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Trends in Professional Development of Mathematics Teachers Using Topic Modeling: A Scoping Review

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Abstract

Professional development for mathematics teachers is a prerequisite for effective student learning. This study conducted a topic modeling analysis of 1,330 articles on the professional development of mathematics teachers published over 20 years from 2004 to 2024. As a result, ten topics related to the professional development of mathematics teachers were identified. These topics are popular research areas that have received a lot of attention from researchers during this period. To track trends in the field, a time-series regression analysis and annual trends in topic proportion were also examined. The 10 topics exhibited different research trends, including increasing, decreasing, and stable trends. The three topics Assessment, Technology, and Lesson reflection and Noticing emerged as hot topics that showed a significant increase in research interest during the period. The interest of researchers focused on the 10 topics varied depending on the year, but the studies were continuously conducted on most of them as time progressed. Based on these findings, this study suggested the current state and future directions in this field.

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Introduction

The preparation of pre-service teachers (PSTs) and the ongoing professional development of in-service teachers have attracted substantial attention from researchers (Hollebrands & Lee, 2020; Scher & O'Reilly, 2009). At the heart of these initiatives lies the fundamental belief that the expertise of mathematics teachers plays a pivotal role in enhancing teaching and fostering student growth (Goldsmith et al., 2014). This process unfolds within a specific educational policy context or school culture, and the tools implemented for development vary according to the goals and needs of both the teachers and students (Avalos, 2011). Given the complexities associated with the professional development of mathematics teachers, extensive literature reviews have been conducted to synthesize previous research. The studies included mathematics professional development interventions (Scher & O'Reilly, 2009), conceptual frameworks for professional development (Goldsmith et al., 2014), and the trends in thinking and practice (Zaslavsky et al., 2003). However, these literature studies have notable limitations. Firstly, existing research tends to concentrate on specific aspects, such as interventions, frameworks, or programs, resulting in a relatively limited number of papers reviewed. Second, manual coding, which is the main approach adopted in the studies, involves a tedious coding process and can be inaccurate as it largely reflects the researcher's subjectivity (Chen et al., 2020). Therefore, there is a pressing need to employ review methods that are suited for large datasets, to overcome the limitations of existing review studies, and to provide a comprehensive overview of the trends and future directions in the professional development of mathematics teachers.

Topic modeling is a statistical method used to analyze collections of text and extract latent topics (Blei, 2012; Blei et al., 2003; Griffiths & Steyvers, 2004). Researchers can employ topic modeling to identify various underlying components that form the foundation of their study (Copur-Gencturk et al., 2023). Recently, extensive research has been conducted in applying topic modeling to the field of mathematics teacher education (e.g., Copur-Gencturk et al., 2023; Hwang et al., 2023; Lutovac & Kaasila, 2019). These studies provided insights into specific factors related to mathematics teachers (e.g., understanding, technology, identity) and implications for future research directions. However, information on research topics related to the professional development of mathematics teachers and how they have evolved remains limited. This study aims to use topic modeling to review all articles related to the professional development of mathematics teachers over the past two decades. Four main research questions guide the present study.

RQ1. How have the overall research trends in the professional development of mathematics teachers changed over time?

RQ2. What are the major research topics in the professional development of mathematics teachers?

RQ3. How have individual research topics evolved over time?

RQ4. How have the principal topics of interest among researchers changed over time?

Literature Review

Professional Development of Teachers in Mathematics Education

Professional development of teacher is an intensive, continuous, and systematic process aimed at improving education, learning, and the school environment (Elmore, 2002; Fenstermacher & Berliner, 1985). Teachers are regarded as playing a central role in mathematics instruction. "Teachers are necessarily at the center of reform, for they must carry out the demands of high standards in the classroom" (Garet et al., 2001: 916). The professional knowledge and skills of mathematics teachers have a significant impact on the quality of teaching and learning in the classroom, and consequently, on student achievement (Hill et al., 2005). Therefore, professional development for teachers has been recognized as a crucial component of policy aimed at improving the quality of teaching and learning in schools (Ingvarson et al., 2005).

Although achieving meaningful improvements in student achievement requires substantial, extended, and continuous professional development for teacher, this process is resource-intensive in terms of time, effort, and cost (Yoon et al., 2007). Teacher professional development is a gradual, nonlinear, and iterative process that involves repeated cycles of inquiry outside the classroom and experimentation within it (Goldsmith et al., 2014). Therefore, it is necessary to conduct an extensive investigation of teachers' professional development and explore the underlying factors that shape the beliefs and practices of mathematics teachers over the long term (Bernack-Schüler et al., 2015).

For this reason, numerous researchers have synthesized studies in mathematics education to examine research trends and uncover hidden factors. For example, Inglis and Foster (2018) used topic modeling to investigate articles published in two major mathematics education journals, Educational Studies in Mathematics and the Journal for Research in Mathematics Education, between 1968 and 2015, identifying 28 topics across four domains. Teacher knowledge and beliefs emerged as one of the key topics. Foster and Inglis (2019) conducted topic modeling on articles published in two major mathematics teacher professional journals in the UK (Mathematics Teaching and Mathematics in School). They identified 15 topics across three domains: mathematical content, pedagogical issues and resources, and administrative matters. Similarly, Gökçe and Güner (2021) examined 1,021 mathematics education articles published between 1980 and 2019, identifying four research domains: foundation, implementation, association, and evaluation. Previous studies provided valuable insights into understanding broader research trends and offering a comprehensive picture of mathematics education and teacher professionalism. However, there has been little extensive research reviewing which topics related to mathematics teacher professional development have been investigated and how these topics have evolved over time.

This study, rather than focusing on specific journals, included broaden the scope of the entirety of mathematics education. This study investigated research trends related to mathematics teacher professional development Using topic modeling. The following section provides a detailed explanation of the topic modeling approach used for data analysis in this study.

Topic Modeling

Topic modeling is a text mining method used to automatically organize large volumes of text into clusters, allowing researchers to explore hidden patterns in unstructured data (Papadimitriou et al., 2000). Researchers have employed topic modeling to analyze trends in large bibliographic datasets (e.g., Foster & Inglis, 2019; Inglis &

Foster, 2018; Son & Lee, 2020). Various topic modeling methods exist, including pLSA (probabilistic Latent Semantic Analysis) and LSI (Latent Semantic Indexing), but the most widely used and oldest method is LDA (Latent Dirichlet Allocation). LDA operates on a hierarchical Bayesian model with three levels—words, topics, and documents—to identify hidden topics in the collected data (Blei et al., 2003).

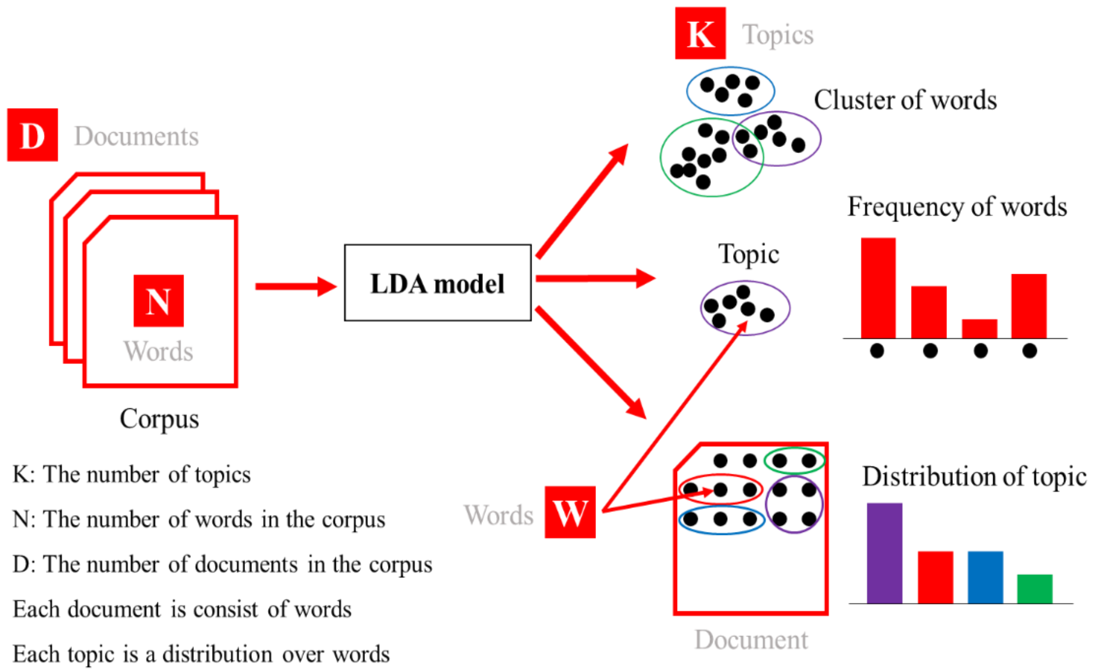

Figure 1. Visualization Model Representing the Topic Modeling Process (adapted from Bernack-Schüler et al., 2015)

Methods

Data Collection and Retrieving Process

The data collection process was conducted in five stages, following the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines proposed by (Page et al., 2021). First, electronic databases of Web of Science, Education Resources Information Center (ERIC), and EBSCO Education Source were used for searching articles. The search strings were systematically formulated as shown in Table 1: (“teacher* OR teaching) AND (professional OR skill OR competence) AND (development OR improvement OR learning) AND (math OR maths OR mathematics). This search was carried out on March 1, 2024, yielding an initial result of 21,642 articles.

Table 1. Searching Strings

A	B	C	D
1. teacher*	1. professional	1. development	1. math
2. teaching	2. skill	2. improvement	2. maths
	3. competence	3. learning	3. mathematics

Note. The asterisk (*) was used to broaden a search.

Second, the collected articles were processed using EndNote reference management software to eliminate duplicates, resulting in a corpus of 15,293 articles. Third, these articles were screened based on inclusion criteria. Studies not in English or published before 2004 were excluded. To ensure academic rigor, dissertations, conference proceedings, review articles, and commentaries were eliminated, focusing on peer-reviewed articles. Fourth, articles without accessible abstracts or full texts were excluded. The primary data for topic modeling in this study were the abstracts of the papers. Abstracts are generally suitable for conceptual review as they summarize the research purposes, questions, and key findings (Cretchley et al., 2010; Yan, 2015; Zhong et al., 2016). This process yielded 2,138 articles. Fifth, a thorough review of each paper's title, abstract, and full text was conducted to exclude those not related to the professional development of mathematics teachers (e.g., articles focusing on the use of professional development programs in science education) were excluded. Consequently, this rigorous screening process resulted in the selection of 1,330 articles. Figure 2 provides a visual representation of the data collection and retrieval process, grounded in the PRISMA framework. This figure aids in illustrating the systematic approach adopted for data screening and selection.

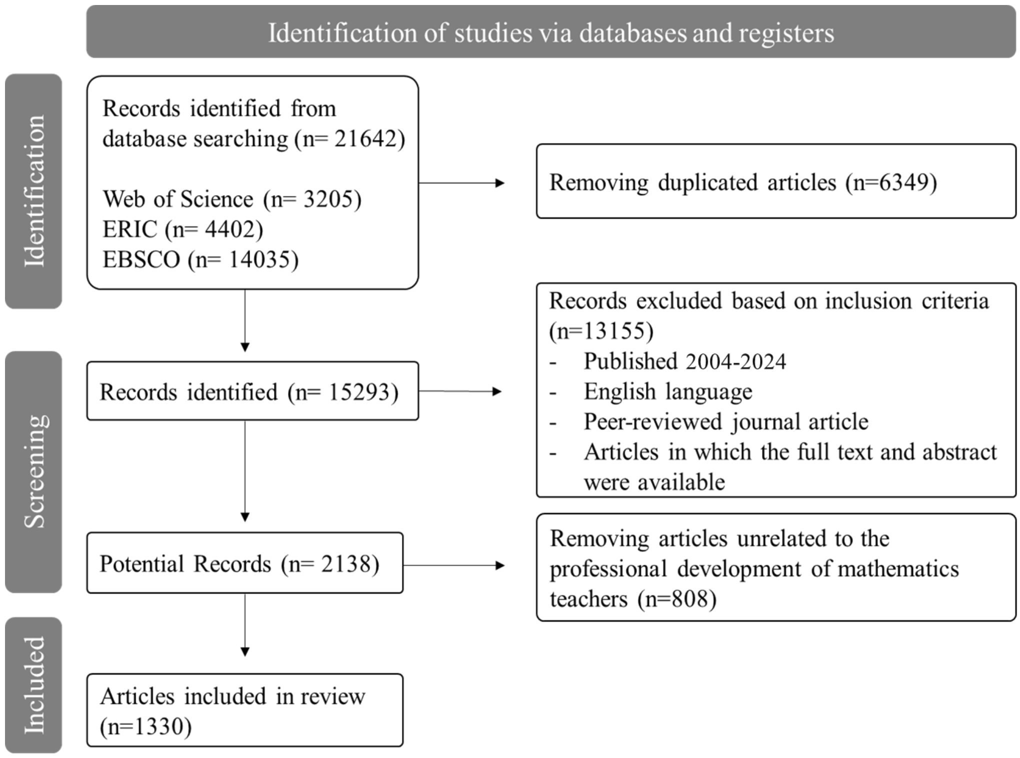

Figure 1. Data Retrieval Process Based on a PRISMA Guideline

Data Analysis

Preprocessing

Data preprocessing was carried out to enhance data quality before conducting topic modeling. First, punctuation, symbols, and stop words (e.g., in, the, and, or, I, we) were removed to increase consistency in the analysis and reduce computational loading (Boyd-graber & Blei, 2008; Hoffman et al., 2010). Second, terms were converted to their singular form and lowercase (e.g., Teachers → teacher). Third, words used with similar meanings were standardized (e.g., prospective teacher → preservice teacher). Fourth, words commonly found in all abstracts of articles, which could potentially confound the analysis, such as 'math', 'mathematics', 'author', 'journal', 'article', 'paper', 'study', were eliminated. Through these preprocessing steps, a total of 86,927 words were included in the analysis.

Determine the Optimal Number of Topics

This study employed the LDA model to identify topics within 1,330 articles related to the professional development of mathematics teachers (Blei et al., 2003). The 'topicmodels' package in R was used for conducting LDA. To determine the optimal number of topics in a dataset, researchers have widely employed statistical analysis methods such as perplexity (Inglis & Foster, 2018), harmonic mean (Griffiths & Steyvers, 2004), cosine similarity (Cao et al., 2009), and coherence (Blair et al., 2020). The number of topics, denoted as K, was set as ranging from 2 to 30, and examined the trend of the perplexity index which indicates an internal index for assessing model fit. Perplexity, which serves as an indicator of how distinct the topics are from each other, suggests that a smaller value indicates a more suitable model (Blei et al., 2003). However, perplexity index has the nature of tends to decrease the value as the number of topics increases. Therefore, it is generally advisable to select the point where there is a sharp change in the gradient (Inglis & Foster, 2018). Figure 3 demonstrates that the perplexity index is the smallest and the gradient change is most abrupt when K is 10. It indicated optimal performance at this point. Consequently, 10 topics were selected to categorize the collected data.

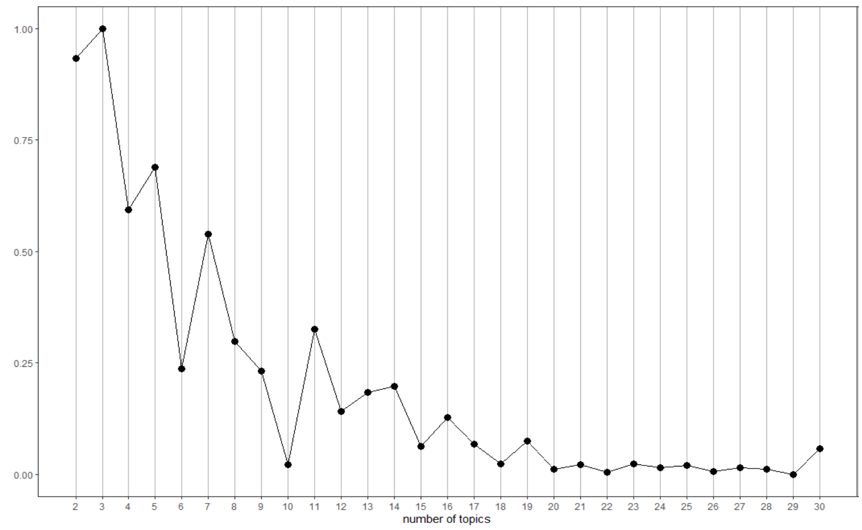

Figure 2. The Perplexity for Determining Optimal Number of Topics

Topic Labeling

Based on the identification of the number of topics, LDA was conducted on the collected data and labeled each topic. The labeling of the topics was determined by examining the top 10 representative words for each topic and the three most representative papers with the highest probability of belonging to each topic. For example, the topic *Assessment* included a set of the top 10 words: {assessment, belief, level, efficacy, test, performance, modeling, competence, attitude, view}. The three representative papers for this topic were as follows. First, Hudson et al.

(Hudson et al., 2012) assessed the beliefs of PSTs in the teaching and learning of mathematics and science. Second, Burgos and Godino (2022) analyzed and assessed the perceptions and competencies of PSTs on proportion tasks. Third, Kusaeri and Aditomo (2019) assessed the pedagogical beliefs of Indonesian mathematics PSTs regarding critical thinking and explored the potential relationship between these pedagogical beliefs and educational experiences. The topic was labeled *Assessment* based on the analysis of the top 10 words and the content of the representative papers. Labels were assigned to the other nine topics following the same strategy.

Trends Analysis

Three analysis methods were implemented to examine the research trends of the topics. First, the trend of the number of papers published each year was examined to assess the popularity and diffusion of professional development of mathematics teachers. Second, the topics that showed significant trends of increase or decrease over the years were examined. To evaluate the validity of these trends for each topic, a time-series regression analysis was conducted. The independent variable was publication year and the dependent variable was the annual proportion of each topic. Topics were labeled as 'Hot topic' when the regression coefficient was positive (+) and statistically significant ($p < 0.05$), or 'Cold topic' when it was negative (-) (Griffiths & Steyvers, 2004). Third, the distribution of topic proportions by year was visualized to investigate which topics received the most attention by year and how the topics of interest to researchers have evolved over time. This approach allows for an in-depth examination of the shifting focus on research topics within the specified time frame.

Results

Overall Research Trends

To examine the overall trends in research on the professional development of mathematics teachers, the number of published papers by publication year was visualized since 2004 (see Figure 4).

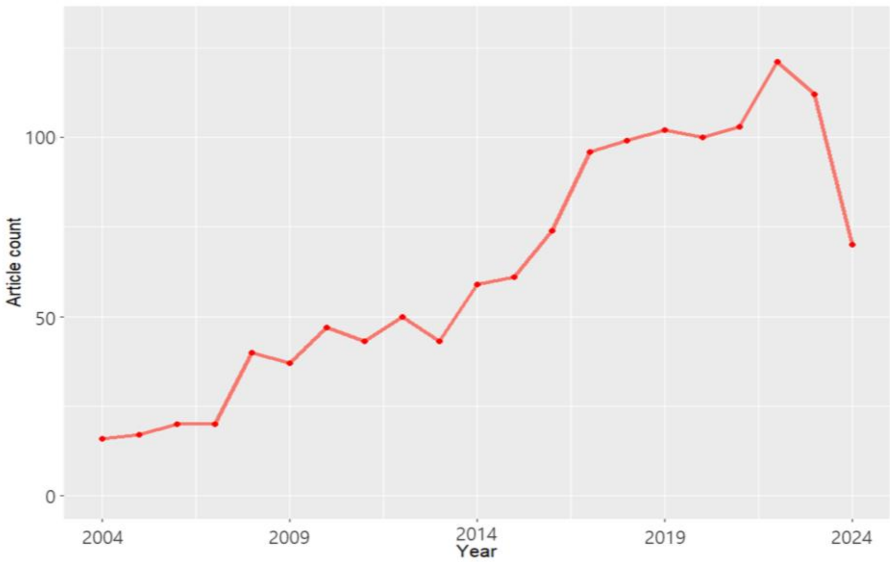

Figure 3. The Count of Articles by Publication Years

Figure 4 illustrates a progressive increase in the number of published articles over time. Table 2 shows the number of papers published in decade intervals (2004-2014 and 2015-2024). Research published between 2004 and 2014 represented only 29.5% of the total (n=392), whereas studies published between 2015 and 2024 accounted for 70.5% (n=938).

Table 2. Number of Publication Articles Per Decade

Period	The Number of Article
2004-2014	392 (29.5%)
2015-2024	938 (70.5%)
Total	1330 (100%)

Topic Identification

Table 3 presents the 10 topics derived from the implementation of LDA, along with the proportion of each topic across all articles. It is important to note that only articles related to the professional development of mathematics teachers were selected during the screening process, the topics were closely related to this field.

Table 3. Top 10 Keywords, Their Proportions in the Whole Corpus, Suggested Topic Labels

Top 10 Keywords	%	Label
assessment, belief, level, efficacy, test, performance, modeling, competence, attitude, view	11.6	Assessment
student, thinking, understanding, reasoning, problem, solving, practice, strategy, ability, response	11.9	Student thinking and understanding
teacher, identity, teaching, primary, change, secondary, experience, reform, educator, report	8.9	Identity
knowledge, content, pedagogical, curriculum, teaching, meta, cognitive, subject, PCK, resource	10.4	Pedagogical Content Knowledge (PCK)
preservice, technology, teaching, skills, training, integration, design, ICT, elementary, qualitative	9.8	Technology
learning, task, design, process, approach, context, role, theory, activity, explore	8.3	Tasks design
lesson, noticing, teacher, video, practice, framework, evidence, reflection, opportunity, develop,	10.2	Lesson reflection and Noticing
student, achievement, grade, quality, academic, school, skill, classroom, quality, children	8.3	Achievement
support, practice, teaching, training, challenge, online, community, barrier, material, context	10.1	Support and challenges
professional, development, program, effect, project, model, inquiry, design, support, implementation	10.6	Program

The topic *Assessment* included articles assessing teacher's factors influencing professional development (e.g., belief, efficacy, attitudes). The topic *Student's thinking and understanding* examined teachers' abilities to assess and foster students' mathematical thinking and understanding. The topic *Identity* included studies on the development and growth of teachers' identity. The topic *PCK* examined various aspects of teacher knowledge, such as content knowledge, knowledge of tools, and conceptual and procedural knowledge. The topic *Technology* covered research on the integration of various technologies, including ICT, multimedia, mobile, and games. The topic *Tasks design* deals with teachers' ability to design tasks for students' mathematics learning and teacher professional development. The topic *Lesson reflection and Noticing* included studies on lesson reflection for teacher professional development and teachers' abilities to attend, interpret, and decide how to respond to students' thinking. The topic *Achievement* covered the impact of teachers' professional development on students' mathematical achievements. The topic *Support and Challenges* included studies focusing on support, challenges, and barriers in professional development of mathematics teachers. The topic *Program* examined the development and application of programs for teacher professional development and their effectiveness. The top five most discussed topics were *Student's thinking and understanding* (11.9%), *Assessment* (11.6%), *Program* (10.6%), *PCK* (10.4%), and *Lesson reflection and Noticing* (10.2%).

Topic Trends

Topic Trends Change over Time

Figure 5 shows the annual proportion (weight) of each topic. Given the nonlinear trends observed in some topics, the visualization includes scatter plots along with curve trend lines.

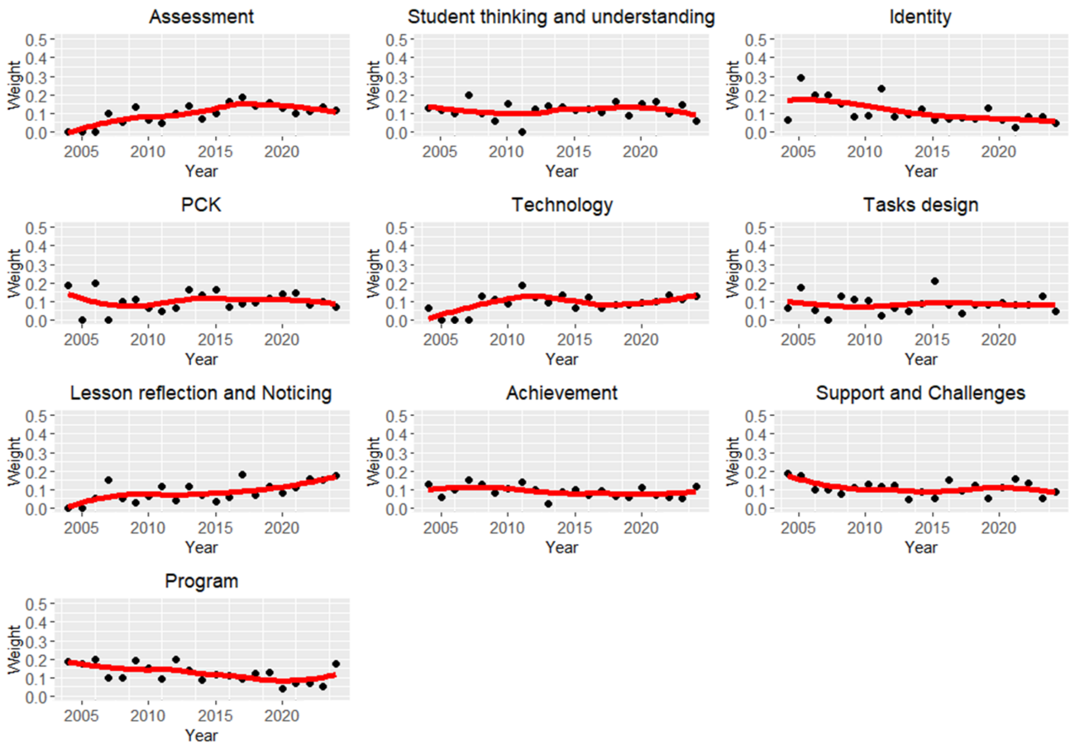

Figure 4. The Change of Annual Topic Proportion Within the Entire Corpus for the 10 Topics

Topics such as *Assessment*, *Technology*, and *Lesson reflection and Noticing* showed increasing trends. In contrast, the topic *Identity*, *Support and Challenges*, and *Program* showed decreasing trends. The remaining topics *Student thinking and understanding*, *PCK*, *Tasks design*, and *Achievement* did not exhibit trends of either substantial increase or decrease.

Hot and Cold Topic

A time-series regression analysis was conducted to examine the significant trend changes in topics over time and identify Hot and Cold topics. Table 4 shows the statistically significant hot and cold topics from the time series regression analysis. Out of a total of 10 topics, three were identified as hot topics: *Assessment, Technology, and Lesson reflection and Noticing*. Conversely, the topic *Identity* and *Program* were identified as Cold topics. The remaining five topics did not show statistically significant results ($p > .05$).

Table 4. Hot and Cold Topics

Topic	Regression Coefficient	p	Trends	Hot/Cold
Assessment	.681	.001	↑↑	Hot
Student thinking and understanding	.020	.932	↑	-
Identity	-.609	.003	↓↓	Cold
PCK	.048	.210	↑	-
Technology	.440	.046	↑↑	Hot
Tasks design	-.014	.951	↓	-
Lesson reflection and noticing	.649	.001	↑↑	Hot
Achievement	-.395	.076	↓	-
Support and Challenges	-.320	.158	↓	-
Program	-.577	.006	↓↓	Cold

Note. ↑(↓): increasing (decreasing) trend but not significant ($p > .05$); ↑↑(↓↓) Significantly increasing (decreasing) trend ($p < .05$).

Research Interests by Year

Figure 6 presents the visualization of the distribution of topic proportions by year. The result clearly shows prominent research interest in each year. For example, the topic *Identity* was the most prominent topic of interest in 2005.

The topic *Tasks design* garnered the most attention in 2015. The topic *Assessment* and *Lesson reflection and Noticing* received attention from researchers in 2017. In 2024, *Lesson reflection and Noticing* stood out as the most prominent area of interest. In the early stages, some topics did not emerge, and there was a tendency for researchers to focus their attention on specific topics. However, as time progressed, research on almost all topics was continuously conducted.

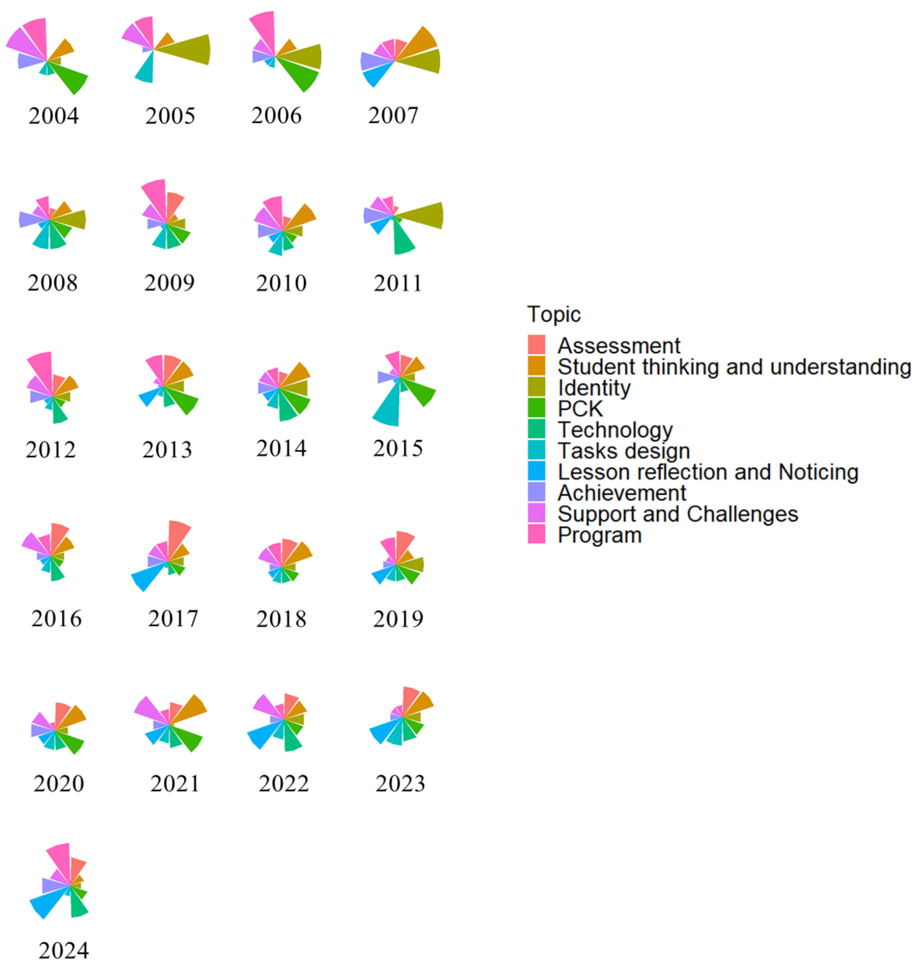

Figure 5. The Distribution of Topic Proportion by Year

Discussion

This study conducted a topic modeling analysis on 1,330 articles published between 2004 and 2024 concerning the professional development of mathematics teachers. The research aimed to identify topics related to mathematics teacher professional development and track trends in each topic over time. The findings of this study provide an overview of the current state and a comprehensive picture of teacher professional development in mathematics education. The results of the first research question showed a steady increase in the number of published articles on mathematics teacher professional development. The number of articles published between 2015 and 2024 was approximately three times greater than those published between 2004 and 2014. This finding aligns with Inglis and Foster (2018), which reported a continuous increase in research on mathematics teachers in mathematics education. Research on mathematics teacher of professional development remains a field of consistent interest among researchers, and it has rapidly grown within the mathematics education community over time.

Regarding the second research question, the topic modeling analysis identified ten topics: *Assessment, Student thinking and understanding, Identity, PCK, Technology, Tasks design, Lesson reflection and Noticing, Achievement, Support and Challenges,* and *Program.* These identified topics refine the potential areas of research on mathematics teacher professional development, expanding on the findings of previous studies that identified general topics in mathematics education (e.g., Gökçe & Güner, 2021; Inglis & Foster, 2018). Furthermore, the identified topics do not neatly align with the categorization of research topics on teacher professionalism by Foster and Inglis (2019). Notably, the present study did not reveal topics related to mathematical content or administrative matters. This difference may be attributed to the type and scope of the used data. While the current study included articles that investigated teacher professional development in mathematics education, Foster and Inglis (2019) only examined articles from two mathematics teacher professional journals.

The topics *Student thinking and understanding*, *Assessment*, *Program*, *PCK*, and *Lesson reflection and Noticing* emerged as the most prominent. These topics represent the most extensively researched areas within the field of mathematics teacher professional development. They are closely related to the development of teacher professionalism in mathematics and hold significant importance in this field. The results for the third research question showed significant increasing trends were observed over time for the hot topics of *Assessment, Technology,* and *Lesson reflection and Noticing*. The topic *Assessment* included studies of teachers' factors such as teachers' beliefs (Lau, 2022), attitudes (Panero et al., 2023), competencies (Kaiser et al., 2017), and views (Dreher et al., 2016). This topic showed continuous growth over time. However, assessing teachers' expertise is included in most studies in this field. Therefore, it is reasonable to interpret the increasing interest in 'assessment' as a result of the cumulative research on the professional development of mathematics teachers. The topic *Technology* emerged as a prominent topic in this field, indicating a growing interest in the use of technology for professional development. For example, Çelik and Pektaş (2017) investigated PSTs' graphic comprehension and interpretation skills in technology-aided learning environments. Hansen et al. (2016) explored how co-designing a virtual manipulative for teaching fractions impacted professional development. Integrating technology into mathematics education has the potential to fundamentally transform teaching and learning (Bray & Tangney, 2017; Zawacki-Richter et al., 2019). Therefore, it can be predicted that using technology for professional development of mathematics teachers will be a promising research area. Research on *Lesson reflection and Noticing* also showed a significant increasing trend. Leavy and Hourigan (2016) reported that ‘Lesson Study' supported PSTs' reflection and enhanced their noticing abilities. van den Kieboom (2021) examined PSTs' noticing skills using reflective journals. This topic still holds research potential and is likely to remain a central focus of studies on professional development of mathematics teachers.

On the other hand, the topics *Identity, Support and Challenges,* and *Program* showed a decreasing trend. Among these topics, *Identity* and *Program* were cold topics that showed a significant decreasing trend. These two topics showed a decrease in research output compared to previous periods, suggesting that they may lose popularity in the near future. Finally, the topics *Student thinking and understanding, PCK, Tasks design,* and *Achievement* showed consistent trends without significant increases or decreases. These topics have matured sufficiently in this field, and while continuous research will likely take place in the future, they may not attract significantly more attention in the near term.

The results of the fourth research question, which analyzed the annual topic distribution, revealed changing trends in researchers' focus within this field. For example, in the early stages, researchers concentrated more on topics such as *Identity*, *Program*, and *PCK.* Over time, the focus shifted, with the topic *Technology* becoming prominent from 2008 onward, and *Lesson reflection and Noticing* gaining significant popularity after 2011. These findings indicate that, in the early 2000s, researchers primarily focused on personal characteristics and capacities, such as teachers' knowledge, beliefs, and identity. After the early 2000s, there was growing interest in teacher's professional development related to the use of technology in mathematics education, as well as reflection on teaching practices and noticing that drives teaching moves.

Limitations

This study has several limitations. First, the used data in this study stemmed from specific databases (i.e., Web of Science, ERIC, EBSCO). Different results may be obtained when articles from other databases are included. Therefore, depending on the research purpose, future studies can choose to use a single database or incorporate data from different databases to conduct similar research. Second, it is important to note that while topic modeling can capture meaningful signals regarding unexplored potential areas, it does not reach the same level as a systematic re-view. Topic modeling is suitable for summarizing and grouping large-scale data but may miss significant aspects of topics compared to a systematic literature review. For example, the result of this study did not reveal which content areas (e.g., arithmetic, algebra) in mathematics education have been the focus of professional development of mathematics teachers. This does not necessarily imply a lack of research in those areas rather than suggests that there may not be enough studies to identify them as independent topics. Therefore, to connect researchers' areas of interest with topic modeling, additional reviews are needed to expand the results. Lastly, considering the results of this study, an in-depth analysis of the most abundant topics and emerging hot topics can contribute to the field by shedding further light on these areas.

Conclusion

Teacher's professional development is essential for ensuring the quality of mathematics teaching and learning. This study synthesizes research published over the past 20 years, from 2004 to 2024, and investigates trends in the field using topic modeling. The results identified overall research trends in the professional development of teachers in mathematics education and highlighted topics that diverged from those identified in previous studies (Foster & Inglis, 2019; Gökçe & Güner, 2021; Inglis & Foster, 2018). The findings of this study offer guidance for further research on teacher professional development. The topic modeling analysis provides a comprehensive overview that can contribute to mathematics teacher education. The exploration of identified topics and their developmental directions serves as a foundation for identifying and comparing strengths in research on the professional development of mathematics teachers, both in the present and in future research.

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