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Flipped Classroom in Mathematics Education: A Scoping Review

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Abstract. This study was based on the scope review research framework and analyzed 221 papers on flipped classroom research in mathematics education, published in Scopus from 2013 to 2024. It adopted both bibliometric and content analysis methods to statistically examine the literature from six dimensions: basic information, research topics, developmental dynamics, research methodology, research content, and implementation effects. The findings revealed a general upward trend in the number of publications, with most studies appearing in the journal *PRIMUS* and focusing predominantly on higher education. The evolution of key topics indicated that the initial phase of research was characterized by theoretical foundations, followed by the application of practical methodologies, and eventually shifted towards evaluating the effects of implementation. The existing body of research was largely empirical, with a strong emphasis on quantitative methods and student feedback. The flipped classroom model showed a positive impact on mathematics education as a whole. Nevertheless, the extant literature exhibited notable limitations, such as the marked similarity across studies, considerable methodological uniformity, and insufficient innovation.

Keywords: bibliometric methodology; content analysis methodology; flipped classroom; maths education; scope review

1. Introduction

The concept of the flipped classroom was first proposed by Baker (2000), but it did not attract widespread attention at the time. It was not until 2007, when two high school chemistry teachers in the United States successfully applied the approach in their teaching practice, that the flipped classroom began receiving

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significant attention from mainstream media in the West. Essentially, the flipped classroom represents a reverse innovation of the traditional teaching process through the integration of information technology. It transforms the conventional "teach first, learn later" model into a "learn first, teach later" approach. This model offers several benefits, including the stimulation of students' intrinsic motivation, increased engagement, enhanced focus on problem solving, the facilitation of deep learning, and the development of higher-order thinking skills (Galindo-Dominguez, 2021).

The flipped classroom typically employs a hybrid online-offline teaching model. Before class, students engage with new learning materials, such as reading assignments or instructional videos, designed to address lower-order cognitive objectives. In-class time is then devoted to achieving higher-order cognitive goals through interactive learning with teachers and peers (Egara & Mosimege, 2024). Since its inception, the flipped classroom has gradually gained traction in mathematics education. A key milestone was Strayer's (2012) study, which marked a turning point in the application of flipped classrooms to mathematics instruction. Since then, mathematics education has emerged as a focal area for flipped classroom research and practice. Driven by global trends in educational technology reform, and grounded in constructivist learning theory, the flipped classroom−empowered by modern information technologies−has opened new avenues for innovation in mathematics instruction. Mathematics educators have increasingly embraced this model and actively integrated it into their teaching practices (Fung et al., 2021).

Despite the steady growth of research in this area, only a limited number of scholars have attempted to comprehensively synthesize findings related to flipped classroom implementation in mathematics education (Wright & Park, 2022). Existing reviews have primarily focused on specific educational levels or singular themes, lacking a holistic examination of mathematics teaching and learning across different educational stages. Furthermore, there remains a paucity of research that systematically explores the variations in instructional strategies, curriculum content, and student populations (Fernández-Martín et al., 2020). Most current studies rely on small-scale content analyses and fall short in providing a comprehensive overview of the long-term developmental trends, research hotspots, and pedagogical outcomes associated with the flipped classroom in mathematics education. These gaps highlight the urgent need for a systematic and evidence-based synthesis of the extant literature. Such an analysis is essential for guiding future research directions and informing evidence-based practice in the evolving landscape of mathematics education.

2. Methodology

A scoping review is an evidence-based methodology used to summarise the literature on broader, more complex, or emerging topics that have not been fully explored. It involves a systematic search, screening, and synthesis of existing knowledge, aiming to rapidly describe the state of research in a particular field, identify the types of evidence, reveal gaps in the literature, and propose directions for future research (Arksey & O' Malley, 2005). A scoping review follows a five-

stage process: first, defining the research question; second, conducting a comprehensive search for relevant studies; third, developing inclusion and exclusion criteria; fourth, presenting the data using tables and graphs; and fifth, summarising the findings and providing recommendations.

Unlike traditional narrative reviews, scoping reviews follow a defined methodological framework that integrates both quantitative and qualitative analyses, allowing for a higher level of evidence. This approach has gained significant attention in the field of education, particularly in mathematics education, where it has been applied to assess the current state and identify trends in research on complex subjects (Kit Ng et al., 2022; Murphy & Ingram, 2023). However, there is a lack of scoping reviews that focus specifically on the flipped classroom in mathematics education, particularly those that combine bibliometric analysis with content analysis.

This study aimed to fill this gap by employing a scoping review methodology, using the CiteSpace bibliometric analysis tool in conjunction with content analysis. Through this approach, the study systematically explored and analysed the existing literature, mapped the implementation of the flipped classroom in mathematics teaching, identified the key research trends and developments, and provided valuable insights and recommendations for both future theoretical research and practical applications.

Although this study used a scoping review approach combined with bibliometric and content analyses in an attempt to provide a comprehensive picture of the research, there are still some limitations. First, the scoping review does not include a quality assessment of the included literature, which may affect the robustness of the study findings. Secondly, the results of the CiteSpace analyses are based on search strategies and parameter settings that are somewhat subjective. Therefore, the study improved the reliability and reproducibility of the analyses by clarifying the screening criteria, double independent coding and cross-validation.

2.1 Identifying the Research Questions

Stage 1 identified four research questions.

1. What is the current state of research on the flipped classroom in mathematics education (the number of publications per year of relevant research, the number of citations per year of published literature, the main journal sources, and the distribution of research across different educational levels)?
2. What are the hot topics in research on the flipped classroom in mathematics education? What are the dynamics of development?
3. What are the main research methods used in research on flipped classrooms in mathematics education? Which dimensions are studied?
4. What is the implementation effect of a flipped classroom in mathematics education?

2.2 Searching for Relevant Studies

In Stage 2, relevant literature databases were specified, with Scopus as the database, and an advanced search was used with the search terms TITLE-ABS-KEY (("Flip* Classroom" OR "Invert* Classroom" OR "Flip* Learning" OR "Flip* Instruction" OR "Reverse Teaching" OR "Backwards Classroom") AND ("Math* Education" OR "Math*")) (Güler et al., 2023; Özdemir, 2024), the time setting was 2013-2024, the search was conducted on 8 December 2024 and 582 documents were retrieved (Figure 1).

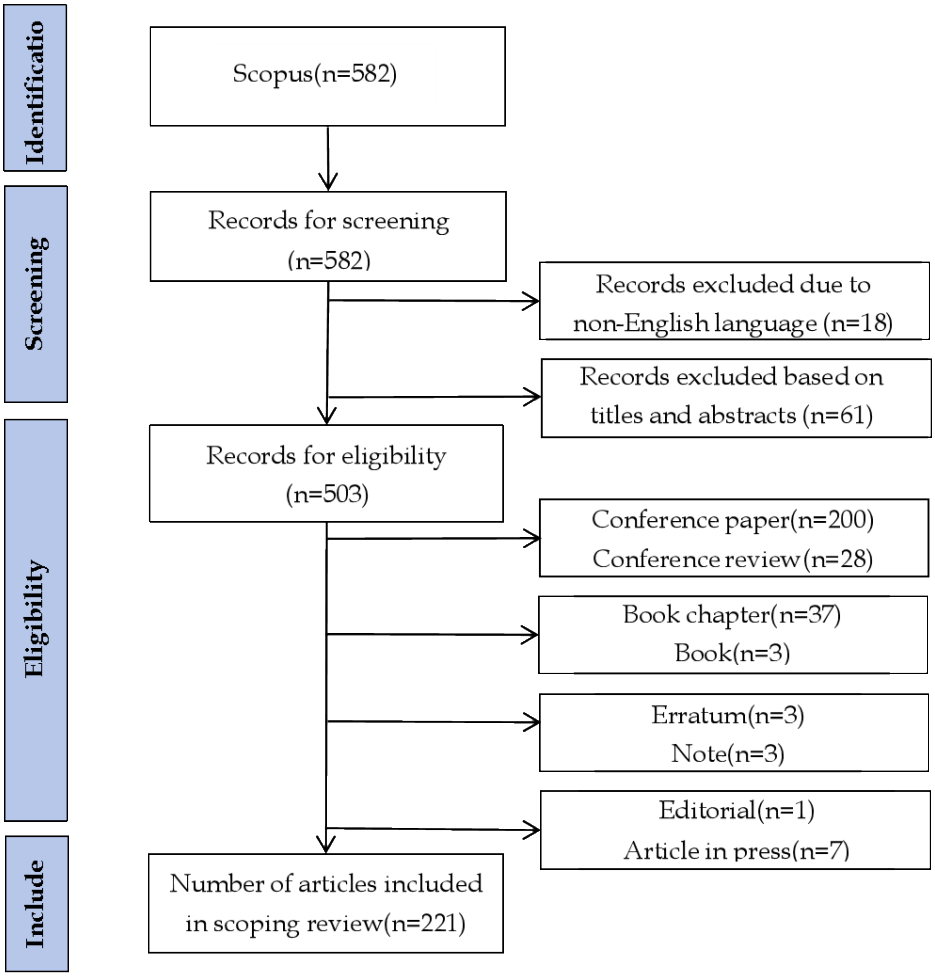


Figure 1: PRISMA flow diagram

2.3 Literature Inclusion and Exclusion Criteria

In the third stage of the research, a total of 582 documents were retrieved from the Scopus database. After the implementation of the literature screening criteria outlined in Table 1, ultimately, a total of 221 documents pertaining to the flipped classroom in mathematics education were included in the final analysis.

Table 1: Inclusion and exclusion criteria

Criteria	Inclusion criteria	Exclusion criteria
Period	Published between 2013-2024	Out of this period
Language	English	Non-English
Article type	Articles, Review	Books and Book chapters, Conference review, Conference paper, Editorials, ect.
Publication stage	Limit to "final"	Article in press
Learning area	Mathematics or its subject area such as algebra or probability	Other disciplines except mathematics

2.4 Graphical Presentation of Relevant Results

In the fourth stage, three steps were delineated: Firstly, the creation of graphs of the basic information of the included literature through manual statistics and coding and classification in an Excel spreadsheet. Secondly, the conversion of the file format of the literature exported from Scopus into a WoS-compatible format and the output of the keyword clustering network mapping and the keywords of high emergent value using CiteSpace software. The purpose of this step is to present the field of mathematics teaching and learning through the visualisation graphs of the hot topics and developments in flipped classroom research. Finally, the content analysis method was combined with the research methods and research contents of the included literature, which were counted and analysed to reveal the research trends and characteristics.

2.5 Summarise the Research Findings and Make Relevant Suggestions

In the fifth stage, a summary and analysis of the implementation effect of the flipped classroom and the current state of research were presented. The existing problems were discussed, and the future research direction and recommendations were proposed.

3. Results and Discussion

3.1 Basic Information About the Included Literature

The basic information of the included literature included four main aspects: the main journal sources of research on the flipped classroom in mathematics, the number of annual publications, the number of annual citations to the published literature, and the extent of distribution of relevant research at different educational levels (Table 2, Figure 2, 3 and 4).

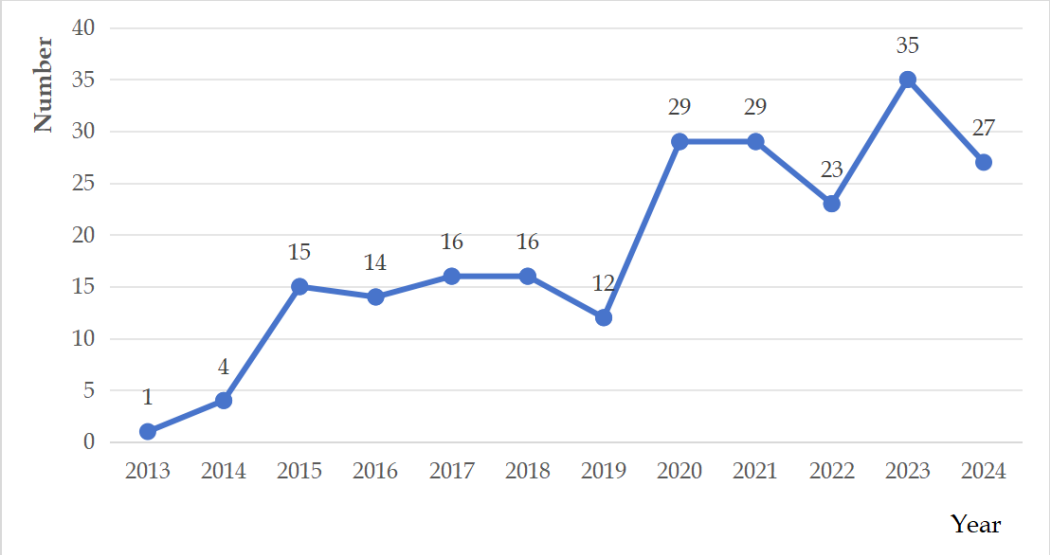


Figure 2: Annual number of publications in relevant literature

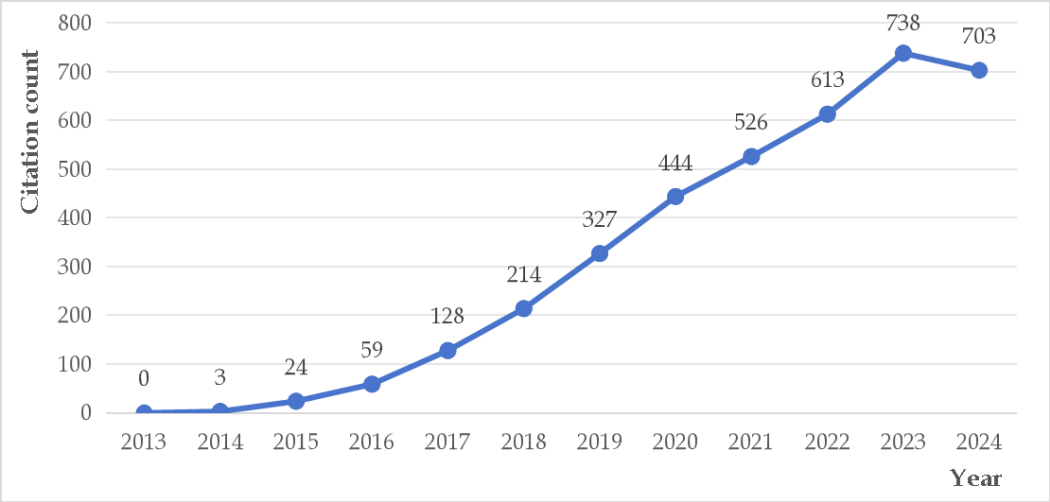


Figure 3: Annual citations to published literature

A combination of Figures 2 and 3 reveals the following trend in the annual number of articles on the flipped classroom in mathematics education between 2013 and 2024.

Phase 1: The early stage of the flipped classroom in mathematics education (2013-2015) was characterised by a low number of articles, indicative of an exploratory and nascent stage. In 2013, only a single article was published, suggesting that the application of the flipped classroom in mathematics education had not yet garnered significant attention. However, there was an increase in the number of publications in 2014 and 2015, with the number rising to 4 and 15 articles, respectively. This suggested that there was an initial increase in research interest. Concurrently, the number of citations escalated from 0 in 2013 to 24 in 2015. This suggested that at this stage, the research impact of flipped classrooms was more limited, and the dissemination and awareness of the relevant literature were still low.

Phase 2: The stable development phase of the flipped classroom in mathematics education (2016-2019), the number of articles issued remained relatively stable, with a small increase. From 2016 to 2018, the annual number of articles published remained consistent at 14-16 articles. However, in 2019, there was a slight decrease to 12 articles, which could be indicative of a slowdown in research growth or a shift in focus during this phase. Concurrently, the number of citations increased from 59 to 327, indicating an escalating level of citation and recognition for research on flipped classrooms in mathematics education. This phenomenon may be attributed to the progressive enrichment of the research content, signifying an increasing utilisation of the research as a reference point for instructional design by a growing number of scholars.

Phase 3: Flipped classroom in mathematics education, the rapid growth phase (2020-2023) was characterised by a significant increase in the number of publications and a peak in research on the flipped classroom in mathematics education. The number of publications increased significantly to 29 in 2020 and 2021 and peaked in 2023 with 35 publications. This surge may be attributed to the heightened demand for online education, precipitated by factors such as the transition to online learning in response to epidemics and the gradual recognition of the pedagogical efficacy of the flipped classroom model. Moreover, the primary reason for the flipped classroom's widespread attention is that the reform of mathematics education and teaching has indeed faced numerous difficulties and challenges over the years, despite continuous calls for it. The flipped classroom, leveraging information technology, seeks to transform the conventional teaching paradigm by disrupting the traditional teacher-student relationship, teaching organisation, teaching methodology, teaching evaluation, teaching environment, and other pivotal components of the teaching system. This transformation aims to empower learners, enhancing their initiative and enthusiasm in the learning process.

Consequently, the model is held in high esteem and actively promoted within the mathematics education community. From 444 citations in 2020 to a peak of 738 citations in 2023, the annual citations of published literature during this period exceeded 500 citations. This substantial increase in citations was indicative of a paradigm shift in the academic landscape, signifying a notable rise in the impact of research in this domain. The dissemination of the flipped classroom practice has been widespread, and its research value has been consistently demonstrated. The publication of a significant number of high-quality research results (including empirical studies and systematic reviews) has contributed to the advancement of the field. The increasing number of studies combining the flipped classroom with educational technologies has enhanced the academic appeal of the field.

Phase 4: Stability or slight decline of flipped classrooms in mathematics education (2024), a period characterised by a decline in the number of articles published, which reached 27 in 2024. Despite this decline, the number of articles published remains high, indicating that research in this area continues to be active. The number of research publications on the flipped classroom in mathematics education has undergone a process of exploration, stabilisation, and then rapid

growth, reflecting the evolution of the field from initial interest to extensive research. As research in this area continues to deepen, there is a growing focus on niche areas such as specific teaching methods and learning outcomes, as well as the integration of technology and teaching, including AI and the flipped classroom. The number of citations in 2024 was 703, which was slightly lower than the 738 citations in 2023, but remained at a high level. There was an observable trend of consolidation in the field, with a gradual accumulation of high-quality literature and a stabilisation of citation rates.

To summarise, the number of research publications on the flipped classroom in mathematics education has experienced an overall shift from exploration to stability to rapid growth, reflecting the evolution of the field from initial interest to extensive research. Nevertheless, there has been a decline in the number of publications and citations since 2023. This decline was further corroborated by the findings of a content analysis of 221 papers and a frontier evolution analysis (Figures 5 and 6), which indicated a persistent focus on the same research topics and methods. A notable observation was the preponderance of research focusing on the implementation of the flipped classroom model in university mathematics during the period spanning from 2020 to 2024, with a significant proportion of studies adopting questionnaire or interview-based research methodologies. The pervasive similarity of research content, the high homogeneity of research methods, and the absence of innovation may well be the primary factors contributing to the challenges encountered in the publication of related papers.

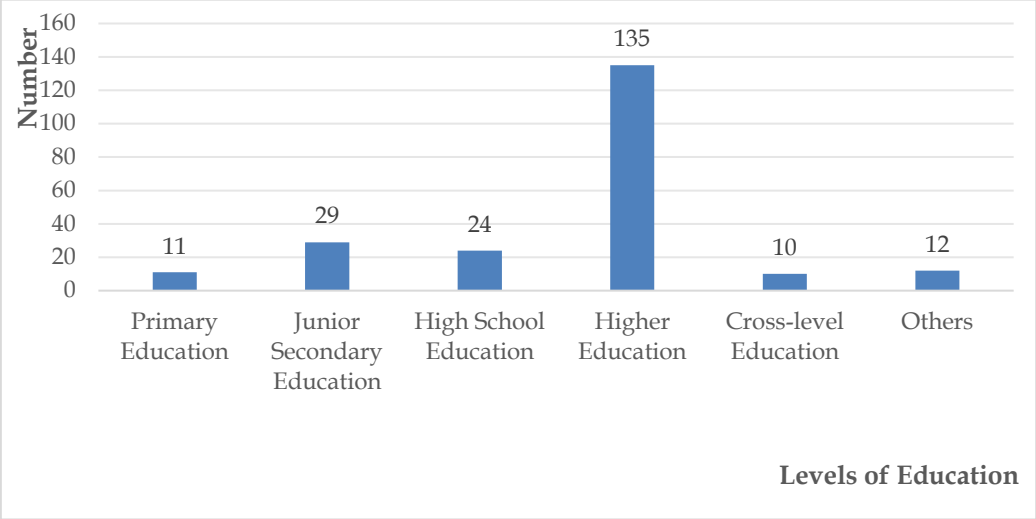


Figure 4: Distribution of studies on flipped classrooms in mathematics at different levels of education

As illustrated by the statistical results presented in Figure 4, higher education teaching reform has led to colleges and universities becoming the primary hub for the implementation of the flipped classroom model in the domain of mathematics education. Among them, research on university mathematics teaching is the most prominent, reflecting the aspiration of university teachers to overcome the limitations of traditional teaching methods through the implementation of flipped classroom teaching reform. In contrast, at the junior and senior high school levels,

although the teaching practice of flipped classrooms has gradually attracted attention, the extant research is comparatively limited. There is a paucity of high-quality studies on flipped classrooms at other levels of education. The primary reasons for this phenomenon can be attributed to two factors. Firstly, university teachers possess greater aptitude, energy and resources for teaching and research in comparison to their counterparts at other levels of education. Secondly, in addition to the necessary human and material resources for implementing the flipped classroom approach, another crucial requirement is that students possess a certain level of independent learning ability. The efficacy of the flipped classroom approach may be hindered in the context of mathematics education if students are too young or have weaker independent learning skills. The promotion of the flipped classroom in the early stages of mathematics education may be hindered by students who are either too young or possess inadequate independent learning skills.

Table 2: Main journal sources of published literature

Literature Source	No.
PRIMUS	22
International Journal of Mathematical Education in Science and Technology	13
Education and Information Technologies	8
Educational Technology and Society	7
Sustainability (Switzerland)	5
International Journal of Information and Education Technology	4
ZDM - Mathematics Education	4
Interactive Learning Environments	4
Technology, Knowledge and Learning	4
Eurasia Journal of Mathematics, Science and Technology Education	4
Mathematics	4

As demonstrated in Table 2, *PRIMUS* is the journal with the most publications in the area of teaching mathematics in the flipped classroom, with a total of 22 relevant documents. This finding underscores the journal's substantial scholarly impact within the field. The journal's dedication to exploring issues, resources and innovative practices in undergraduate mathematics education is evident in its extensive coverage of a range of areas, including curriculum design, teaching strategies, assessment methods and technological applications. The journal's emphasis on the practicality and innovativeness of teaching methods is noteworthy, particularly in the context of the flipped classroom approach, which is widely adopted in university-level mathematics education. Furthermore, the *International Journal of Mathematical Education in Science and Technology* and *Education and Information Technologies* closely follow with 13 and 8 articles, respectively, also in the research area of mathematics education and IT-supported teaching and learning.

3.2 Analysis of Hot Topics and Frontier Evolution

3.2.1 Analysis of hot topics

In bibliometrics, the term "hot topic" is employed to denote a set of literature focusing on a specific issue within a given period. The term "high-frequency keywords" is used to represent hot topics in a specific field within a given period. It is generally accepted that the higher the frequency, the more attention a topic receives, i.e. the more attention it is the focus of in that field (Chen, 2006).

Keyword clustering analysis is predicated on keyword co-occurrence analysis, in which high-frequency keywords are divided into different class groups according to their distance from each other, with each class group representing a research subfield. However, due to individual differences in expression, the phenomenon of multiple words in one meaning may occur, which has a detrimental effect on the accuracy of the co-occurrence mapping. To address this challenge, the keywords of all documents in CiteSpace are initially standardised. For instance, "flipped learning", "flipped instruction", "flipped classroom model" are standardised as "flipped classroom", and "interactive learning environments" are standardised as "interactive learning environment". Subsequently, CiteSpace v.6.4.R1 software was utilised for the analysis, with the node type designated as keywords, and the three sets of parameters c, cc, and ccv of the threshold set at 1, 1, 20; 2, 2, 20; 2, 2, 20. The LLR algorithm was selected to generate the keyword clustering network maps (Figure 5), as well as the top sixteen keywords with high emergent values (Figure 6). This process has been demonstrated to enhance the precision of keyword co-occurrence analysis, thereby providing a more robust foundation for the delineation of research subfields and the subsequent analysis of hotspot trends.

As illustrated in Figure 5, the eleven most prevalent clusters are listed in descending order according to their size, and are categorised as follows: "flipped instruction", "problem types", "qualitative research", "higher education", "active learning", "teaching/learning strategies", "accuracy", "blended learning", "training of personnel", "mathematics education", "directed numbers", the average profile of the generated plots has S value=0.9726>0.5 and ModularityQ=0.8782>0.3. In general, S>0.3 means that the delineated association structure is significant (Chen, 2016). As a result, the knowledge clustering map involved in this study is significant and reasonable. The following clustering labels also demonstrated the subjects of greatest interest in the field of research on the flipped classroom from 2013 to 2024. These subjects of interest were further delineated in the following list, which also included the year in which each subject first appeared in the field of research on the flipped classroom (Figure 6).

Considering the overlapping nature of the clusters, a content analysis of the literature allowed the eleven key topics to be categorised into four main groups: The first group comprised three sub-clusters (#0 flipped instruction, #7 blended learning, #5 teaching/learning strategies). This category focused on the design and application of innovative teaching models such as flipped classrooms and blended learning, as well as research on teaching strategies (Johnston, 2017; Mohamed & Lamia, 2018; Sahin et al., 2015). The second group included two sub-

clusters (#6 accuracy, #1 problem types). This category emphasised the detailed analysis and evaluation of students' learning performance, encompassing research on problem-solving types and learning accuracy (Mattis, 2015). The third group consisted of three sub-clusters (#2 qualitative research, #3 higher education, #8 training of personnel). This group primarily explored the application of educational research methods (e.g., qualitative research), practices within the context of higher education, and studies on teacher training and professional development (Kiem & Keodavan, 2024; Li et al., 2016; Wong et al., 2024). The fourth group included three sub-clusters (#9 mathematics education, #10 directed numbers, #4 active learning). This category focused on mathematics education, highlighting core issues in subject-specific pedagogy and research on enhancing classroom engagement and learning outcomes through active learning approaches (Hwang & Lai, 2017; Tawfik & Lilly, 2015; Yohannes & Chen, 2024).

In summary, research on the flipped classroom included the theory and application of teaching models, the assessment of student learning outcomes, the application of educational research methods, and teacher development. The research focused not only on the design and practice of the flipped classroom and blended learning, but also on student learning outcomes, types and accuracy of problem solving, and on the study of teaching methods and teacher training in higher education. The extant literature demonstrated that flipped classrooms had significant value in improving teaching effectiveness and student engagement and provided theoretical support for innovation in educational models.

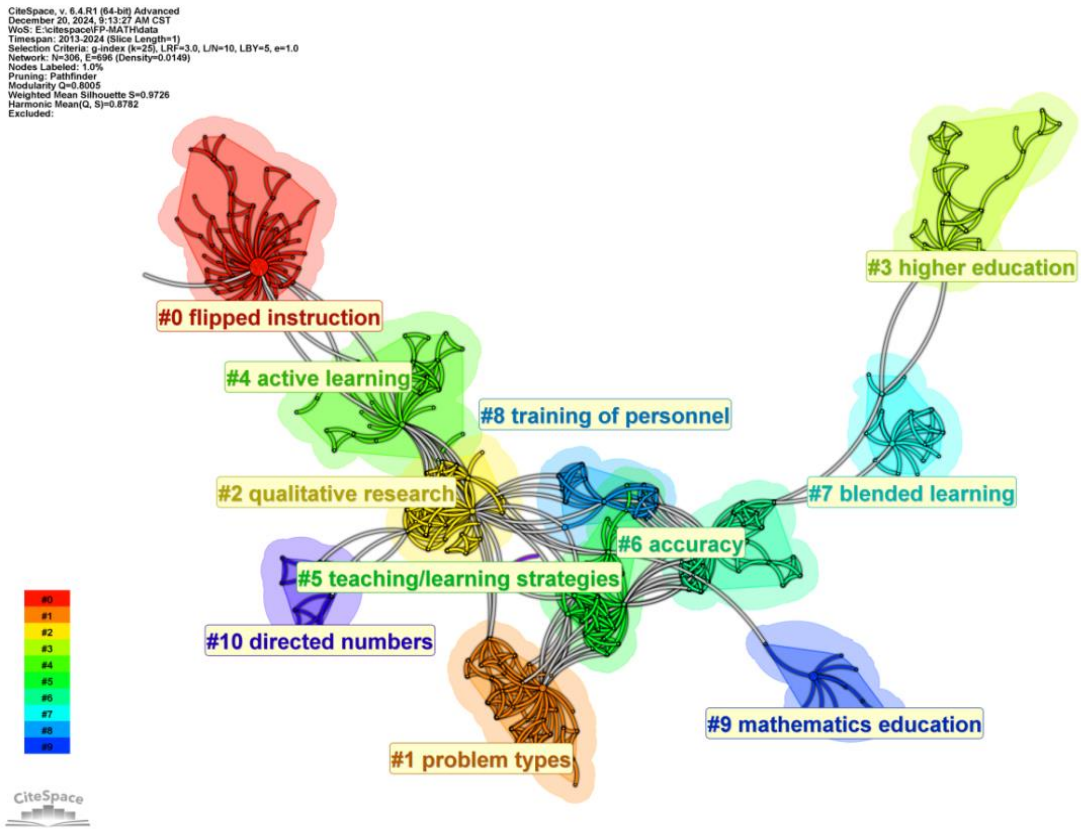
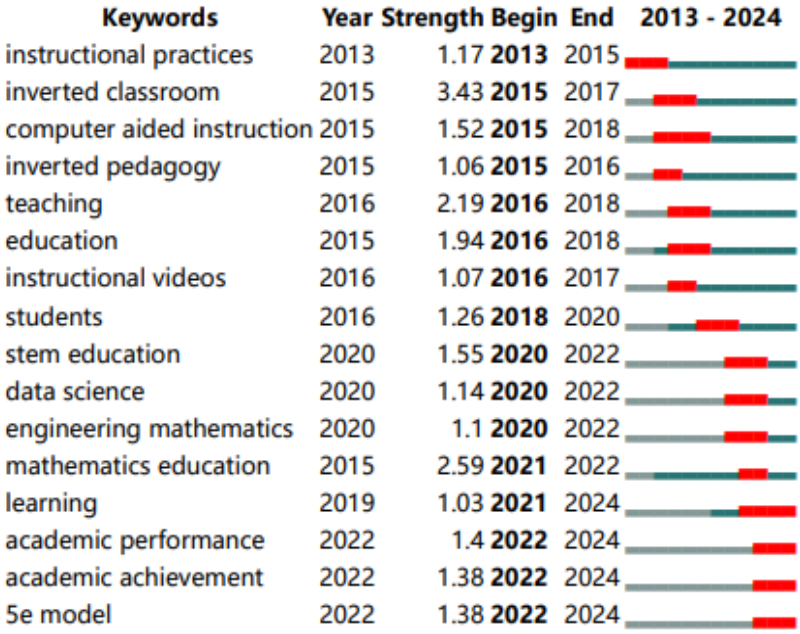


Figure 5: Hot topics in flipped classroom research in mathematics education

3.2.2 Evolutionary analysis of frontiers

A research frontier is defined as a specific question being explored by a set of intrinsically related keywords or literature, based on knowledge of emergent words or emergent literature within a given period (Chen, 2016). The identification and tracking of emergent words or emergent literature facilitates an understanding of the evolutionary dynamics of a particular field at different stages, the prediction of development trends, and the identification of further issues to be explored. Figure 6 illustrates the top 16 keywords with high emergence values from 2013 to 2024.



Keywords	Year	Strength	Begin	End	2013 - 2024
instructional practices	2013	1.17	2013	2015	
inverted classroom	2015	3.43	2015	2017	
computer aided instruction	2015	1.52	2015	2018	
inverted pedagogy	2015	1.06	2015	2016	
teaching	2016	2.19	2016	2018	
education	2015	1.94	2016	2018	
instructional videos	2016	1.07	2016	2017	
students	2016	1.26	2018	2020	
stem education	2020	1.55	2020	2022	
data science	2020	1.14	2020	2022	
engineering mathematics	2020	1.1	2020	2022	
mathematics education	2015	2.59	2021	2022	
learning	2019	1.03	2021	2024	
academic performance	2022	1.4	2022	2024	
academic achievement	2022	1.38	2022	2024	
5e model	2022	1.38	2022	2024	

Figure 6: Top 16 keywords with high sudden present value, 2013-2024

As illustrated by the beginning and end of the emergence of keywords with high emergence value in Figure 6, the evolution of hot topics can be roughly divided into three stages: early, middle and late.

In the early phase, from 2013 to 2016, the keywords "inverted pedagogy", "computer aided instruction" and "teaching" were more frequently cited. When combined with the content analysis method, it was evident that the literature of this period primarily focused on the theoretical development of the flipped classroom, the introduction of the concept and its integration with technology, and the innovation of teaching methods and the transformation of the educational model. The pedagogical concept of the flipped classroom was gradually being incorporated into the study of teaching methods, with an emphasis on improving learning efficiency through innovative teaching methods (Guerrero et al., 2015; Naccarato & Karakok, 2015; Wilson, 2013).

The middle phase was dominated by the years 2017 to 2020, with the most frequently co-cited theme words being "students", "STEM education", "data science", "engineering mathematics" and "instructional videos". This phase of

research saw an expansion into STEM fields, with the integration of flipped classrooms with professional disciplines and technologies, with a focus on student learning outcomes and engagement (Johnston, 2017; Weinhandl et al., 2020). Compared to the early years, research on the flipped classroom has gradually moved from initial implementation and exploration to a phase of broader application and disciplinary expansion of flipped classroom research (Weinhandl et al., 2020).

In the subsequent phase, spanning from 2021 to 2024, the terms "learning", "academic performance", "academic achievement", and "5e model" emerged as the most frequently cited keywords, signifying a heightened level of interest in these domains during the recent years. The terms "achievement" and "5E model" have also attained the highest frequency of citations, underscoring their relevance and interest in recent times. Research at this stage focused on evaluating the actual effectiveness of the flipped classroom, particularly its impact on students' academic achievement, while combining it with other pedagogical frameworks such as the 5E model to promote the deeper application of the flipped classroom (Demir et al., 2023; Fung et al., 2024; Schallert et al., 2022). Furthermore, the intensity and duration of the emergence of the four keywords indicated their probable continued status as the primary subjects of research in the field of the flipped classroom in forthcoming years.

The three phases of the evolution of the hot topics shown in Figure 6 are complemented by the results of the cluster analysis of the hot topics shown in Figure 5, which demonstrates the pattern of research on the flipped classroom in mathematics education. These stages demonstrate the gradual development of the flipped classroom model in mathematics education from theoretical research to applied practice to effective evaluation, covering research progress at multiple levels, including teaching methodology, student learning, disciplinary innovations, and academic performance. The utilisation of contemporary information technology, namely the flipped classroom, which has become the prevailing form of blended teaching, effectively circumvents the constraints on time and space imposed by traditional teaching methods. It seamlessly integrates the benefits of online and offline teaching, exhibiting a rapid growth trajectory. It is anticipated that this approach will evolve into the prevailing educational paradigm in the future.

3.3 Statistics and Analysis of Research Methods in Related Literature

The paradigm of flipped classroom research in mathematics education can be broadly categorised into two distinct groups: non-empirical and empirical studies. This categorisation is based on the research methodological framework proposed by Dan (2017), which centres on distinguishing between the sources of research data and the way they are analysed. Specifically, non-empirical research relies chiefly on theories and literature to define, cite, interpret and reflect (Wilson, 2013), while empirical research is conducted by researchers through independent collection of data to formulate or test theoretical hypotheses, and is characterised by distinctive direct experience. Empirical research methodologies encompass a wide range of approaches, including quantitative methods (e.g., experiments,

questionnaires, etc.), qualitative methods (e.g., observations, case studies, interviews, etc.), and mixed research methods (Egara & Mosimege, 2024).

Table 3: Classification statistics of research methods in related literature

Research Paradigm	No.	Research Method	No.	Percentage	Example
Empirical Research	201	Quantitative Research Method	94	42.53%	Egara & Mosimege (2024) Menino et al. (2024)
		Qualitative Research Method	31	14.03%	Fredriksen (2021) Toivola et al. (2023)
		Mixed Research Method	76	34.39%	Ali et al. (2022) Cortez et al. (2023)
Non-Empirical Research	20	Literature Method	3	1.36%	Díaz Palencia (2024)
		Case Study Method	3	1.36%	Yang et al. (2019)
		Review Method	13	5.88%	Lo & Hew (2021) Cevikbas & Kaiser (2023)
		Comparative Research Method	1	0.45%	Abbasian & Sieben (2016)

As demonstrated in Table 3, the majority of the 20 non-empirical research documents employ the literature method, case study method, review method and comparative research method. The literature method is primarily employed to introduce the origin of the flipped classroom, define its core concepts, and elaborate on its theoretical basis, teaching mode, and teaching characteristics (3 articles). Furthermore, the teaching effect and problems of the flipped classroom are analysed based on specific cases (3 articles). The synthesis method comprehensively reviews the relevant research findings and analyses the research status and development trend (13 articles). The comparative research method focuses on comparing the use of different teaching platforms in flipped classroom design. By comparing the characteristics of different platforms, the optimal design solution is explored (1 article).

A total of 94 of the 201 empirical research papers employed quantitative analysis methods, primarily utilising pre-test-post-test experimental methods to investigate the effects of the flipped classroom on learning achievement, student engagement, self-efficacy, problem-solving ability, and other variables. Conversely, 31 papers employed qualitative analysis methods, primarily through interviews or observation methods, to describe the students' learning behaviours following the implementation of the flipped classroom, and learning attitudes. The remaining 76 articles adopted a mixed research method, in which the researchers usually choose two or more of the pre-test-post-test experimental methods, questionnaires, interviews, reflective journals, observation methods, and case study analyses. This indicated that most researchers adopted the triangulation method to conduct a multidimensional investigation, which

improved the reliability and validity of the research results, and the probability of the paper being published was increased accordingly.

3.3.1 Statistics and analysis of research content

Table 4: Classification statistics of research content in related literature

Research Paradigm	No.	Research Content	No.	Percentage	Example
Empirical Research	201	Student Feedback	153	69.23%	Love et al. (2014) Wei et al. (2020)
		Teacher Feedback	13	5.88%	Naccarato & Karakok (2015) de Araujo et al. (2017)
		Expert Feedback	3	1.36%	Weinhandl et al. (2020) Kiem & Keodavan (2024)
		Multi-Stakeholder Feedback	32	14.48%	Cevikbas & Kaiser (2022) Yarım et al. (2024)
Non-Empirical Research	20	Introductory Type	3	1.36%	Metpattarahiran (2020)
		Review Type	13	5.88%	Yang et al. (2021) Fung et al. (2021)
		Reflective/ Suggestive Type	4	1.81%	Li et al. (2016)

As illustrated in Table 4, the research content of non-empirical research literature is primarily categorised into three domains: introduction, review and reflective/suggestive. The largest category is that of reviews, which are distinguished by the absence of direct engagement with flipped classroom teaching on the part of the researcher. This category is also notable for the absence of practical experience and first-hand data. The papers in this category are characterised by a systematic collation and analysis of existing studies, with the aim of providing a comprehensive overview of the current status of research on a specific topic, including its problems and future directions. It is distinguished by its systematic analysis of the discrepancies, points of contention, or gaps between existing studies, offering critical insights to guide the implementation of the flipped classroom. In contradistinction to the other two types of articles, review articles are more likely to have practical guidance and reference value and therefore have a relatively higher likelihood of being published.

Empirical research literature can be categorised into four distinct classifications according to the specific research topics: firstly, student feedback surveys, for example, students' satisfaction or opinions on online resources, the flipped classroom teaching model, and the teaching environment, or surveys on the impact of the flipped classroom teaching model on academic performance, learning strategies, ability development, and affective attitudes. Secondly, teacher

feedback surveys, such as teachers' evaluation of the flipped classroom teaching mode, teaching environment, or surveys on teachers' instructional design, discourse strategies, assessment literacy, etc. Thirdly, expert feedback surveys focused on examining how various factors, such as teacher characteristics, instructional practices, and learning activities, contribute to the development and implementation of flipped classroom pedagogy, particularly for professional mathematics or STEM educators. In addition, the experts explored the forms of STEM integration, assessment methods, teaching resources and the design of pre- and in-class teaching activities. Fourthly, the multi-subject feedback survey, which included teachers, pupils, parents and experts, was conducted. A survey of the extant literature revealed that empirical studies with student feedback or multi-subject feedback dominated, and the number of studies investigating teacher feedback and expert feedback was low. This finding provided a direction for future research on flipped classrooms. While students are the primary focus in flipped classrooms, the success of this implementation is contingent on teachers' and experts' pedagogical concepts, teaching attitudes, teaching skills, and information technology literacy, among other factors. Consequently, there is an urgent need to enhance research in this area.

3.4 Effectiveness of Flipped Classroom Implementation

The present study was an examination of the effects of implementing the flipped classroom, with a focus on the extant empirical research literature. As previously discussed in the analysis of journal sources and publication trends, the number of empirical studies in this field has increased steadily, reflecting growing scholarly interest. Of the 201 empirical studies analysed, the majority of the literature discussed the positive effects of the flipped classroom on mathematics education. For instance, it has been demonstrated that the flipped classroom optimises learning resources to varying degrees, improves learning efficiency, facilitates academic achievement, deepens understanding of knowledge, improves students' attitudes towards learning, stimulates interest in learning, and improves students' cognitive and affective interactions. Furthermore, the flipped classroom has been found to contribute to the development of students' autonomy and integrative skills (Hiwarekar, 2023; Jeong & González-Gómez, 2022). From an educator's perspective, the implementation of the flipped classroom model has the potential to alleviate a portion of the repetitive workload, thereby allowing for more efficient utilisation of classroom time in cultivating students' higher-order skills (Yarım et al., 2024).

Despite the numerous advantages of the flipped classroom model in mathematics education, several studies have highlighted challenges associated with its implementation. For example, the effectiveness of the flipped classroom is often limited by students' self-discipline, language proficiency, and independent learning skills, potentially leading to a polarisation of academic performance (Awi et al., 2024). Moreover, the student-centred nature of the flipped classroom frequently requires students to engage in open verbal communication during class, which may impose significant psychological pressure on low-achieving students. These students often exhibit higher levels of anxiety compared to those in traditional classrooms (Kreis et al., 2024).

A further notable challenge concerned the heavy reliance on technology inherent in the flipped classroom approach. In regions with unstable internet connections and limited bandwidth, students faced considerable difficulties in accessing online materials and streaming lecture videos. Inadequate internet infrastructure in these areas has been shown to hinder effective participation, thereby compromising students' learning experiences and equitable access to educational resources (Mazana et al., 2024). In addition, the flipped classroom model imposed greater demands on teachers. Compared to traditional teaching methods, teachers must devote substantially more time and effort to tasks such as creating instructional videos, offering personalised guidance, and conducting formative assessments. This instructional model also sets higher expectations for teachers' competencies in instructional design, technological literacy, role adaptability, and classroom assessment (Cevikbas & Kaiser, 2020).

Although a substantial body of research has reported positive effects of the flipped classroom model on both students and teachers, these findings should be interpreted with caution. Most studies have employed short implementation periods−typically ranging from several weeks to a single academic semester−and have been conducted on a relatively small scale, often involving only a limited number of students within a single course (Song & Kapur, 2017). As such, the broader applicability and long-term effects of the flipped classroom approach remain underexplored and warrant further investigation.

4. Conclusion

In recent years, research on flipped classrooms in mathematics education has witnessed substantial progress. This body of work has predominantly focused on the reform of university mathematics teaching methods, evolving through three distinct stages. The initial stage involved the introduction of core concepts, theoretical foundations, and the exploration of its feasibility in the context of mathematics education. In the subsequent phase, the focus shifted towards practical application, exploring how flipped classrooms could be implemented effectively. The final stage has concentrated on evaluating the outcomes and impact of flipped classroom implementation. While the volume of research has fluctuated, it generally showed an upward trend, indicating growing interest in this pedagogical model.

From a methodological perspective, the majority of studies in this field were empirical, predominantly using quantitative research methods. In contrast, non-empirical research was largely centered around review-based approaches, summarizing and synthesizing existing findings. The content of non-empirical studies primarily fell into three categories: introductory, review, and reflective/suggestive. Among these, review articles constituted the majority. Empirical studies, on the other hand, mainly focused on the impact of flipped classrooms on students' academic performance, emotional attitudes, and feedback. However, there was a notable lack of studies examining the perspectives of teachers and educational experts, indicating an area for future exploration.

The findings of the majority of empirical studies indicated that flipped classroom models had a positive impact on various aspects of teaching and learning. However, some studies also highlighted challenges in the implementation of this model, suggesting areas that require further attention.

5. Recommendations

Future development of the flipped classroom in mathematics education should focus on three key areas.

Firstly, broadening the research scope and methodological approaches. Although the body of literature on flipped mathematics classrooms has grown steadily, it remains limited by repetitive themes and methodological uniformity, with a predominant reliance on short-term, quantitative studies focusing mainly on students. Future research should adopt a more comprehensive and differentiated approach by exploring the long-term effectiveness of flipped instruction, examining the influence of individual learner characteristics (such as learning styles, self-regulation skills, and gender) on engagement and outcomes, and assessing the comparative value of online versus offline teacher-student interactions. Incorporating longitudinal, mixed-methods, and cross-cultural studies will offer more robust empirical foundations and guide evidence-based, context-sensitive implementation strategies.

Secondly, developing comprehensive and culturally responsive evaluation frameworks. Given the pedagogical shift that flipped classrooms represent, a standardized and multidimensional evaluation system is urgently needed. While frameworks such as the Commonwealth of Learning's quality assurance rubric for blended learning (2020) provide a reference point, there is a lack of models tailored specifically to the flipped learning environment. Future evaluation systems should account for the distinctive features of flipped instruction, such as pre-class preparation, student autonomy, and interactive learning spaces, while remaining adaptable to varied educational and cultural contexts. Such frameworks would facilitate the measurement of both cognitive and affective learning outcomes and promote continuous instructional improvement.

Thirdly, strengthening teachers' professional capacities in flipped contexts. As the findings suggest, the effectiveness of flipped classrooms is strongly mediated by teachers' ability to design, implement, and manage this pedagogical approach. Yet, limited research attention has been devoted to understanding and supporting teacher development in this area. Future work should explore the specific competencies required for flipped instruction, including digital literacy, instructional design, formative assessment, classroom facilitation, and cultural responsiveness, and examine professional development models that effectively cultivate these skills. Equipping educators with the necessary tools and support will be essential to ensuring the long-term sustainability and scalability of flipped mathematics education.

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