. (2023). Investigating the Effectiveness of ChatGPT in Mathematical Reasoning and Problem Solving: Evidence from the Vietnamese National High School Graduation Examination.	ChatGPT	Vietnam	School children	2023	ChatGPT was analyzed for accuracy in solving mathematics multiple choice questions.
11	Yousef Wardat, Mohammad A. Tashtoush, Rommel AlAli, Adeeb M. Jarrah, ChatGPT: A revolutionary tool for teaching and learning mathematics. EURASIA Journal of Mathematics, Science and Technology Education.	ChatGPT	UAE	School	2023	User experience and content analysis of mathematics
12	Jia Tracy Shen, Michiharu Yamashita, Ethan Prihar, Neil Heffernan, Xintao Wu, Ben Graf, Dongwon Lee, MathBERT: A Pre- trained Language Model for General NLP Tasks in Mathematics Education	NLP	USA	Prekinder Kindergarten to college graduate level	2023	Comparative study of Base BERT and MathBert
13	Education and Information Technologies	Intelligent Tutoring System	Taiwan	sixth grade students	2023	Mathematics ITS which made the students learn multiplication and division of fractions through one to one dialogue based ITS. Control group and experimental group students were considered for analysis
14	International Journal of Education in Mathematics, Science and Technology	Intelligent Tutoring System	Various countries mainly contributi on from US	students learning school level math	2024	Systematic review technique applied

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