JERM 2023;33(3):537-557.
eISSN 2288-8357
https://doi.org/10.29275/jerm.2023.33.3.537

JERM
Journal of Educational Research in Mathematics

Original Article

The Use of Technology in Korean Mathematics Education: A Systematic Review

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Abstract

The use of educational technology has the potential to enhance teachers' instructional quality and student achievement. The international research community has conducted various studies to address the opportunities and challenges of using technologies for teaching and learning mathematics education. However, relatively little attention has been given to identifying research topics in Korean domestic research. Therefore, the present study aims to provide a systematic literature review that identifies and compares the research topics studied nationally and internationally. The domestic literature was collected from the KCI database. We employed a topic modeling technique to analyze overall research topics and trends in technology use in mathematics education. Additionally, we compared these findings with our previous studies where we examined international research trends. This study revealed some similarities and differences in research trends between domestic and international studies and suggested implications for future studies.

Keywords: technology use, topic modeling, research topics, research trends, systematic review

Received: June 29, 2023 **Revised:** July 19, 2023 **Accepted:** July 19, 2023
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I. INTRODUCTION

Human life and society are influenced by technology. Technologies have changed how we think, act, feel, communicate, and learn (Kenski, 2008). As individuals can have diverse learning experiences and outcomes with the use of technology, many schools and governments have embraced technologies to assist teachers in instruction and students in learning (Chen et al., 2020). Mathematics educators have also extensively integrated technological devices to develop mathematical tasks, curricula, and teaching methods (Bray & Tangney, 2017)

The National Council of Teachers of Mathematics (NCTM, 2000) suggested the use of technological tools to help students with mathematical investigation, problem-solving, and reasoning. They argued that mathematics teachers should use "technology as essential resources to help students learn and make sense of mathematical ideas, reason mathematically, and communicate their mathematical thinking" (NCTM, 2014, p. 5). Similarly, the revised Korean mathematics curriculum in 2022 highlights the importance of employing technologies to help students understand mathematical concepts and principles, and develop an intuitive understanding and logical thinking (Korean Ministry of Education, 2022). Other organizations, both in the United States and globally, have also put forth similar arguments (e.g., Association of Mathematics Teacher Educators [AMTE], 2022; Organisation for Economic Co-operation and Development, 2019).

With the growing emphasis on technology, many scholars have implemented technologies into mathematics education in various ways. Pang et al. (2019), who examined the research trends in Korean mathematics education from 1963 to 2019, discovered that although research on technologies constituted a small proportion (8%), the number of studies in this area has consistently increased over time. Similarly, Shin (2020) employed topic modeling and identified technologies as one of the 23 research topics in Korean mathematics education. Despite the mounting research on technology use in mathematics education, there were very few review studies available on the subject. The most recent review study was published in 2016 (Jang, 2016). Consequently, there is limited information available regarding the trends of research topics related to technology use in mathematics education such as which topics have garnered increasing or decreasing attention among the Korean mathematics education community. To address this gap, the present study conducts a systematic literature review of technology use in Korean mathematics education. In particular, this study examines articles published after 2000, as most Korean mathematics education journals were indexed in the Korean Citation Index (KCI) after 2000 (Shin, 2020).

II. LITERATURE REVIEW

1. The benefits of using technology for mathematics education

Several psychological theories explain how and why the use of technology supports student mathematics learning. One such theory is Papert's constructionism, which suggests that the use of tools helps students construct new knowledge by allowing them to make sense of their activities, experiences, and interactions with the environment (Ackermann, 2001; Papert, 1980). In the technology-embedded mathematics classroom, students can test their ideas, create models, and visualize abstract mathematical concepts that may be difficult to achieve through traditional hands-on activities (AMTE, 2022). For example, using software like Cabri 3D enables elementary school students to construct and manipulate various three-dimensional figures (e.g., solids, pyramids, and cylinders) and design net diagrams, enhancing their understanding of abstract mathematical knowledge. As students have autonomy over their learning and explore their ideas through technological devices, they can develop confidence in mathematics and foster a positive attitude, leading to improved mathematics achievement (Birgin & Acar, 2022; Bray & Tangney, 2017).

Another perspective is social constructivism, as proposed by Vygotsky (1978). This theory supports the integration of technology in mathematics education because it facilitates student collaboration and interaction. Vygotsky argued that through collaboration with others who possess more knowledge such as peers and teachers, a child can solve challenging problems and acquire relevant knowledge to solve similar problems independently in the future. In learning environments that incorporate technology, students can actively interact with their peers using online chat and forums, enabling broader participation in knowledge construction compared to traditional classrooms (Higgins et al., 2019; Roschelle et al., 2017). This increased interaction through technology has been found to have positive effects on students' mathematics achievement (Birgin & Acar, 2022).

Mathematics educators have also proposed various roles of technology in mathematics education. Cullen et al. (2020) outlined these roles as supporting reasoning and proof, helping to relate diverse representations, and functioning as a tutee. Similarly, Drijverse (2015) and Roschelle et al. (2017) suggested that technology serves didactical functions in mathematics classrooms, including doing mathematics, practicing skills, developing conceptual understanding, and creating contexts for interest-driven mathematics that enhance student motivation and curiosity. For example, their notion of 'doing mathematics' refers to the use of technology to replace manual tasks like drawing figures. In sum, the use of technology has transformed mathematics teaching and learning environments (Roschelle et al., 2017), impacting students' mathematics achievement, motivation, and attitude (Higgins et al., 2019).

2. Previous review studies

To provide a comprehensive understanding of technology use in mathematics education, we reviewed two studies conducted in the Korean context using a manual coding process. We will refer to these studies as "domestic review studies" to highlight their nature of analyzing articles related to mathematics education in the context of Korea. Subsequently, we will present a summary of our own study (Hwang et al., 2023), which utilized topic modeling on English-written articles that go beyond the scope of the studies conducted within the Korean context. This study also examined the use of technology in mathematics education.

Few domestic review studies examined the research trends of technology use. Jang (2016) analyzed 153 articles published in mathematics education journals between 2000 and 2016. The findings revealed that 70% of the research focused on computers, Geometer's Sketchpad (GSP), calculators, and software. The majority of the studies (69.3%) targeted K-12 students rather than college students (11.7%). Regarding research methods, qualitative methods accounted for the largest proportion (47%), followed by mixed methods (29%), literature review (15%), and quantitative methods (9%). However, Jang's study only examined types of technology tools, research methods, and participants without providing information on which topics have been studied.

In the second domestic review study, Lee et al. (2013) analyzed 52 mathematics education articles published between 2005 and 2009. Similar to Jang's study (2016), they examined the types of technologies and participants. The findings revealed that research on spreadsheets (23%), programming language (19%), and graphic calculators (17%) accounted for approximately 60% of the studies. Moreover, about 37% of the studies focused on teacher instruction, while 27% focused on student learning. In terms of research topics, 54% of the studies analyzed teaching and learning methods and their effects on achievement. Other studies focused on theoretical explanations (21%), introducing functions of technologies (15%), and providing information (10%). The most studied mathematics domains were geometry and measurement (29%) and number, operation, and algebra (29%).

While these studies provided valuable information on the research trends in technology use in mathematics education, their findings are no longer up-to-date. Additionally, the manual coding methods used in these studies might have led to classification errors due to the labor-intensive categorization process (Chen et al., 2020). More importantly, these studies did not examine the changing pattern in the research topics studied over time.

To address these limitations, our previous study utilized topic modeling to examine the research trends in technology use in mathematics education (Hwang et al., 2023). We reviewed 2,433 English-written articles published between 1981 and 2022 and identified seven distinct research topics (see Table 1). Here 'I_Topic' refers to the topics identified from articles published in international journals to distinguish them from domestic topics ('D_Topic') detected in Korean mathematics education journal articles. The largest proportion of international research focused on the effects of technology on cognitive and affective development (I_Topic 7, 15.2%), followed by using technology for conceptual understanding (I_Topic 6, 12.7%).

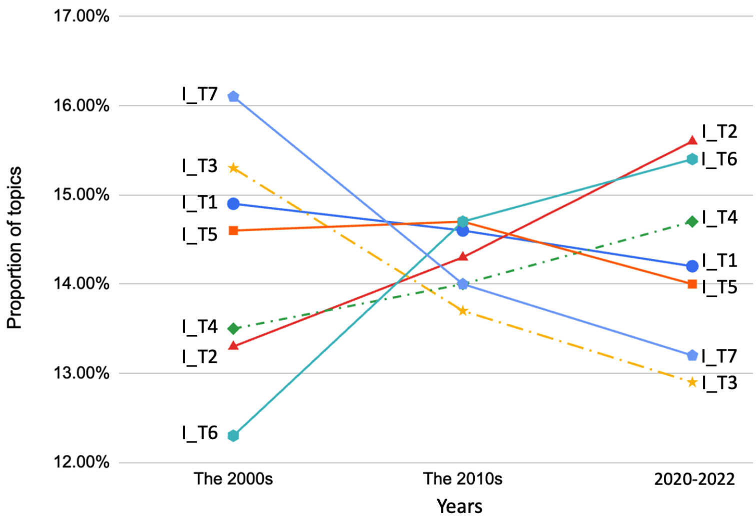
Moreover, when we specifically analyzed international research trends between 2000 and 2022, as shown in Figure 1, we observed that research on using technology to support mathematics learning (I_Topic 1) and teacher instruction and technological pedagogical and content knowledge (I_Topic 5) showed a stable pattern of attention obtained by researchers. However, research on technology in K-12 curriculum (I_Topic 2), technology use at higher education (I_Topic 4), and using technology for conceptual understanding (I_Topic 6) demonstrated increasing attention from researchers over time. Conversely, research on computers and information and communication technology (ICT) use in schools (I_Topic 3) and examining the effects of technology on cognitive and affective development (I_Topic 7) received decreasing attention.

Table 1 International research topic trend on technology use in mathematics education (Adopted from Hwang et al., 2023)

Research topic (Patterns of research trend, percent)	The 2000s	The 2010s	2020−2022
I_T1. Using technology to support mathematics learning (Stable, 14.5%)	14.9%	14.6%	14.2%
I_T2. Technology in K−12 curriculum (Increasing, 14.8%)	13.3%	14.3%	15.6%
I_T3. Computers and ICT use at school (Decreasing, 14.0%)	15.3%	13.7%	12.9%
I_T4. Technology use at higher education (Increasing, 13.9%)	13.5%	14.0%	14.7%
I_T5. Teacher instruction and Technological Pedagogical Content Knowledge (TPACK) (Stable, 14.9%)	14.6%	14.7%	14.0%
I_T6. Using technology for conceptual understanding (Increasing, 12.7%)	12.3%	14.7%	15.4%
I_T7. Examining the effect of technology on cognitive and affective development (Decreasing, 15.2%)	16.1%	14.0%	13.2%

Note. Only English-written articles were analyzed. Each cell under the column name includes the average percentage of the topic studied in the specified year range. For example, in the second row, second column, the value 14.5% (T1) indicates that for the year range between 2000–2009, Topic 1 accounts for an average of 14.5% of the total analyzed articles.

Figure 1 Research trends of each topic from 2000 to 2022 (English-written article)



3. The current study

Despite the growing significance of technology use in mathematics education (AMTE, 2022; NCTM, 2014), there is a dearth of comprehensive literature reviews on this topic within the Korean context. Therefore, this study aims to fill this gap by conducting a literature review on technology use in Korean mathematics education. Our study will utilize topic modeling to synthesize previous relevant studies, allowing for an examination of emerging topics and their evolutionary patterns, including whether they have been on the rise or decline. Moreover, by comparing the findings of this study with those of international studies conducted in English peer-reviewed journals (Hwang et al., 2023), novel insights can be gained for future studies. The specific research questions addressed in this study are as follows.

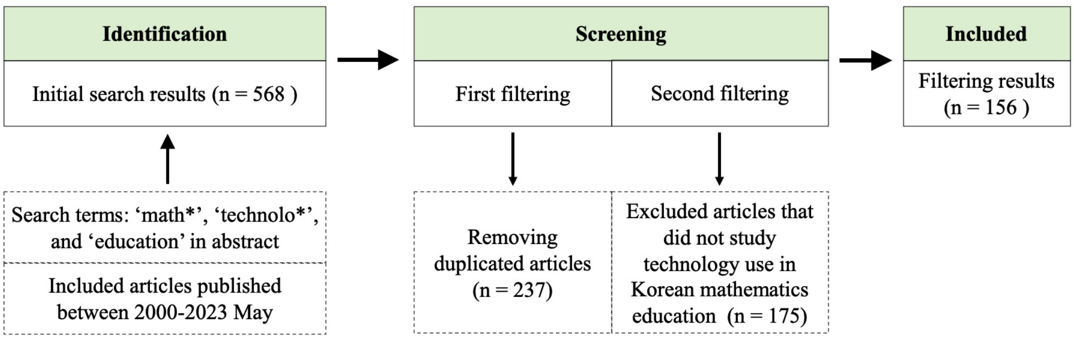
RQ 1. What were the major research topics on technology use in Korean mathematics education?
RQ 2. How did research topics change over time?
RQ 3. What were the similarities and differences between domestic and international research trends?

III. METHODOLOGY

1. Data collection

We collected relevant articles using the process presented in Figure 2. First, we searched articles containing the three terms in the abstracts: 'math*,' 'technolo*,' and 'education.' Because the abstract contains critical information about the research, articles did not include those words in the abstracts might not align with our research purpose (Chen, 2020; Shin, 2020). Second, we only searched articles published between January 1, 2000 and May 31, 2023 as most mathematics education journals were indexed in KCI after January 2000 (Shin, 2020). Therefore, articles in a journal that was not indexed in KCI were excluded from this

Figure 2 Data retrieving process following the guidelines of the PRISMA group (Moher et al., 2009)



study. Note that KCI is regarded as a tool examining the journal quality, so journals not indexed in their database are often perceived as lower in quality according to KCI (2023). Third, we excluded the duplicated articles. Through these processes, a total of 568 articles were obtained. Fourth, we reviewed each article and excluded those that did not focus on technology use in Korean mathematics education. Finally, we retrieved 156 articles and used English abstracts for topic modeling.

2. Data analysis

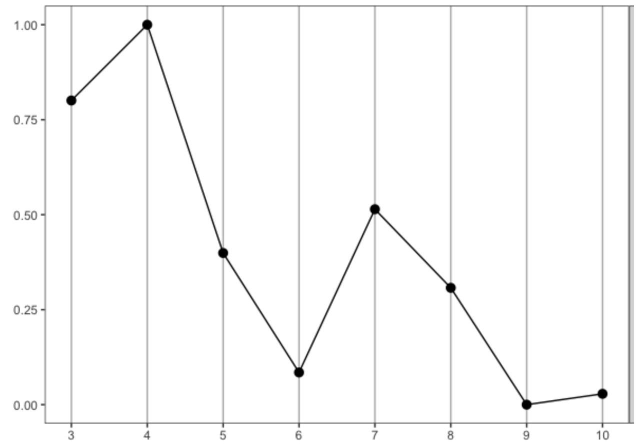
1) Pre-processing

We employed the R programming language to carry out two consecutive pre-processing steps, namely stop words removal and stemming (Hwang et al., 2023). First, we eliminated words that do not pertain to the topics of research articles, such as conjunctions, prepositions, and pronouns. We also excluded terms commonly found in research article abstracts such as 'author,' 'paper,' and 'database.' Subsequently, we conducted a stemming process to reduce words to their word stem, thereby avoiding repetitive representations of words within the same meaning. For example, 'classrooms' was transformed to 'classroom' and 'learning' was truncated to 'learn.' This technique enhances the efficiency and accuracy of the data analysis, specifically our Latent Dirichlet allocation (LDA) natural language processing algorithm.

2) Perplexity analysis

Perplexity or predictive likelihood is a measure of how well a statistical model fits a dataset. In our study, we conducted a perplexity analysis to determine the optimal number of topics, referred to as the k-number, in our dataset. We utilized the *ldatuning* package in the R programming language, which provides model fitness scores for different topic numbers (Nikita, 2020). The model fitness score was calculated using the *CaoJuan2009* metric, as provided by the *ldatuning* package (Cao et al., 2009). This score helped us identify the k number for our dataset by measuring the stability of the topic structures through the distances between each pair of topics. In this algorithm, a shorter average distance indicates a more stable topic. Therefore, a lower value in the *CaoJuan2009* metric represents a better model fit. Identifying when this value levels off indicates significant stability in the topic structures is important. Our analysis in Figure 3 demonstrates that the average line significantly levels off between five and six topics. This indicates that the best generalization performance of the model will be achieved when we conclude that our dataset has six latent topics. As a result, we made the decision to categorize the collected articles into six topics.

Figure 3 Perplexity of topic model



Note. X-axis: Number of topics, Y-axis: Metrics of CaoJuan2009 calculating the average distances of topics

3) Determining research topic name

We utilized three types of information to assign names to each topic: (a) top 15 characteristic words, (b) word clouds, and (c) top 15 representative articles. Initially, we examined the top 15 characteristic words for each of the six topics. These are the words with the highest term-topic probability and frequently appeared in the research article abstracts. This analysis provided us with initial outlooks for potential topic names. Next, we generated word clouds for each topic, using the *wordcloud2* package in the R programming language. We displayed the top 50 words for each topic. The size of a term in the word cloud represented its term-topic probability, with larger terms indicating higher probabilities. This visualization helped us identify which research areas were representative of each topic. Lastly, we reviewed the top 15 articles that had the highest proportion of words in each topic. This process aided us in efficiently identifying the articles pertinent to the topics and verifying the similarities in the narratives of the research articles assigned to each topic. Moreover, for the comparison between domestic and international research trends, we referred to the topic names of the international research trend on technology use in mathematics education (Hwang et al., 2023).

아래 노란색으로 하이라이트 된 곳은 모든 쉼표를 따옴표 안으로 옮겨주세요.
예) ‘learn,’ ‘develop,’ ‘AI,’ …

For example, D_Topic 5 was named ‘The learning and design of artificial intelligence (AI)’ for the following reasons. Note that ‘D_Topic’ refers to the domestic topics found from Korean mathematics education journal articles. First, the top 15 terms identified by the LDA algorithm included ‘learn’, ‘develop’, ‘AI’, ‘intellig(ence)’, ‘applic(ation)’, ‘field’, ‘design’, ‘artificial’, ‘inform’, ‘converg, ‘appli(ed)’, ‘future’, ‘suggest’, ‘learner, ‘addit(ion).’ Second, the word cloud analysis (see Figure 4) revealed that ‘learn’, and ‘develop’ are the top two largest proportions, followed by ‘ai’, ‘intellig,’ and so on. Lastly, the articles with the highest topic-article probability examined the trends of using artificial intelligence in mathematics education (Park, 2020) and the characteristics and design components of educational artificial intelligence applications (Lee et al., 2020).

converg & learner는 따옴표가 없습니다. 수정바랍니다.
==>’converg,’
==>’learner,’

Figure 4 A word cloud of topic 5 with the fifty highest term-topic probability words

Note. The bigger and bolder the word stem indicates the higher the word stem's term-topic probability is.

However, individual research topics were not mutually exclusive; instead, some research topics could overlap partially. For example, Wang and Song (2008) examined the development of an intelligent tutoring system (ITS), which is a type of AI, for student mathematics learning. Although the study was categorized as D_Topic 5 "The learning and design of AI" based on the LDA algorithm (Blei, 2012), it also had relevance to D_Topic 3 "Using technology to support mathematics learning." This is because, when a study covers multiple topics, the LDA algorithm assigns different proportions across different research topics (e.g., a study related to D_Topic 5 with 50%, D_Topic 3 with 20%, and so on), resulting in partial overlap across research topics. Therefore, although each study was categorized into a research topic based on the highest document-topic probability distributions (Blei, 2012; Nikita, 2020), it does not imply that the study solely focused on that particular topic.

4) Comparison between domestic and international research trends

Regarding research question 3, we compared the research trends of domestic research and international research, using the data (table data with frequency and percentage) from Hwang et al. (2023). Thus, we did not re-analyze Hwang et al.'s data. The results of this comparative analysis are presented in the conclusion and implications section of Chapter 5.

IV. RESULTS

1. Overall research trends and word frequency

To gain an understanding of the overall research trends, we initially analyzed the descriptive information. Our study included a total of 156 articles, after cleaning data, published between January 2000 and May

2023. Table 2 presents the distribution of articles across the three periods. The first two periods cover the years 2000 to 2009 and 2010 to 2019, while the third period represents the years 2020 to 2023. During the initial 10 years of the 2000s (Period 1), a total of 40 articles were published on the topic of technology use in mathematics. In the subsequent 10-year period from 2010 to 2019 (Period 2), the number of articles increased to 77. With 39 articles already published in the period from 2020 to 2023, it is likely that the trend of increasing article publication will continue. Figure 5 presents the distribution of articles across individual years from 2000 to 2023. It represents a consistent increase in the number of articles over time, despite some variations by year. This finding indicates the growing popularity of this field, which aligns with previous research that highlights the increasing integration of educational technology in mathematics education (Pang et al., 2019).

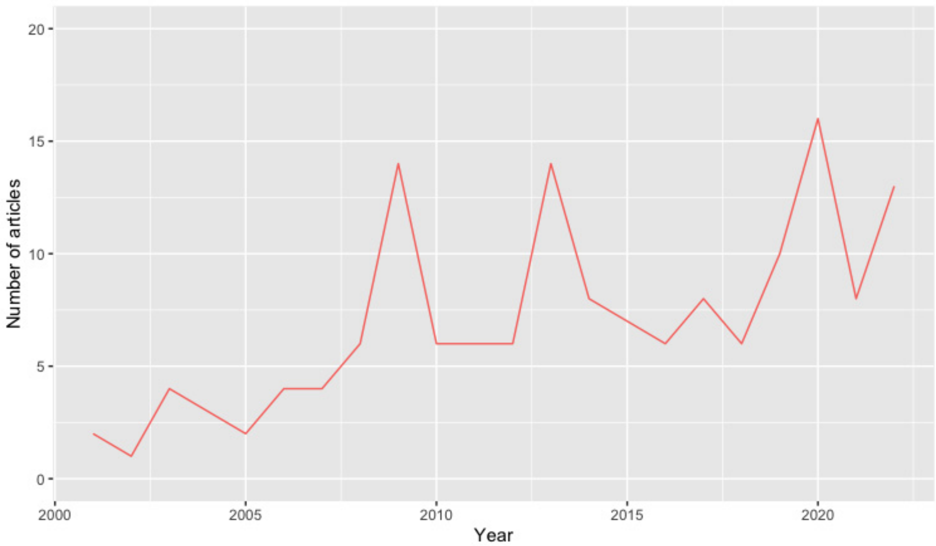
The number of articles by period

Table 2 The numbers of articles by periods (Total = 156 articles)

	Period 1 (2000 – 2009)	Period 2 (2010 – 2019)	Period 3 (2020 – May 2023)
Number (%)	40 (25.6%)	77 (49.4%)	39 (25.0%)

by year

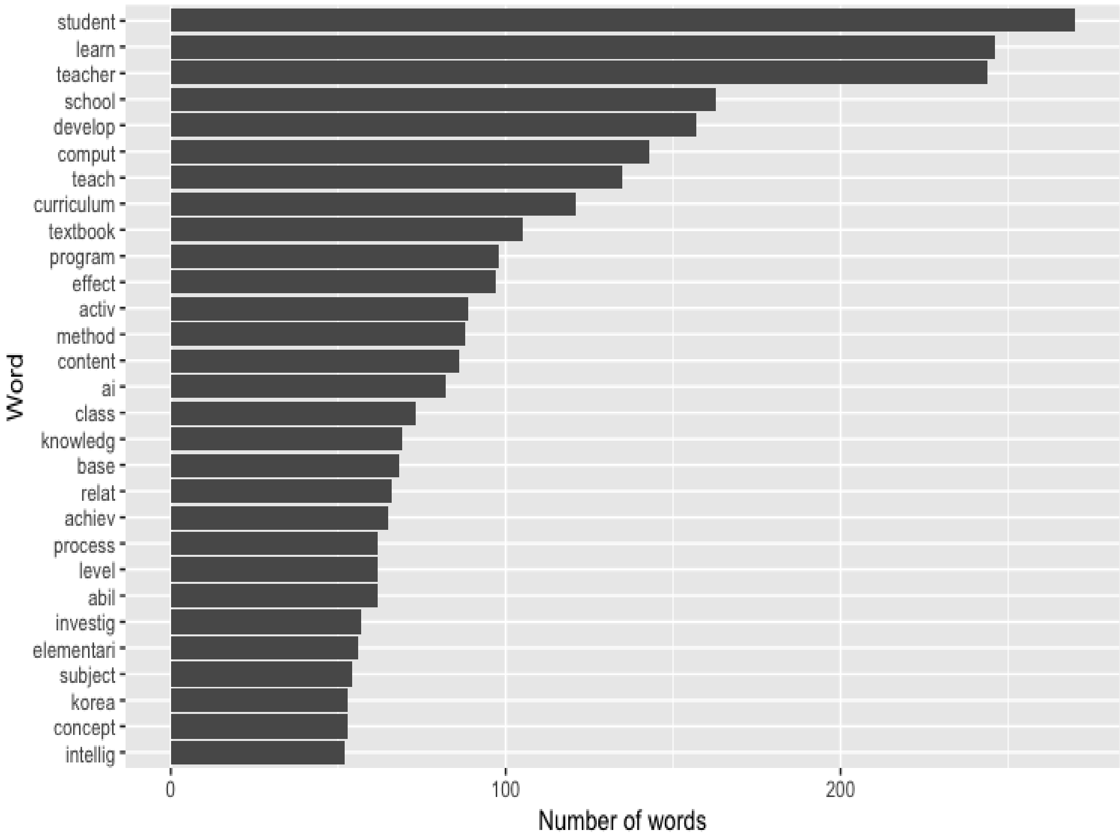
Figure 5 The number of articles by a year



'math*,' 'technolo,*' and 'education,'

Next, we conducted an analysis of the most frequently used words in the abstracts. Since all articles contained the terms 'math*', 'technolo*', and 'education', those words were excluded from the analysis. Figure 6 illustrates the top 30 words. This list includes words such as 'student,' 'learn,' 'teacher,' 'school,' 'develop,' 'comput(er),' 'teach,' 'curriculum,' 'textbook,' 'program,' 'effect,' 'activ(e),' 'method,' 'content,' and 'ai' (artificial intelligence). These findings are similar to those of a review article that analyzed international articles on the use of technology in mathematics (Hwang et al., 2023). However, there are some differences. Korean articles tend to focus more on research related to artificial intelligence (AI), and there is also a greater emphasis on achievement-related topics such as 'effect,' 'achievement,' and 'level.' The combinations of these worlds could represent research topics. For example, the combination of 'comput(er)' and 'curriculum' could refer to a topic that studies a mathematics curriculum integrating the use of a computer.

Figure 6 Top 30 frequently used words in the abstract



Note. The words shown in Fig. 6 are technically stemmed words. For example, 'comput' is a word stem of computer and computing.

2. Determining names of research topics

Table 3 and Figure 7 provide information on evidence of how we determined the six topics that we derived from the LDA algorithm. Table 3 shows the topic names, the top 15 words, and a sample representative article of each topic. Figure 7 presents word clouds that visually represent each topic using the top 50 frequently used words. It is important to note that although most topic names do not contain the terms 'mathematics,' 'technology,' and 'education,' all topics are related to them since we only selected articles containing those words in the abstract.

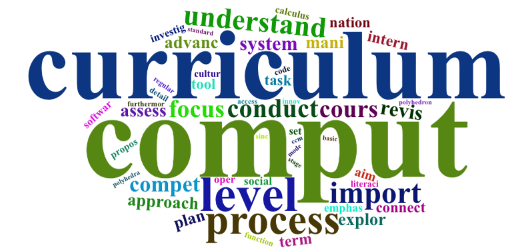
Table 3 Topic names, characteristics words, and a sample representative article of domestic research topics

Topic Name	Top 15 Characteristic Words	A Sample Representative Article
D_T1. Technology in the textbook	Textbook, school, concept, korea, subject, content, relat, digit, environm, univers, discuss, major, topic, consid, secondari,	A study on the educational technology design and application of mathematics education in terms of the introduction of digital textbooks and software education (Song, 2016)
D_T2. Computer and curriculum implementation	Comput, curriculum, level, process, import, understand, conduct, focus, cours, compet, revis, system, assess, mani, explor	Exploring the change in achievement by the transition of the test mode from paper to computer: Focusing on the national assessment of educational achievement of high school mathematics (Jung et al., 2022)
D_T3. Using technology to support mathematics learning	Teach, active, method, materi, content, statist, evalu, lesson, test, proof, experiment, chang, attitud, manipul, follow	On developments of teaching-learning contents and constructivist teaching methods using mobile applications based on augmented reality in mathematics education (Kim et al., 2019)
D_T4. Teachers' TPACK	Teacher, knowledge, program, base, integr, improv, implement, experi, survey, classroom, provid, support, investing, preservice, instruct	A study on TPACK of mathematics teachers: Focusing on recognitions and educational needs of TPACK (Lee & Hwang, 2018)
D_T5. The learning and design of AI	Learn, develop, AI, intellig, applic, field, design, artificial, inform, converg, appli, future, suggest, learner, addit	The trends of using artificial intelligence in mathematics education (Park, 2020)
D_T6. Examination of the effect of technology on cognitive and affective development	Student, school, effect, class, achiev, abil, program, steam, model, middl, creativ, signific, Korean, grade, particip, engin	The impact of computer use for learning and recreation on the level of academic performance according to gender: A latent growth modeling (Kim, 2009)

Figure 7 Words cloud of domestic research topic with the fifty highest term-topic probability words

D_T1. Technology in the textbook

D_T2. Computer and curriculum implementation



D_T3. Using technology to support mathematics learning

D_T4. Teachers' TPACK

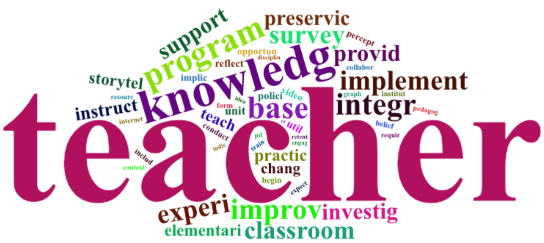
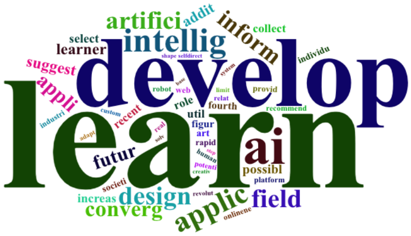


Figure 7 Continued

D_T5. The learning and design of AI



D_T6. Examination of the effect of technology on cognitive and affective development

The first topic, labeled as D_Topic 1 and named "Technology in the textbook", focuses on articles that explore the technology presented in mathematics textbooks and the use of digital textbooks. For example, Hong et al. (2013) and Kim (2016) examined the use of digital textbooks for mathematics teaching and learning.

D_Topic 2, labeled "Computer and curriculum implementation," investigates how technology resources in curriculum materials impact teacher instruction and student learning. The articles on this topic examined the perceptions and impact of utilizing computer-embedded tools in the mathematics classroom (e.g., Jung et al., 2022; Lee & Sim, 2012; Park & Lee, 2015). For example, Jung et al. (2022) studied the impact of using computers on mathematics achievement, while Lee and Sim (2012) examined the mathematics teachers' perceptions of the use of computers in a secondary mathematics classroom.

D_Topic 3, labeled "Using technology to support mathematics learning," focuses on articles that explore principles, pedagogies, and teaching methods to support mathematics learning with technology. This topic revolves around discussions on the applications of constructivist teaching methods in mathematics instruction when using specific tools such as mobile and augmented reality (Kim et al., 2019). It also explores mathematical activities (e.g., inductive activity, game-based activity) implemented with technology tools for mathematics learning (e.g., Cho & Lee, 2012; Kwon & Ryu, 2013; Park et al., 2015).

Moving on to D_Topic 4, it is named "Teachers' TPACK." This topic primarily focuses on mathematics teachers' TPACK. A sample of these teachers spans various grade levels, including both elementary and secondary levels (e.g., Kim, 2016; Lee & Hwang, 2018; Sim & Lee, 2013).

D_Topic 5 is labeled "The learning and design of AI." This topic centers around articles that examine the learning and design aspects of AI. The articles studied the trends of using AI in mathematics education (Park, 2020), characteristics and design principles of AI application (Lee et al., 2020), different types of AI applications such as ITS (Wang & Song, 2008), and students' perceptions (Park & Sin, 2017).

Lastly, D_Topic 6 is named "Examination of the effect of technology on cognitive and affective development." The articles on this topic primarily investigated the impact of technology use on students' cognitive development such as mathematical thinking (Choi-Koh & Ko, 2007), and affective development such as motivation and creativity (Lee et al., 2020). Among various mathematics domains, geometry was the most studied mathematics domain within the top 15 representative articles (e.g., Park, 2013). Specific demographic subgroups were also studied such as gender differences and gifted students as the focus of this topic (Kim, 2009; Kim & Min, 2020).

3. Research trends analysis

We conducted an additional analysis to determine the proportion of each topic over three time periods in order to understand the research trends (see Table 4). A higher proportion indicates that a topic received more attention from researchers during that specific period. During the 2000 to May 2023 period, D_Topic 4, "Teachers' TPACK," and D_Topic 5, "The learning and design of AI," were the two most studied topics (D_T4: 17.9% and D_T5: 17.9%). Conversely, D_Topic 1, "Technology in the textbook," and D_Topic 2, "Computer and curriculum implementation," were the least studied topics (D_T1: 15.7% and D_T2: 15.6%).

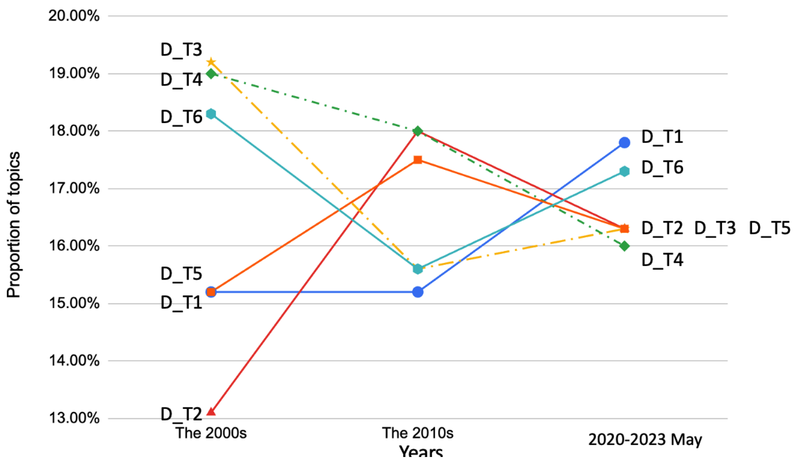
Table 4 Domestic research trends on technology use in mathematics education

	Research topic (Patterns of research trend, overall percent)	The 2000s	The 2010s	2020–2023 May
D_T1.	Technology in the textbook (Increasing, 15.7%)	15.2%	15.2%	17.8%
D_T2.	Computer and curriculum implementation (Fluctuating, 15.6%)	13.1%	18.0%	16.3%
D_T3.	Using technology to support mathematics learning (Fluctuating, 17.6%)	19.2%	15.6%	16.3%
D_T4.	Teachers' TPACK (Decreasing, 17.9%)	19.0%	18.0%	16.0%
D_T5.	The learning and design of AI (Fluctuating, 16.4%)	15.2%	17.6%	16.3%
D_T6.	Examination of the effect of technology on cognitive and affective development (Fluctuating, 16.8%)	18.3%	15.6%	17.3%

Note: Each cell under the column name includes the average percentage of the topic studied in the specified year range. For example, in the second row, third column, the value 15.2% (D_T1) indicates that for the year range between 2000–2009, D_Topic 1 accounts for an average of 15.2% of the total analyzed articles.

As a next step, we investigated how the topic proportions changed between 2000 and May 2023 to identify patterns for each topic, specifically whether they gained or lost popularity over time. Figure 8 depicts the research trend across three time periods. The topic proportion of D_Topic 1 "Technology in the textbook" showed an overall increase, particularly from the 2000-2009 period (15.2%) to the 2020-2023 May period (17.8%). In contrast, D_Topic 4 "Teachers' TPACK" demonstrated an overall decrease over time, with a drop from the 2000-2009 period (19.0%) to the 2020-2023 May period (16.0%). Other topics (T2, T3, T5, and T6) revealed fluctuating patterns. For example, D_T2 "Computer and curriculum implementation" received the least attention during the 2000s (13.1%) but the most attention during the 2010s (18%). Then, it lost attention between the 2020-2023 May period (16.3%).

Figure 8 Domestic Research trends of each topic from 2000 to 2023 May (Korean-written article)



V. DISCUSSIONS AND IMPLICATIONS

This research delved into the research topics and trends related to technology use in mathematics education in Korea over the past two decades. Using the topic modeling technique (Blei, 2012), we analyzed 156 papers published in KCI-indexed journals between 2000 and May 2023 that met the inclusion criteria. This section briefly revisits the study's results regarding significant research topics and trends. Also, as a successor of the work for analysis of international research trends on the same topic, we compared the research trends of domestic and international research. Particularly, we pay attention to the commonalities between domestic and global research settings and uniqueness in the domestic context to discuss implications for future direction.

1. Comparison between domestic and international research trends: Commonalities

Our study has revealed that the research topics and trends in Korean domestic research share many commonalities with those in the global context. First, our study showed that the research on technology use in mathematics education in the Korean domestic context has continuously gained popularity, as evidenced by the growing volume of research studies over time. The last period in our study included data available as of now (2020 - May 2023), but we anticipate that this upward trend will continue based on the number of studies identified during this short period. This increasing research interest is also observed internationally (Hwang et al., 2023) and aligned with the widely accepted recommendations in the global arena for the importance of technology use in mathematics education (e.g., NCTM, 2000, 2014; OECD, 2019).

Second, as shown in Table 5, the research topics derived from the LDA algorithm in the domestic and international contexts were similar enough to conclude that topics such as studies on using technology to support mathematics learning (I_T1 and D_T3) and examining the effect of technology on cognitive and affective development (I_T7 and D_T6) are considered crucial by both domestic and international researchers. Additionally, the distribution of topics showed multiple competing research topics, and none of the topics substantially dominated the field in both contexts. The highest and lowest proportions of international research topics were 15.2 % (I_Topic 7) and 12.7% (I_Topic 6), respectively. Similarly, the highest and lowest proportions of domestic research topics were 17.9% (D_Topic 5) and 15.6% (D_Topic 2), respectively. In general, the commonalities mentioned indicate that Korean research on technology use in mathematics education keeps pace with and contributes to global research trends.

Table 5 Comparison between domestic and international research trends (Patterns and percent)

International research trends (Hwang et al., 2023)	Domestic research trends
I_T1. Using technology to support mathematics learning (Stable, 14.5%)	D_T3. Using technology to support mathematics learning (Fluctuating, 17.6%)
I_T2. Technology in K–12 curriculum (Increasing, 14.8%)	D_T1. Technology in the textbook (Increasing, 15.7%)
I_T3. Computers and ICT use at school (Decreasing, 14.0%)	D_T2. Computer and curriculum implementation (Fluctuating, 15.6%)
I_T4. Technology use at higher education (Increasing, 13.9%)	
I_T5. Teacher instruction and TPACK (Stable, 14.9%)	D_T4. Teachers' TPACK (Decreasing, 17.9%)
I_T6. Using technology for conceptual understanding (Increasing, 12.7%)	
I_T7. Examining the effect of technology on cognitive and affective development (Decreasing, 15.2%)	D_T6. Examination of the effect of technology on cognitive and affective development (Fluctuating, 16.8%)
	D_T5. The learning and design of AI (Fluctuating, 16.4%)

Note. For the comparison, the order of topics in domestic research trends was rearranged to present similar research topics in the same row.

2. Unique characteristics within domestic research

While commonalities were more prevalent in research topics and trends between domestic and international research, our study identified a few aspects unique to the Korean domestic research context. We noticed that a few frequent words were exclusively identified or more highly ranked in the Korean research context. Those included 'textbook,' 'achiev(e),' 'abil(ity),' and 'ai.' This result implies greater attention and interest in developing and using digital textbooks and AI compared to other counterparts in the international context (Hwang et al., 2023). The frequently used words such as 'achievement' and 'ability' may indicate a greater emphasis on student achievement in the Korean context.

Likewise, while most research topics were common between domestic and international research, several did not align clearly. As presented in Table 5, two topics in the list of international research topics were absent in the list of domestic research topics (I_T4: “technology use at higher education” and I_T6: “Using technology for conceptual understanding”). Jang’s (2016) prior review of domestic research during 2000-2016 partially explains the lack of research on “technology use at higher education” as it reported the majority of studies’ participants were K-12 students, and the studies with students in higher education took up the least amount. According to a similar review study at the international level (Hwang et al., 2023), “using technology for conceptual understanding” was the topic that steadily increased attention. Thus, this result in the domestic research context is somewhat moot. Although it is beyond the scope of the present study, it is plausible that the absence of these two topics in the Korean domestic context can be better understood in other social, cultural, and educational contexts specific to Korea, and follow-up studies may offer a clearer picture.

In contrast to the missing topics in domestic research, “the learning and design of AI” (D_T5) was only identified in the list of domestic research topics. The prior review study (Hwang et al., 2023) pointed out the absence of topics on utilizing new technology in education in the international research context. Thus, this is an inspiring result, even though the discussion on the quality and depth of such a research strand is beyond the scope of the present study. We conjecture that this result might be attributed to the unique social, cultural, and political forces prevalent in the mid-2000s in Korea, such as the emphasis on the advent of the fourth industrial revolution or AlphaGO shock (Korea Institute for Curriculum and Evaluation, 2016; Zastrow, 2016).

We also noted that the trends of individual research topics over the extended time in the domestic setting were not clearly aligned with those in the international context, exception of one topic that showed an increasing research trend (D_T1: “Technology in the textbook,” I_T2: “Technology in K-12 curriculum”). For example, the topic of “teachers’ TPACK (D_T4)” showed a decreasing pattern in Korea when it showed a stable research pattern in the international context. The different trends shown in D_T1 and D_T4 warrant further investigation. One plausible reason for the continuously increasing pattern in technology in the textbook (D_T1) might be the influence of regular school curriculum revisions in Korea, and the technology use has been increasingly emphasized. However, the reason for the decreasing research on “teachers’ TPACK (D_T4)” is uncertain because the effective use of technology-integrated curriculum materials largely depends on teachers’ technology use in mathematics classrooms and their TPACK (Bray & Tangney, 2017; Remilard, 2005).

Additionally, in comparison to international research trends that displayed relatively constant patterns (e.g., stable, increasing, or decreasing), domestic research trends showed more fluctuating patterns (D_T2, D_T3, D_T5, and D_T6). This finding suggests that domestic scholars tend to change their research topics more frequently than their international counterparts. This result is similar to the previous study examining domestic and international research trends of assessment in mathematics education (Son & Hwang, 2020), which reported that domestic research trends on assessment have changed more frequently compared to international research trends. These results might indicate that domestic scholars are more prone to sporadically exploring various topics compared to international scholars. Also, this could imply that the demands surrounding technology use in mathematics education in the Korean context have evolved more frequently.

3. Limitations

It is important to acknowledge some limitations of this study. Firstly, the research trends were identified solely based on the words found in the abstract. While this is a common method used by many researchers, it may not provide a complete picture of how related topics have been studied. To address this, we suggest a more comprehensive approach for future research, which combines the identification of research trends with specific word ratios or patterns, along with information about researchers' backgrounds, names, and their research trends. By integrating these factors, we can gain a more holistic understanding of the research landscape.

Secondly, we gathered data from the KCI website by using English keywords. This approach led to excluding papers without English abstracts from our sample, which may have left out research papers published before English abstracts became required in KCI journals. Furthermore, our inclusion criteria may have excluded papers that did not explicitly mention the word ‘technology’ in the abstract, even if they were related to technology. To address this, we suggest using various keywords like artificial intelligence, metaverse, virtual reality, and computer, in addition to ‘technology’ for future searches. This approach will help ensure a more comprehensive selection of relevant papers and provide a broader understanding of the research landscape.

Third, this study analyzed a limited number of papers (n = 156). Thus, caution should be exercised when interpreting the results. For example, we observed a decrease in T2's share from 18% (Period 2) to 16.3% (Period 3), which may indicate a decline in interest over time. However, given the small sample size, this could suggest a variance in interest by topic during Period 2, while interest in all topics might have been evenly distributed in Period 3. To gain a deeper understanding of the research trends, such as fluctuations, increases, and decreases, it is recommended to consult with experts in the field through interviews or surveys. Such triangulation can help validate and contextualize the findings obtained from the limited quantitative analysis.

4. Looking forward

With the waves of development of technology, the spectrum of technology use in mathematics education has widened over the years, continuously remaining a moving target. In this regard, we looked back on research studies in the Korean domestic context over the last two decades to identify trends, gaps, and advancements, especially by comparing them with those in international research.

Our study has provided several avenues for future research. First, we discovered distinct characteristics in domestic research and hypothesized that Korean scholars might have been influenced by adjustments to the national curriculum, educational policies, and societal or cultural demands. To verify our assumptions, we recommend conducting additional studies to explore these domestic-specific factors in greater detail.

Second, our study found that there has been a decrease in the attention given to the topic of teachers' TPACK, which is not consistent with the global trend (Hwang et al., 2023). Because teachers' knowledge and skills are crucial in responding to rapidly changing trends in technology use in mathematics, we believe that further investigation is necessary to understand the reasons behind this decreasing trend in the domestic context. The nature of the present study did not allow for delving further into the details of the studies. Therefore, we propose follow-up studies that closely examine this topic regarding teachers' capacity and role in technology use in mathematics and explain the decreasing trend identified in our study.

Finally, the recent COVID-19 pandemic has caused disruptions in our lives, education, and educational research (Daniel, 2020). However, it has been the time technology integration in education was more critical than ever before, and we anticipate the results of empirical studies in the coming years. Along the same vein, we note that the pandemic brought up equity and access issues in the use of technology (Becker et al., 2020). Despite the potential for technology use to enhance equity and access in mathematics education (AMTE, 2022), this topic has not been identified as an important research topic in our domestic and international review studies. Thus, we encourage scholars to look into the issue of equity and access based on their recent experiences and data and take this as an opportunity to diversify research topics in technology use in mathematics education.

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