

Trends of Adaptive/Personalized Learning and Intelligent Tutoring Systems in Mathematics: A Review of Academic Publications from 2010 to 2022 [†]

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Abstract: Technology is used in research to satisfy the needs of the public. As there is a growing trend for adaptive/personalized learning, intelligent tutoring systems are used in various studies to overcome personal limitations. Thus, we reviewed the trends and characteristics of adaptive/personalized learning and intelligent tutoring systems in mathematics learning. Fifty-four relevant research articles (from 2010 to 2022) were selected and analyzed to investigate system parameters, roles of the systems in learning, mathematics contents, and learning outcomes. The analysis results showed the trends in research issues and challenges to be solved.

Keywords: personalized learning; adaptive learning; intelligent tutoring system; mathematics education; application in subject areas



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1. Introduction

Abstract concepts in mathematics are always referred to for understanding why learners have difficulty in learning mathematics. Many scholars have proposed methods to help students learn mathematics with appropriate technology. Emerging adaptive/personalized learning and intelligent tutoring systems have been developed to support learners in acquiring mathematics skills more efficiently. According to the definition from the United States National Education Technology Plan 2017, personalized learning represents instructions in which the pace of learning and the instructional approach are optimized for the needs of each learner. Learning objectives, instructional approaches, and instructional content (and its sequencing) vary depending on learner needs. Learning activities need to be meaningful and relevant to learners, driven by their interests, and often self-initiated [1].

The activities are for learners who struggle with learning mathematics. In particular, an adaptive learning feature was considered regarding the state of technology-enhanced mathematics learning by Plass and Pawar. A learning system was used to investigate a learner's specific needs for appropriate adjustments to enhance learning outcomes [2]. The characteristics of personal learning showed that implementing technology-assisted learners was effective for learning mathematics. With technological development, an "Intelligent Tutoring System" has been proposed. For example, intelligent tutoring systems (ITSs) are computer programs that incorporate AI technology to provide tutors with what, who, and how to teach [3].

These three definitions focused on using technology to develop learning aids to assist learners and construct a learning environment in the classroom. Learning behavior needs to be understood for learner-centered teaching. Therefore, an application to the classroom is

required. Based on students' characteristics, personalized learning systems in mathematics education can be developed [4–8]. Accordingly, we researched articles on personalized learning, adaptive learning, and intelligent tutoring systems in mathematics learning to investigate the system parameters used to develop the systems, the roles of the system in providing support, the contents and educational levels, and how to measure the learning outcomes in mathematics education using data from 2010 to 2022.

2. Data Collection and Process

2.1. Resources

The selected articles were found using the keywords “personalized learning in mathematics”, “adaptive learning in mathematics”, and “intelligent tutoring system in mathematics” in the Web of Science database. The publication years were set from 2010 to 2022. The results showed 197 related articles. A total of 54 articles not in the first quartile in education were excluded. In addition, articles related to pedagogical content knowledge, professional development, non-technological personalized learning, non-mathematics content, and STEM were excluded. Lastly, 54 articles were selected for this study.

2.2. Selected Articles

Figure 1 shows an overall increase in the number of relevant articles with decreases in 2011–2015 and 2016–2019. From 2020 to 2022, the number of articles increased significantly. The direction of researched showed a great leap forward. A previous study [9] in 2011 implemented Cognitive Tutor Authoring Tools (CTATs) for high school learners to study algebra. At that time, the system used embedded adaptive features (i.e., feedback and on-demand tips) to support learning by analyzing a learner's behavior, such as marking erroneous text/answers with red and providing clues after a third mistake. In other words, the system understood personal abilities based on a framework to recommend appropriate tasks, materials, and tools to assist the learner in reaching the learning goals. Digital games were designed to support mathematics learning and adaptive/personalized learning using learning concepts through playing [10–12].

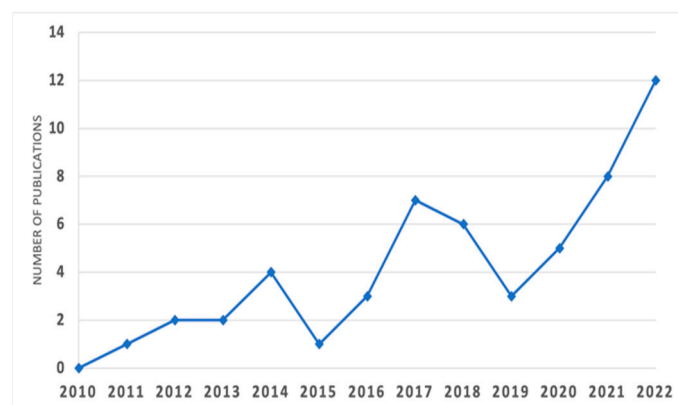


Figure 1. Number of publications from 2010 to 2022.

2.3. Coding Scheme

In this study, five categories of coding schemes were used.

1. Code for the system parameters: The code for system parameters refers to how technologies support mathematics learning, the learning activity environment, the assessment process, teacher–learner interactions, and the learning environment.
2. Code for system roles: The code for system roles is about how learners acquire knowledge while learning with the systems. In this study, the regulation proposed by Lai and Hwang [5] was used for accessible material, learning with the material, conducting assessments, and learning with full online support. Full online support

refers to systems that offer learning materials, allow learners to use the system, evaluate their learning abilities, and promote teacher–learner interaction.

3. Code for mathematics content: The code for mathematics content is used to categorize the systems based on the particular mathematics content designed for learners to learn. Likewise, this study classified rational numbers and fractions, algebra, calculus, geometry, probability, arithmetic operations, decimal numbers, modeling, arithmetic mean, mixed contents in mathematics, and non-specified content.
4. Code for learners: The code for learners is used to investigate the learners' levels of education. Therefore, we categorized it as kindergarten, elementary school, junior and senior high school, higher education, teachers, and non-specified educational level.
5. Code for learning outcomes: This code was used for three themes—cognitive, affective, and technical–behavioral correlation, referred to in Ref. [5].

3. Results

3.1. System Parameters

For 54 reviewed articles, 43.08% showed a feature that supported mathematics learning. There were five top-trend traits, including feedback, adaptive activity, on-demand hints, tutoring, and interactive tools. Other characteristics were content sequencing concerns, i.e., mastery approach, consecutive questions, or content. The support features for learning management were explored by 22.64% of the articles, including environmental structuring, individual learning paths, learning status, reviewing graded work, learning time, and student preferences. Similarly, assessment support features were used to identify a collection of log files to monitor learning paths and to serve formative and summative assessments in 14.78%. Additionally, the teacher–learner-interaction-supported feature was investigated in terms of collaborative activity, seeking assistance, and use of a chat room or online viewing mode and forum in 13.84%. These features were typically developed to allow learners and teachers to interact simultaneously. In 5.66% of articles, features that contributed to an excellent learning environment were explored using a combination of gamification (i.e., score, time) and emotional support (i.e., animated characters, avatars).

3.2. System Roles

Twenty-two articles (40.74%) showed that learners only participated in the systems by accessing the provided materials. However, accessible material did not mean handouts and assignments but activities for learning, practicing, and relearning by themselves. In total, 38.89% of learners used the provided materials. Full online learning support was important. In 20.37% of articles, the support was considered significant. For instance, an intelligent tutoring system was designed to help learners with intelligent tutoring systems (ITSs) combined with cognitive tutor authoring tools (CTATs) individually and collaboratively [13].

3.3. Mathematics Content

Rational numbers and fractions content was considered the most, in 20.37%. Non-specified content was the second most important as explored in 18.52% [14,15]. Arithmetic operations were also important in mathematics learning systems. Algebra-related content was the third most investigated, in 16.67%. The frequency of content was considered differently depending on geometry, decimals, calculus, and probability. Rational numbers and fractions, arithmetic operations, and algebra were considered appropriate to be implemented in the adaptive/personalized or intellectual tutoring systems at various difficulty levels. However, higher level concepts were considered in few studies, which needs further study.

3.4. Learner Level

Adaptive/personalized and intellectual tutoring systems in mathematics learning in the articles were explored for an elementary level in 51.72% (30 of 58 articles). At the junior and senior high school levels, 22.41% of the articles explored these systems. For higher education, 7 of 58 articles investigated the use of these systems. In Ref. [16], higher education, elementary level, and junior and senior high level were evenly explored for the use of the systems. Mathematics teachers' roles were regarded as important in 8.62%. However, the learner level was not specified in two articles. Instead, they explained the system design rather than the implementation. Lastly, in one study, a system for pupils at the kindergarten level was developed. The results showed that adaptive/personalized and intellectual tutoring systems could be used for mathematics learning in any age range.

3.5. Learning Outcomes

In 46.15%, learners' cognitive abilities were measured. In 32.05%, the technological-behavioral correlation was considered, while in 21.79%, learning effectiveness was determined. Cognitive abilities were focused on in all studies. In the cognitive category, learning achievement was studied in 23 articles, whereas low- or high-order thinking skills were explored in 7 articles. In terms of technical-behavioral correlation, in 14 articles the correlation between learning performance and the usability of systems was considered. In seven articles, the cause and effect of the use of the systems were explored. Learners' behaviors were investigated in four articles. An adaptive digital game called the Number Navigation Game (NNG) was used to enhance flexibility and adaptivity in mathematical thinking [10]. In six articles, self-efficacy was measured. Attitude, perception, self-regulation, and mathematics anxiety were examined in a few studies.

4. Discussions and Conclusions

The results of the research on articles from 2010 to 2022 showed what needs to be studied further in mathematics education. Elementary-level mathematics contents were usually taught at the elementary stage including arithmetic operations, rational numbers, and fractions as fundamental concepts, which are a foundation of in-depth knowledge. Understanding rational numbers was crucial for learning primary school mathematics as pointed out by Refs. [17,18], where students' arithmetic achievement was predicted. It was essential for mathematical proficiency to be developed every day in life. A few existing practical tools were used to support learning mathematical concepts [17]. For system development, feedback and adaptive features were considered top priorities in developing systems for learning mathematics. The lack of fundamental concepts impacted the learners' hierarchical mathematics learning. Thus, feedback and adaptive features were critical to a supported mathematics learning system. Reference [19] developed an adaptive software based on the concept of rational numbers and fractions, namely Woot Math Adaptive Learning (WMAL), a minor revision in 2020, for students to learn mathematics by providing automatic feedback. However, the system provided alternative features such as an assessment process, self-sequencing, collaborative working, or learning stimuli to increase learners' opportunities to participate in after-school or private learning [15,20].

Most learning systems were designed to provide learning materials. At the same time, several systems combined accessible learning materials and an evaluation of learning. In Ref. [12], a system was developed to embed adaptive learning based on an assessment approach. It was possible to provide feedback and support to learners individually. In an adaptive game [18], the learning materials and assessments were provided for personal users. Full online support systems were explored in a few studies. In the future, such systems are required to focus on the learning process, assessment, and the interaction between teachers and students. These features can be used to increase learners' engagement and their use of an adaptive/personalized or intellectual tutoring mathematics learning environment. The MathE platform was developed as an interactive environment where learners followed the individual learning process, increased their learning engagement,

and improved learning outcomes [4]. It was an online collaborative system that consisted of three sections: learners' assessment, a library (learning tools), and a community for practice. These supports could provide a favorable environment for learners. Learning outcomes were in the cognitive domain. Technical-behavioral correlation was investigated in several studies as adaptive/personalized learning or intelligent tutoring systems responded directly to personal needs and abilities and positively impacted learning. Thus, efficacy studies on the impact of use, the relation between parameters, or even the expected behaviors/skills were carried out [13,21].

The findings in this study showed that the use of adaptive/personalized learning or intelligent tutoring systems in learning mathematics enhanced learners' abilities or learning process in any mathematics content at different learner levels. The characteristics of the systems support the learning process and help learners acquire and improve their mathematics knowledge/skills. Their cognition ability could be improved at the right pace. Therefore, the development of adaptive/personalized learning or intelligent tutoring systems is necessary to consider in the future to teach at various levels and provide appropriate mathematics content. The features of the system need to be adaptive depending on learners' preferences. In addition, assessment is required to process learning achievements and provide on-demand hints/suggestions. The collaboration in learning mathematics through the system allows learner and learner or learner and teacher to work online/learn together in real-time, which requires further research in mathematics education.

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