Creative Education, 2024, 15, 1692-1704
https://www.scirp.org/journal/ce
ISSN Online: 2151-4771
ISSN Print: 2151-4755

Leveraging Technology for Math Education: A Systematic Literature Review

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How to cite this paper: Mohamudally-Boolaky, A., & Padachi, K. (2024). Leveraging Technology for Math Education: A Systematic Literature Review. *Creative Education, 15,* 1692-1704.
https://doi.org/10.4236/ce.2024.158102

Received: July 18, 2024
Accepted: August,13, 2024
Published: August 16, 2024

Abstract

This study contributes to the growing body of literature on innovative technological tools with strong potential to enhance the teaching and learning of mathematics and related subjects. The primary objective is to assess how technology can transform math education. The study employs a rigorous systematic methodological approach, encompassing three key steps: planning, screening, and conducting a content analysis. From the 423 papers retrieved from selected databases, a stringent screening based on inclusion and exclusion criteria, as well as a qualitative assessment, was conducted. Consequently, 117 papers were selected for an automated content analysis using the Leximancer software tool. The study's main findings indicate that technology acts as a significant enabler, preparing students for a world of hyper-complexity and providing opportunities for all students to access mathematical thinking, thus potentially improving their future prospects in a technology-driven society. Innovative technologies are shown to significantly empower and support both teachers and students in meaningful mathematics teaching and learning. However, the study also highlights the limitations of these technologies. Effective integration with work techniques, curriculum, learning, and mathematical assessment is necessary, while the role of the teacher remains critical in math instruction.

Keywords

Math Education, Technology, Math Teaching and Learning

1. Introduction

This study contributes to a systematic Literature review (SLR) of an increasing body of research on the technology that has strong potential to support teaching and learning of Math and Math-related subjects from preprimary school to

University encompassing vocational education. Technology emerges as an enabler to prepare students to a world of hyper-complexity in order to provide opportunities for all students to have access to mathematical thinking (Lee & Yeo, 2022). Innovative technologies and ICT tools support teachers and students in meaningful mathematics teaching and learning (Popenici & Kerr, 2017). The design and setting up of technology-based environments that support teaching and learning processes are topics that have been object of abundant research, in the past years (Maharjan, Dahal, & Pant, 2022). Ahmad et al. (2023) list the enabling technologies for Education 5.0 which include Artificial intelligence (AI), Virtual and Augmented Reality (VR and AR), Internet of Things (IoT), Big Data and Analytics, Blockchain and 5G Net-works. AI-powered adaptive learning systems can personalize learning experiences, teaching students how to effectively and ethically use generative AI and thus prepare them to better integrate an AI-dominated work environment (Baidoo-Anu & Ansah, 2023). On the other hand, VR and AR can provide immersive and interactive learning experiences. Furthermore, digital media including digital learning content and online resources can be used to support math engagement. Game based learning is another innovative approach that can enhance students' interest and engagement in mathematics. For instance, Minecraft, a popular game, is being used in educational settings, as the game's fundamental structure requires exploration and a problem-solving approach (Nebel, Schneider, & Rey, 2016). The use of technologies is optimized when integrated into the math curriculum in a way that complements and enhances the learning experience, rather than replacing it.

The purpose of this study is to systematically evaluate the transformative potential of innovative technological tools in mathematics education. By analyzing a comprehensive collection of literature, this study aims to understand how these technologies can enhance both teaching and learning processes, identify their benefits and limitations, and explore the necessary conditions for their effective integration into educational practices. The primary research objective is to assess how Technology can transform math education. The rest of the paper is organised as follows: Section 2 describes the methodology deployed for planning, screening and content analysis using the Leximancer software. The data analysis in Section 3 describes the main themes and concepts from the content analysis and critically discuss the themes. Concluding remarks appear in Section 4.

2. Methodology

A Systematic Literature Review is conducted using a rigorous and systematic methodological approach (Aromataris & Pearson, 2014). The primary research question is: "How can technology transform math education?" The methodological approach adopted comprises the three following steps: planning, screening and conducting the automated content analysis (Boland, Cherry, & Dickson, 2014).

2.1. Planning

The chosen databases were Scopus and Science Direct based on their reputation for publishing quality research papers in the area of technology for math education. Scopus ensured access to a broad spectrum of research articles relevant to the intersection of technology and math education, while science direct would potential provide full-text access to a large collection of scientific and technical research articles, particularly strong in fields like educational technology and STEM education, making it highly relevant for the study. A total of 423 papers were retrieved from these databases on the 16th December 2023. The following search phrases were used to retrieve the research papers: ("Innovative Technology" OR "Enabling Technology") AND ("Math Instruction" OR "Mathematics Education" OR "Math teaching and learning").

2.2. Screening

The screening was based on the inclusion/exclusion criteria shown in Table 1. The initial screening identified 77 articles which were not accessible, 16 duplicates and 9 non-English papers. Thereafter, the remaining 321 sources were screened to ensure that they met our inclusion criteria. This process resulted in the exclusion 68 editorials, opinion pieces or content that did not directly address the research question.

Table 1. Inclusion and Exclusion criteria for the screening phase.

Inclusion criteria	Exclusion criteria
Peer-reviewed conference or journal papers	Papers published in non-English language
Papers that focused on the enabling	Duplicate papers from different databases
Technologies for math education	Papers with full text not accessed

Thereafter, the remaining 253 papers were assessed for quality using the following quality assessment (QA) criteria:

1) *Does the paper discuss the different dimensions or components of the technologies adopted for math education*?

2) *Does the paper discuss how technologies could impact the potential transformation in math education*?

Each Quality Assessment question carried a score of 1. Based on criterion 1, papers that clearly detailed the technological aspects received a score of 1, while those that lacked this information scored 0. In line with criterion 2, papers that provided a thorough analysis of the potential transformative effects of technology in math education received a score of 1, whereas papers that did not address this aspect scored 0. Thus, a paper could have a maximum score of 2. Only sources that obtained at a score of at least 1 were considered for inclusion in the SLR.

2.3. Automated Content Analysis

Following the QA process, a total of 117 papers were retained for the SLR. These papers met the minimum quality threshold and were considered to provide valuable contributions to the understanding of how innovative technologies can enhance math education. 63 papers obtained a score of 1 while 54 obtained a score of 2. Figure 1 shows the number of papers selected for the automated content analysis by year. It is observed that the majority of them have been published for the last 5 years suggesting a relatively recent emergence of these technologies.

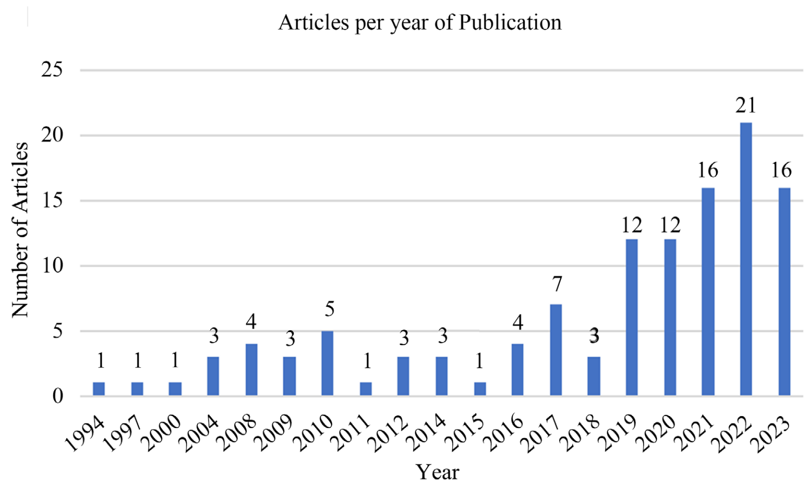

Figure 1. Classification of the 117 selected articles by their year of publication.

The review was conducted using the Leximancer which is a software package developed for performing conceptual analysis of natural language textual data and was conducted on the basis of the four stages of the Leximancer project control, namely "select documents, generate concept seeds, generate thesaurus and generate results." For the "select document" stage, the 117 papers were included. The second step was to initiate the generation of concept seeds. During this step, the software also executes the stemming task (reducing words to their base form) and removes common stop words (e.g., "and," "the," "is" "paper", "study") to focus on more meaningful terms. In the third step, Leximancer identifies concepts and relationships within the text, based on different algorithms. In the last step, Leximancer provides interactive visualization tools such as concept maps to analyze the results (Leximancer, 2021).

3. Data Analysis

In this section a textual analysis is generated by means of a concept map and then identified concepts are critically discussed to address the research question.

3.1. Concepts and Themes

Out of the 117 selected papers, Leximancer generated a total of 7 themes with their corresponding concepts. The themes with the most significant number of hits are "student", "Learning", "mathematics", "model", "Intelligence", "ChatGPT" and "Technology" as shown in Figure 2 which also showcases the concept map for the 7 themes. Furthermore, Table 2 lists the main concepts associated with the corresponding themes.

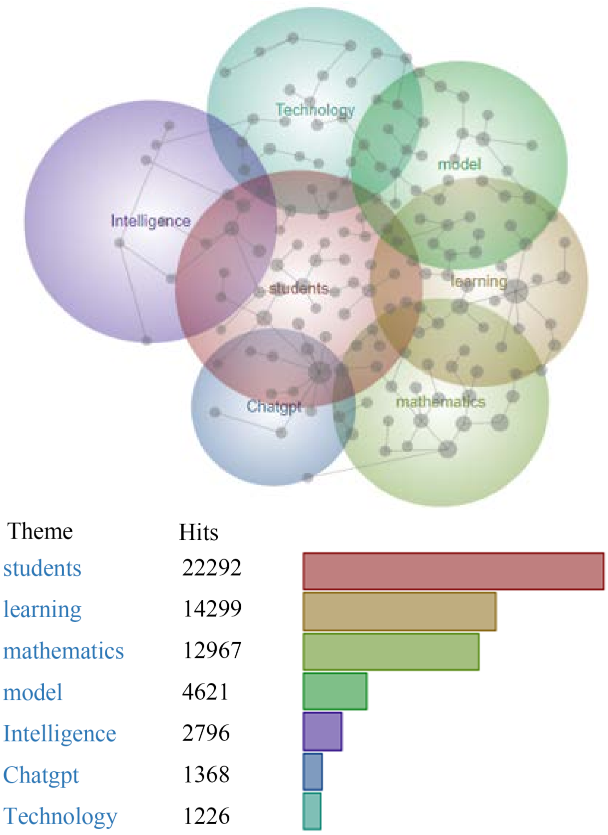

Figure 2. The concept map with the relevant themes (source: Leximancer generated).

Table 2. Themes and the corresponding concepts.

Themes	Main concepts
Students	Knowledge, Data, Problem, Model, Approach, Performance, Level, Learn, Results
Learning	Student, Teacher, Work, System, Study, Tool, Support, Classroom, Understanding, Content, Skill, Thinking
Mathematics	Problem-solving, Heuristics, Proportional, Reasoning, Approach, Theory, Methods, Support, Research
Model	Theory, System, Design, Information, Process
Intelligence	Education, Research, AI, Technology, Educational development
ChatGPT	Technology, Support, Tools, Tutor
Technology	System, Network, Algorithms, Data

Source: Authors' own compilation.

3.2. Analysis and Discussion

Technology integration models

Wachira & Keengwe (2011) define technology integration as "incorporating technology and technology-based practices into all aspects of teaching and learning and assessments." The literature suggests four important technology integration models namely, the Technological Pedagogical Content Knowledge (TPCK), the Technological Acceptance Model (TAM), the Unified Theory of Acceptance and Use of Technology (UTAUT) and the Technology-Organization-Environment (TOE). These models delve into several aspects of technology integration and adoption including acceptance, knowledge, will, belief and performance. Guerrero (2010) showed that TPCK embodies a teacher's ability to distinguish between the types of technology that are most suited to their mathematical content and instructional goals and make decisions regarding its appropriate application. The Technology Acceptance Model (TAM) is the key model uncovering behavioural patterns for accepting or rejecting technology in the area of teaching and learning. In the context of mathematics education, learning conditions, parental involvement, school curriculum and teacher training, emerge as factors contributing to acceptance (Arthur, 2022). The UTAUT comprises 4 main components namely, social influence, performance expectancy, effort expectancy and enabling conditions (Venkatesh et al., 2003). The TOE on the other hand explains the influence of technology, organizational attributes, and environmental factors in the process of implementation and adoption. (Baker, 2012)

Technology for Math Instruction

Learning mathematical procedures is important, but it is also crucial to equip students with strong problem-solving and reasoning, through mathematical skills acquisition (Lake et al., 2017). Kynigos (2019) and Sriraman & English (2010) stipulate that within each educational institution, a model needs to be built and sustained on how to use technology to make math instruction more effective. Sacristán (2017) consider the diverse elements of the development model: training, continuous support, processes of reflection, self-observation and point out to the fact that promoting equally the technological, mathematical and pedagogical aspects, help to construct didactic strategies in accordance with the local educational practices. Studies of Hoyles et al. (2020) and Trinh Thi Phuong et al. (2022) lay emphasis on the integration of a wide range of culturally relevant digital tools for teaching mathematics, as well as the importance of teacher training for an effective and strategic use of those resources in the classroom.

Leveraging Technology for Teacher support

Technology contributes to developing teachers' responsive teaching skills and instructional methods to support the development of the learners' skills in presenting their mathematical thinking (Hoyles et al., 2020; Kaitera & Harmoinen, 2022). Advances in Artificial Intelligence (AI) and Natural Language Processing

(NLP) support teachers with automated feedback on their use of classroom discourse. Applications building on advances in deep learning for natural language processing and speech recognition analyze classroom recordings and provide math teachers with personalized feedback on their instructional practices (Suresh, 2022). According to Sinclair and Yerushalmy (2016), classroom response systems are participatory and include feedback tools to enhance the students' engagement in math learning. Technology helps teachers support groups of students by stimulating mathematical discussions and enhance classroom communication (Calor et al., 2022). Furthermore, Schwarz et al. (2021) stress on the adaptive guidance through dashboards to provide effective support for teachers to interact with multiple small groups of students, collaborating on mathematics. Nevertheless, it is imperative to acknowledge the limitations of these technological tools for math teaching and learning and use them in a way that complements the human educators rather than replacing them (Atlas, 2023; Viberg, Gronlund, & Andersson, 2023). Sacristán (2017) uncovers the difficulties and obstacles teachers and students face while integrating the technological tasks with the established curriculum. These are often due to limited time and resources for the pedagogical content preparation, and implementation. Trigueros & Sacristan (2008) establish that the use of technological tools for understanding of mathematical concepts, does not necessarily lead to increase achievement, particularly because much of the knowledge developed can remain situated in the technological context.

Student Centered Learning

Students are at the center of all teaching and learning activities. A broad-based approach is fundamental to ensure that the math learning activities optimally engage the student through adequate knowledge representations coupled with experiential, contextual, and collaborative learning (Lai & Cheong, 2022). Woolf (2010) states that intelligent tutors demonstrate their effectiveness in a broad range of applications which can infer student learning strategies. For example, machine learning enables tutors to reason about uncertainty and predict performance, based on observed student behavior. In addition, chatbots can also be used to track student progress and provide data to teachers and administrators about student performance. This approach is aligned with the larger framework of external accountability, which places a greater emphasis on measuring student achievement and holding schools and teachers accountable for their performance (Birenbaum, 2023). Calor et al. (2022) analyse classroom response systems which are participatory and include feedback tools that can increase the students' engagement in math learning and enhance classroom communication between teacher and students. Kim et al. (2020) highlight significant implications for instructional communication for math related content. While technological skills are well advanced to create machine teachers, there is little understanding about how students would perceive the idea of machine teachers especially for technical mathematical content (Azevedo et al., 2022). The focus is nonetheless on developing an understanding of "students' mathematics and students' mathematical realities." (Schoenfeld, 2010)

Personalised Learning with Technology

According to Ahmad et al. (2023) the traditional classroom teaching and learning in Education 1.0 was a one-size-fits-all approach which did not consider the individual needs of students. This made it difficult for teachers to provide personalized instruction and support to students with different learning styles and abilities. Personalised teaching and learning using technological tools such as intelligent tutoring systems help them adapt their content support to individual students' different levels of understanding which can be heterogeneous in math classrooms. Hwang & Tu (2021) review the adaptive systems to provide personalized guidance to almost all levels of students by analysing their learning status and behaviors. They point out to the fact that in addition to mathematical skills, motivational aspects play important roles in an individual's capacity in mathematical problem solving situations. Communication and collaboration with peers are also essential for expressing mathematical ideas (Kaitera & Harmoinen, 2022). Additionally, the use of technology such as game-based learning can promote problem-solving and critical thinking skills, which are important 21st-century skills. Furthermore, game-based learning can be personalized to the needs of individual students, allowing them to work at their own pace, which can help improve learning outcomes for all students (Ahmad et al., 2023). This in turn contributes to build up students' mathematical self-confidence in describing their problem-solving processes. As a result, students gain a deeper understanding of mathematical ideas (Hwang, Flavin, & Lee., 2023). Nevertheless, simply using technology is not enough: technology must be properly integrated with work techniques, curriculum, learning and mathematical assessment (Cahyono & Asikin, 2019).

Artificial Intelligence (*AI*) *in Math Education*

According to Chen, Chen, & Lin (2020), AI induces instructional quality and effectiveness in the contemporary technology-based adaptive teaching and learning systems. These foster customization and personalized content in line with the learner capabilities and needs, thereby improving learners experience and contributing to the achievement of the set learning objectives. Automation and AI-based tools have the potential to support teachers in improving their pedagogical skills and increasing their self-efficacy (Suresh 2022). Studies such as Lee & Perret (2022) and Kasneci et al. (2023) indicate a positive attitude towards AI for education and a high motivation to introduce AI-related content at school. Teacherbots emerge as disruptive alternative to traditional teaching staff (Popenici & Kerr, 2017). AI-generated strategies provide teachers with step-by-step explanations of math procedures to guide their thinking as they plan and implement individual learning experiences for students (Gattupalli, Maloy, & Edwards, 2023). Leveraging and using AI in education has fostered effectiveness and efficiency in the performance of administrative tasks, such as grading of students' assignments. AI has significantly reduced the paperwork and workload on instructors, enabling them to focus on their core mandate (Russell & Norvig, 2010). Chen, Chen & Lin (2020) highlight the different pedagogical tools that incorporate and leverage AI into web-based education. Teachers utilize chatbots to design tutoring interventions and assessment tools customized to students' different preferences and levels, give feedback on students' performances, and stimulate students' curiosity and higher-order thinking. As reported by Luckin and Holmes (2016), intelligent support for teachers could also help address the issue of teacher retention in a field where many skilled professionals are leaving due to "burnout".

ChatGPT and other language models can be useful tools for teaching and learning Mathematics. They can assist human educators in their work by providing additional resources and support (Atlas, 2023). ChatGPT is a chatbot recognized for its improved math capabilities and ability to offer comprehensive instruction and increase educational understanding of mathematical concepts. (Wardat et al., 2023). This tool can be used for incorporating critical thinking and problem-solving activities into the curriculum, and help students develop these skills. However, educators should provide training and support to students on how to use ChatGPT responsibly, including proper attribution and ethical considerations. It is crucial to respect the academic integrity policies of the institution (Atlas, 2023). ChatGPT is nevertheless not capable of replacing the unique skills and abilities of human educators to review, validate and explain the mathematical concepts. It is important to use these tools in conjunction with human instruction and support and be aware of their limitations for math education (Baidoo-Anu & Ansah, 2023). Birenbaum (2023) refers to ChatGPT's lack of emotional intelligence whereas human teachers bring creativity, critical thinking skills, and emotional intelligence to the classroom that cannot be replicated by chatbots.

4. Concluding Remark

In mathematics education, technology constitutes a foundational tool to support students and teachers, actively participating in the discovery of concepts. There is public recognition of the necessity of integrating a wide range of innovative digital tools and instructional technology for learners to engage in mathematics. This study has reviewed a broad strand of literature encompassing the integration of technologies in math classrooms to enhance the learner's overall experience. It has been observed that significant technological changes in math education have occurred in the last five years. Seven main themes—Students, Learning, Mathematics, Model, Intelligence, ChatGPT, and Technology—emerged from the automated content analysis. The systematic literature review (SLR) has highlighted key technology integration models and their roles in education, emphasizing how math instruction can benefit from technological tools in supporting personalized and student-centered learning. Technology aids teachers through AI and NLP, enhancing instructional methods and classroom communication. Challenges include integrating technology with existing curricula and ensuring human educators' roles are complemented, not replaced, by technology. Proper integration and ethical use of these tools are crucial. AI and language models like ChatGPT offer additional resources but cannot replicate the creativity and emotional intelligence of human educators.

In summary, this paper has attempted to provide insights into the current state of research around innovations in technology to transform math teaching and learning. It serves as a roadmap for keeping research up-to-date with the latest developments within a dynamic educational ecosystem. However, future studies could consider a more diverse range of databases to provide additional insights into the integration of technology in math education.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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