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Research Trends of Flipped Classroom Model in Mathematics Education: A Bibliometric Mapping Analysis

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Abstract

The COVID-19 pandemic has expedited the integration of technology into instructional practices through the transition to emergency distance education. The flipped classroom has emerged as a prominent approach among the notable models in this process. The flipped classroom leverages technological opportunities to enhance productivity by shifting the teacher's role from in-person explanations to facilitating individualized learning outside the classroom. CiteSpace, VOSviewer, and R Bibliometrix are three knowledge graph software tools used in this work to carefully look over, evaluate, and diversify the selected data, drawing on previous research on the subject. By querying the Web of Science database, 226 articles on the flipped classroom model in mathematics education were accessed. Performance analysis, science mapping, and network analysis were performed on the obtained articles. The earliest publications on this subject date back to 2014, and the number of publications has grown steadily. Lo is the author who ranks first in productivity due to his most publications on flipped classrooms in mathematics education. The countries that show the most interest in flipped classroom in mathematics education and have publications on this subject are the USA, China, and Spain. In addition, international co-authorship results of 21.7% of the publications were reached. Also, future research implications based on the findings were discussed.

Keywords: Bibliometric analysis, educational technology, flipped classroom, mathematics education

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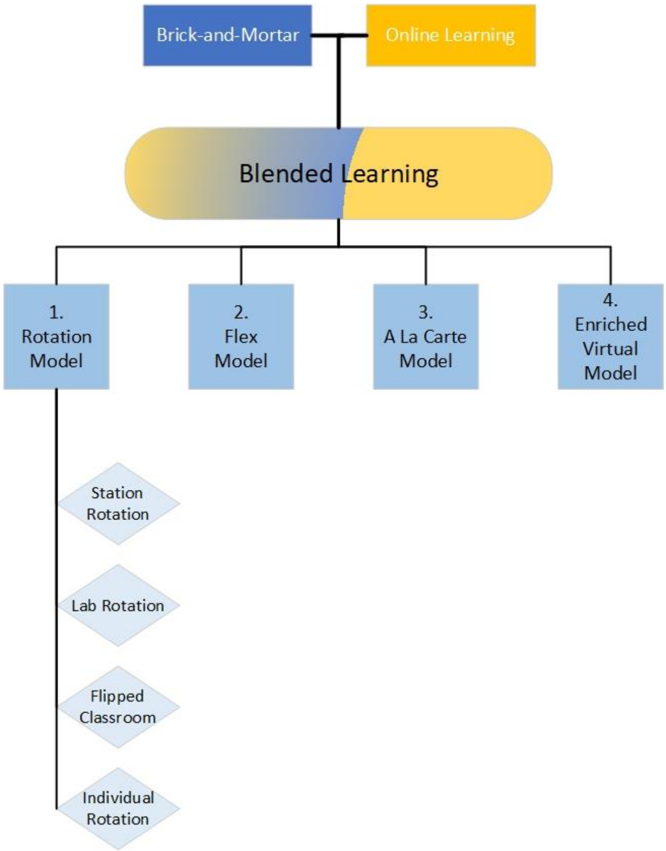
Introduction

Mathematics is an essential tool applicable across various facets of life, facilitating the development of systematic and logical thought processes (Bulut, 1988). Proficiency in mathematical thinking equips individuals with the capacity to address problems effectively. As the prevalence of artificial intelligence and machine learning grows, the demand for mathematical knowledge intensifies. To ensure the efficacy of mathematics education in the 21st century, it is imperative to confront the impediments hindering student learning. A pivotal strategy involves shifting away from conventional pedagogical methods (Civil & Bernier, 2006; Contreras, 2014; Foster, 2013). Instead of relying solely on traditional instructional approaches, we should harness contemporary resources, including diverse pedagogical methods, techniques, tools, games, and activities (Sinclair et al., 2010). Research has demonstrated that the integration of information technologies in the classroom setting enhances educational efficiency, diminishes financial burdens, elevates the quality of learning environments, and fosters enhanced student comprehension (Hill & Solent, 1999; Heterick, 1993; Menges, 1994; Oblinger & Maruyama, 1996). Given that conventional methods are often insufficient to address the complexities of educational challenges, one of the most efficacious strategies today is to leverage the opportunities presented by information technologies (Artigue, 2002; Drijvers et al., 2010; Geiger et al., 2010; Olive et al., 2010).

Blended learning is a structured framework that affords educational opportunities to a diverse range of learners across various domains. It is characterized not by introducing new theses and antitheses but rather by a quest to enhance the quality of the learning-teaching process. This framework addresses the burgeoning temporal demands imposed by learner-centered methodologies while also creating environments conducive to research, experimentation, and practical application that align with the pedagogical paradigm asserting that 'everyone within the classroom, including the teacher, is a learner.' Effective communication remains integral to this endeavor. In the development of blended learning programs, educational institutions endeavor to devise models that best suit their specific contexts, considering factors such as content, learners, available instructional technologies, human resources, and the perspectives of educators. Horn and Staker (2015), in their research predominantly focused on K-12 educational settings, have categorized blended learning models into four distinct groups (see Figure 1).

Figure 1

Blended Learning Models (K12) (Horn & Staker, 2015, p. 38)



The Flipped Classroom, a constituent model within the rotation model category, stands as one of the most significant advancements in blended learning methodologies, as noted by Johnson et al. (2014). Initially conceptualized by Baker (2000), the flipped classroom model, also known by various synonymous appellations, such as the "Inverted Classroom," "Reverse Teaching," "Backwards Classroom," "Flipped Instruction," and "Flipped Learning" (Baker, 2000; Bates & Galloway, 2012; Bergmann & Sams, 2012; Brown, 2012; Butt, 2014; Dove, 2013; Lage et al., 2000; Talbert, 2012), was designed to enhance collaborative engagement within the classroom environment. Bergmann and Sams (2014) advocate for "flipped learning" as it underscores the significance of utilizing in-class time for active and participatory learning experiences. In scholarly discourse, the terms "flipped classroom" and "flipped learning" are often used interchangeably (Estes et al., 2014; Hwang et al., 2015).

The Flipped Classroom model capitalizes on technological capabilities to relocate the dissemination of instructional content to learners' individual spaces outside the physical classroom. Within this model, the in-class time is dedicated to the remediation of identified educational deficits (Chen et al., 2015; Ojennus, 2016; Dove & Dove, 2015; Van Vliet et al., 2015), engagement in higher-order thinking and skill-based activities, the tracking of learners' progress, and the facilitation of learning experiences (Bergmann & Sams, 2015; Bishop & Vergler, 2013; Effield, 2013; Gaughan, 2014; Moroney, 2013). The Flipped Classroom Model, which harmonizes the principles of constructivism with technological integration, offers a robust pedagogical alternative (Baker, 2000; Bergmann & Sams, 2012; Lage et al., 2000; Özdemir & Şentürk, 2021; Talbert, 2012).

Although extensive research has been dedicated to comprehending the flipped classroom model in mathematics education over several decades, our knowledge regarding past and present research trends in this domain remains limited. Exploring historical and contemporary research trends in mathematics education, specifically focusing on the flipped classroom model, has yet to encompass comprehensive examinations of publications, influential journals, geographic regions, academic institutions, prolific authors, and academic networks. Therefore, it becomes essential to assess the current state and evolution of research related to the flipped classroom model in mathematics education. This assessment will shed light on emerging trends and research areas progressively gaining prominence.

To bridge the existing gaps in academic literature, this study employs a bibliometric analysis of research related to the flipped classroom model within the domain of mathematics education. By using bibliometric methodologies, this research endeavors to statistically model the nature and trajectory of scientific communication within research studies, chiefly by examining citations and the references cited within scholarly works (Liao et al., 2018). Bibliometric analysis serves as an invaluable tool for unearthing various insights into the dynamics of scientific communication (Al, 2012; Al & Coştur, 2007; Barca & Hızıroğlu, 2009; Sengupta, 1992). This approach involves a quantitative investigation into specific attributes of academic publications, including elements such as authorship, subject matter, citation patterns, geographic origins, affiliations, and referenced sources. The primary aim of bibliometric analysis is to unveil recurring publication patterns within a specific academic field or body of literature, discern the influence of individual authors on the subject matter, and illuminate collaborative efforts among authors (Abdi et al., 2018; Jain et al., 2015; Koehler, 2001).

Moreover, bibliometrics presents the distinct advantage of efficiently aggregating and processing extensive volumes of information, thus facilitating the systematic dissemination of knowledge and the identification of trends and gaps within a specific field through rigorous quantitative analysis of the scholarly corpus (Borgman, 1999; Hassan & Haddawy, 2015; Hood & Wilson, 2001; Noyons et al., 1999; Payumo & Sutton, 2015; Tsay, 2011; van Leeuwen, 2004). A noticeable void exists in the literature when considering the absence of comprehensive bibliometric examinations encompassing the entirety of relevant research contributions linking the flipped classroom model with mathematics education. Conducting a global-scale bibliometric analysis of studies focused on implementing the flipped classroom model within mathematics education is of paramount significance. This undertaking will serve to rectify this gap in literature, offering valuable guidance to researchers and educators as they engage in further scientific dialogues and investigations. Hence, the present study's application of bibliometric analysis serves as a substantial contribution to the academic discourse, offering critical insights into the current state of the field, emerging trends, influential authors, significant publications, and other pertinent dimensions.

This research employs mapping techniques and bibliometric data analysis to examine articles related to flipped learning in mathematics education published in the Web of Science (WoS) database from 2014 to 2023. In alignment with the core objectives of this study, the following questions were pursued:

- Regarding the implementation of the flipped classroom model in mathematics education, what is the distribution of publications across different years?
- In the field of flipped classroom in mathematics education, which authors have the highest number of publications?

• Among the authors contributing to the research on flipped classroom in mathematics education, which institutions do the most prolific authors belong to?
• Which countries have the highest number of publications and collaborations in the realm of flipped classroom in mathematics education?
• What are the most frequently cited publications in the field of flipped classroom in mathematics education?
• How well do the bibliographic references of publications on flipped classroom in mathematics education align with each other?
• According to Bradford's Law, which journals should researchers interested in publishing their work on flipped classroom in mathematics education consider reviewing?
• What are the trending terms associated with flipped classroom in mathematics education?

Method

Research Design

This survey-based descriptive study (Frankel & Wallen, 2006) employed a bibliometric analysis approach to examine scientific publications in the field of flipped classroom in mathematics education. The aim was to investigate bibliometric parameters and unveil the current state of research. Bibliometric analysis is defined as the quantitative examination of a body of literature based on its bibliographic characteristics (Hawkins, 2001). In bibliometric studies, the literature is evaluated using specific criteria, and quantitative analysis and statistics are employed to uncover publication patterns (Agarwal et al., 2016; Donthu et al., 2021; Gravetter & Forzona, 2018). Bibliometric studies have gained significant popularity recently as they provide crucial data for identifying emerging research trends (Chuang et al., 2011).

Data Source and Search Strategy

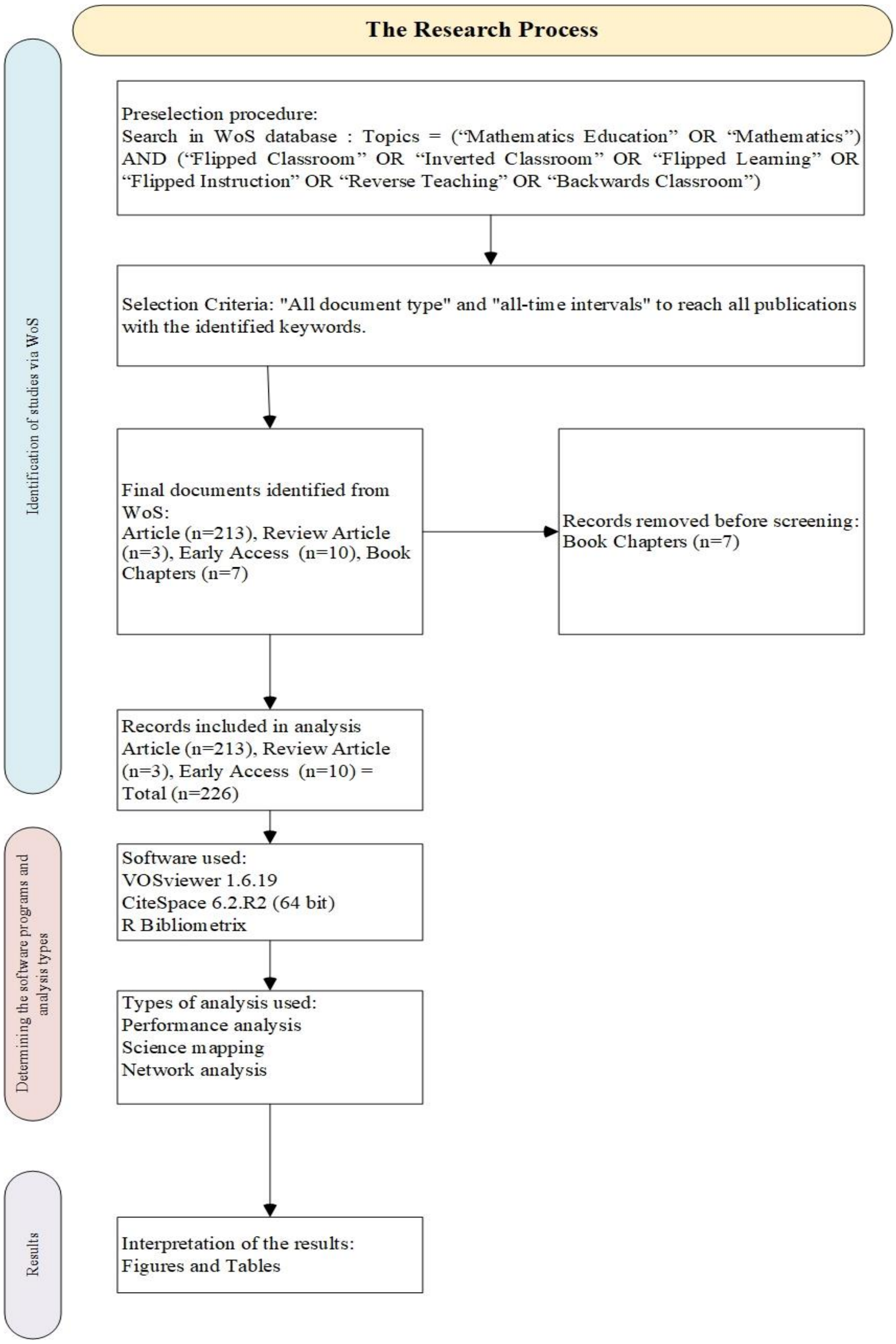
The research data were collected from the Web of Science Core Collection (WoS) databases, including SSCI, SCI-Expanded, and ESCI. WoS, developed by the "Thomson Reuters Institute of Scientific Information" (ISI) in the early 1960s, has long been recognized as a comprehensive database facilitating citation tracking and analysis. It offers reliable coverage of both citation data and bibliographic information (Adriaanse & Rensleigh, 2001; Garcia et al., 2017; Merigo et al., 2015; Silva et al., 2018).

Data Collection

The keywords "Mathematics Education OR Mathematics" and "Flipped Classroom OR Inverted Classroom OR Flipped Learning OR Reverse Teaching OR Backwards Classroom OR Flipped Instruction" and the "OR, AND" operators were used to search for data across all databases within the Web of Science (WoS). The search criteria included "all records" and "all-time intervals" to retrieve all relevant publications. On May 17, 2023, two different researchers accessed the WoS database to collect the data. Each publication was assigned a code of either "S" (Suitable) or "NS" (Not Suitable) based on its relevance to the study. The inter-coder agreement was calculated using the formula 'number of agreements between coders / (number of agreements + number of disagreements between coders) x 100' (Houten and Hall, 2001), resulting in 100% agreement between the two researchers. As a next step, a thesaurus file was compiled to identify any repeated entries. This research covered author names, which were compiled into a single file. The output showed that there were no author names or institutions in common. Consequently, a total of 226 articles related to the flipped classroom in mathematics education, published between 2014 and 2023, were identified. The obtained data file was prepared for analysis, considering the specific requirements of bibliometric analysis and research. The research process is depicted in Figure 2.

Figure 2

Research Process



Analysis of Data

This study used bibliometric research methods, including co-authorship, citation, co-citation, and co-occurrence analysis of keywords and hot topics of terms. The bibliometric data were visualized using three software programs: R Bibliometrix, CiteSpace, and VOS-viewer.

Bibliometrix is a package program for bibliometric analysis developed in 2017 by Massimo Aria and Corrado Cuccurullo (Aria & Cuccurullo, 2017). It is a flexible tool that provides quantitative information about scientific trends related to a field of study. Bibliometrix is written in R, which makes it a powerful and versatile tool for statistical analysis (Aria and Cuccurullo, 2017; Gandrud, 2013).

CiteSpace is a complementary tool that helps scholars understand the status and dynamics of a knowledge domain. It facilitates qualitative and quantitative research by implementing cluster views and time zone views using Kleinberg's burst detection algorithm and Freeman's betweenness centrality metric (Kleinberg, 2003; Freeman, 1979). CiteSpace has been proven to be advantageous in detecting and visualizing emerging trends and sudden changes in a specific field (Chen, 2006). Therefore, combining bibliometric mapping tools and quantitative analysis can lead to comprehensive and effective conclusions.

In the third step, we used VOSviewer software version 1.6.19 to generate clustered bibliometric networks visually depicting item similarities (van Eck & Waltman,2010). The size of the associated circle in this visualization corresponds to the relevance of an item, while the connections between items are displayed as lines linking them together. The software also facilitated graphical representations of co-authorship, co-citations, and keyword co-occurrence (Small,1973).

Ethical Issues

In this study, research and publication ethics were followed. This research is among the studies that do not require ethics committee approval.

Findings

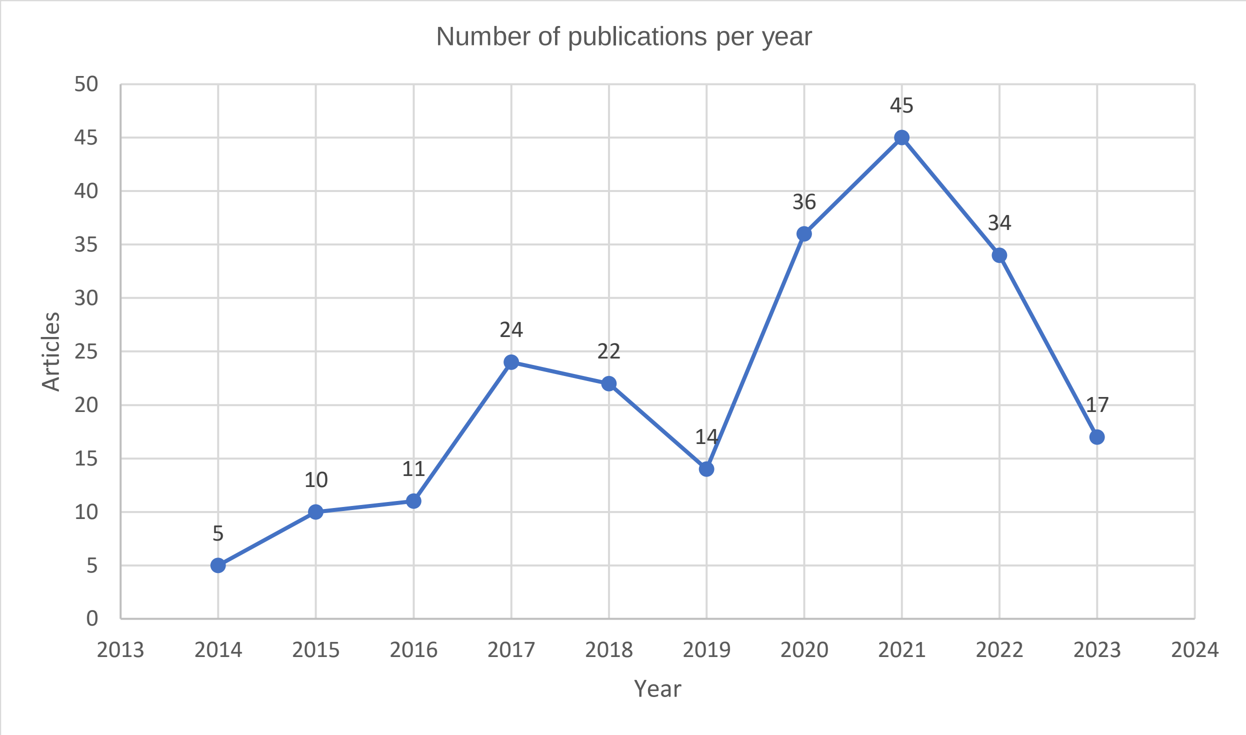
This section of the research presents the findings of studies on flipped classrooms in mathematics education in accordance with the study's sub-purposes.

Findings Regarding the Research Question: Distribution of Publications by Years

Figure 3 illustrates the distribution of academic studies published in WoS over the years. The analysis reveals that the first publication on flipped classrooms in mathematics was documented in 2014. Notably, the years with the highest number of publications in this domain were 2021 (f=45), 2020 (f=36), and 2022 (f=34), as depicted in Figure 3 (Data obtained from R Bibliometrix). The data obtained from the WoS database indicate an Annual Growth Rate of 14.57% for flipped classrooms in mathematics. Considering that the data collection concluded before the end of 2023 and examining the corresponding graph, it is evident that the interest in this research area has experienced a recent surge and continues to follow an upward trajectory.

Figure 3

Annual number of articles published



Findings Related to the Research Question: Top Publishing Authors

The study utilized four performance indicators: total publications (TP), total citations (TC), citations per publication (CPP), and the h-index. CPP is determined by dividing TC by TP. The h-index, developed by Hirsch in 2005, is the final performance indicator employed in this study. It enables the assessment of researchers' scientific publication performance.

The study also considers Price's law as an important factor to be considered. According to Price (1965), the number of articles published in scientific research is an important factor in reflecting the academic activities of the authors. For this reason, analyses were carried out based on Price' law (1965)'s formula in the core author analysis. This formula is expressed as: (M represents the minimum number of papers published by core authors, and Nmax refers to the number of papers published by the author with the largest number of papers in the research period).

Looking at Table 1, Nmax = 9. If we substitute this number in the formula, we get M ≅ 2.247. Thus, the number of articles in the analysis is taken as M = 2. Authors who publish 2 articles or more than in this analysis are core authors.

Considering the large number of authors in this category (n=521), Table 1 presents the top 5 most productive authors (Data obtained from R Bibliometrix). The order of authors in the table is based on TP, with preference given to authors with higher TC in case of the same number of publications. Among the authors who have made significant contributions to the literature on flipped classroom in mathematics, Lo, C. K. stands out as the most prolific author with nine publications and a total of 385 citations. Hew, K.F. follows closely in second place with eight publications (TC=377). Gonzales-Gomez, D. and Jeong, J. S. rank third and fourth, both with eight publications and equal TC of 75. When considering citations per publication

(CPP), the authors with the highest CPP are Hew, K.F. (CPP=47.13), Lo, C. K. (CPP=42.78), Gonzales-Gomez, D. (CPP=9.38), and Jeong, J. S. (CPP=9.38).

Table 1

Top 5 Most Productive Authors

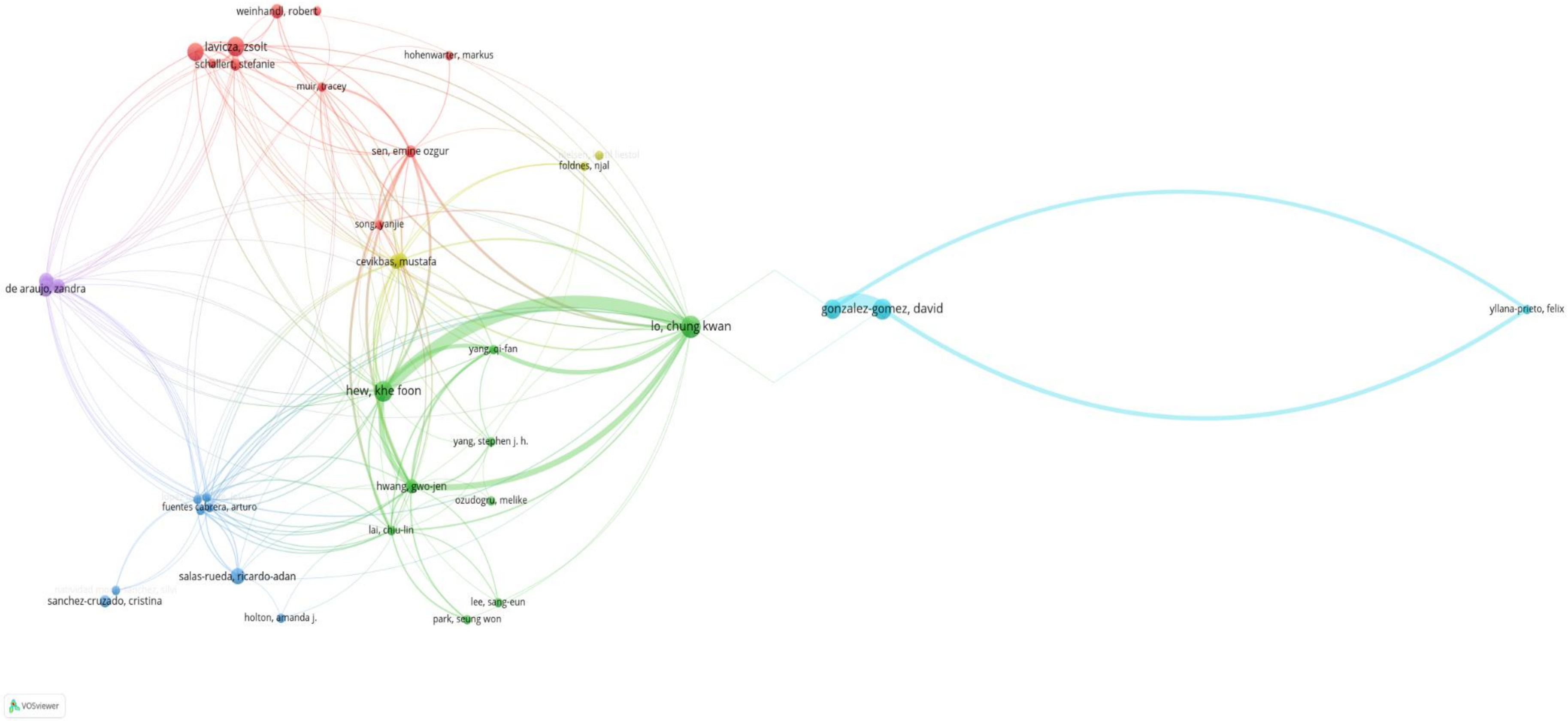
Rank	Authors	TP	TC	CPP	h-index
1	Lo, C. K.	9	385	42.78	8
2	Hew, K.F.	8	377	47.13	7
3	Gonzales-Gomez, D.	8	75	9.38	5
4	Jeong, J. S.	8	75	9.38	5
5	Lavicza, Z.	7	34	4.86	4

Note. TP = total publications; TC = total citations; CPP (TC/TP) = total citations per publication.

Figure 4 presents the citation analysis as another indicator of authors (Data obtained from VOSviewer 1.6.19). This analysis examined the authors' relationship based on reciprocal citations. The citation analysis revealed the mutual citation relations among 37 authors connected through at least two articles out of a total of 521 authors, and 40 authors were identified within the scope of at least one citation. The relationships are illustrated in Figure 4, where authors in the same colour group have publications from similar study areas. The size of the circles represents the number of cited publications, with larger circles indicating a higher count. The curved links define citation relationships between publications, and their quantity influences the proximity of the groups in the analysis. The convergence of these groups can also be attributed to the similarities observed among the publications. Upon examining Figure 4, it is evident that the 37 authors considered in mutual citation relationships are divided into 2 clusters. Unlike Table 1, the author with the strongest overall link is "Lo, C. K." with 87 connections, followed by "Hew, K. F." with 77 connections and "Hwang, G. J." with 66 connections.

Figure 4

Mutual Citation Analysis by Authors



Findings Regarding the Research Question: Institutions of Top Publishing Authors

Table 2 presents the distribution of authors of academic studies on flipped classroom in mathematics, published in WoS, based on their affiliated institutions. The table consists of three performance indicators: total publications (TP), total citations (TC), and citations per publication (CPP). TP determines the order of institutions in Table 2 (Data obtained from R Bibliometrix). Due to the large number of institutions in this category (n=256), the table includes only the top five institutions ranked by the number of publications. In cases where institutions have the same number of publications, the ranking is based on the institution with the highest TC. The University of Hong Kong emerges as the institution that has made the most significant contribution to the literature, with ten publications and a total of 401 citations, among the institutions with the highest number of publications on flipped classroom in mathematics. The University of Granada ranks second with ten publications (TC=63), while the University of Extremadura ranks third with nine publications (TC=75). Regarding the institutions with the highest CPP, the National Taiwan University of Science and Technology takes the lead with a CPP of 70.67, followed by The University of Hong Kong with a CPP of 40.10. The Education University of Hong Kong and National Central University also have significant CPP values of 15.17 and 12.17, respectively.

Table 2

Numbers of Publications by Institution

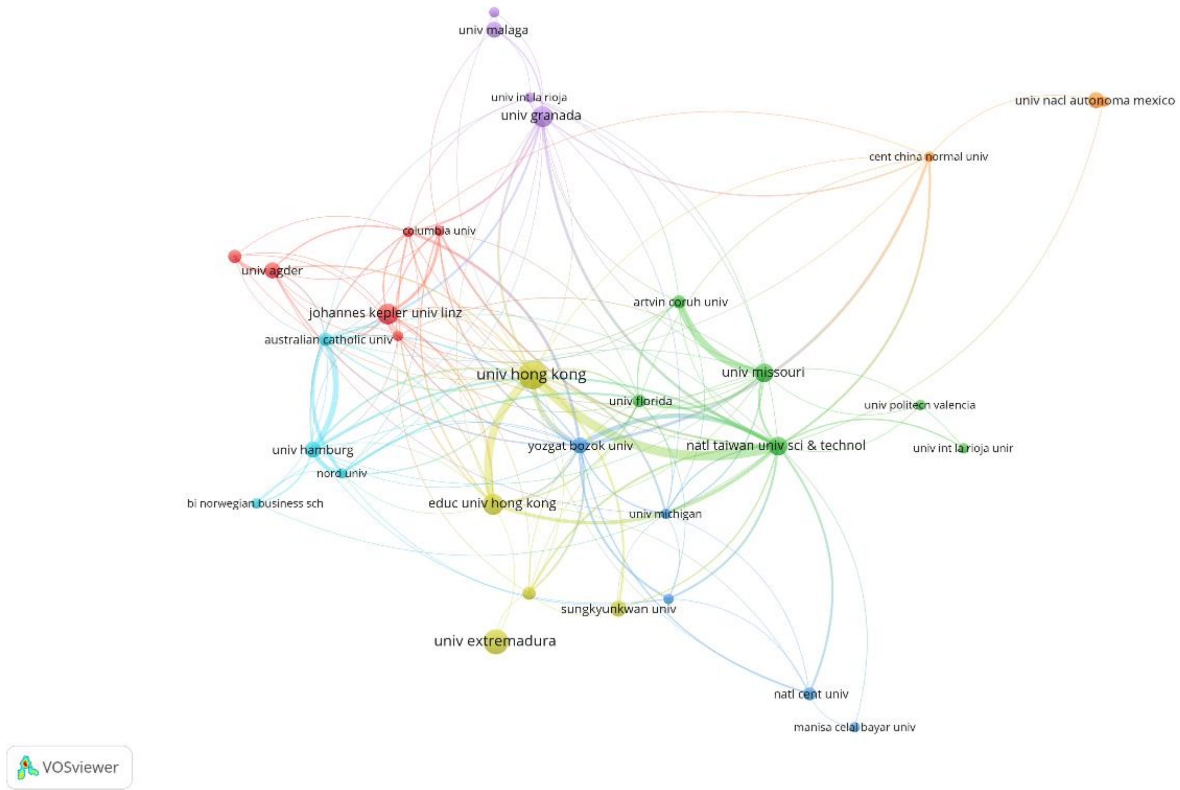
Rank	Institutions	TP	TC	CPP
1	The University of Hong Kong	10	401	40.10
2	University of Granada	10	63	6.30
3	University of Extremadura	9	75	8.33
4	Johannes Kepler University Linz	7	31	4.43
5	National Taiwan University of Science and Technology	6	424	70.67
6	The Education University of Hong Kong	6	91	15.17
7	National Central University	6	73	12.17

Note. TP = total publications; TC = total citations; CPP (TC/TP) = total citations per publication.

Figure 5 illustrates the citation analysis of institutions, showcasing the mutual citation relationships among 158 universities out of a total of 256 institutions, involving 206 universities that were found to be related through at least two articles and at least one citation (Data obtained from VOSviewer 1.6.19). The analysis reveals that these 158 institutions, considered within the context of mutual referencing, can be categorized into 16 clusters. Contrary to Table 2, which focuses on the total publication strength of institutions, the institution with the strongest connection is "The University of Hong Kong," with 159 connections. Following closely is "The National Taiwan University of Science and Technology," with 158 connections, and "Yozgat Bozok University," with 124 connections.

Figure 5

Institutions Mutual Citation Analysis



Findings Regarding the Research Question: Countries with the Most Publications and Collaborations

Within the scope of the productivity analysis of the countries, total publications (TP), total citations (TC), and citations per publication (CPP) of the five most productive countries were determined, and country ranking was made in line with these numbers. In this ranking, the total number of publications was taken as the basis, and the country with the highest number of publications ranked first as the most productive country. Information on this ranking is shown in Table 3 (Data obtained from R Bibliometrix).

Table 3

Top 5 Most Productive Countries

Rank	Countries	TP	TC	CPP
1	USA	59	1208	20.47
2	China	37	1198	32.38
3	Spain	30	480	16.00
4	Türkiye	12	156	13.00
5	Australia	9	123	13.67
6	Norway	9	101	11.22

Note. TP = total publications; TC = total citations; CPP (TC/TP) = total citations per publication.

Table 3 shows that the USA holds the top position as the most productive country, with 59 publications and a total of 1208 citations, according to TR and TP. Following the USA, China (TP=37), Spain (TP=30), Türkiye (TP=12), Australia (TP=9), and Norway (TP=9) hold the following positions in terms of the number of publications. In addition, when the number of publications per citation (CPP) is examined, it can be said that China (CPP=32.38) and the USA (CPP=20.47) have produced more effective studies in the literature than other countries.

Figure 6

Cooperation Map of Countries

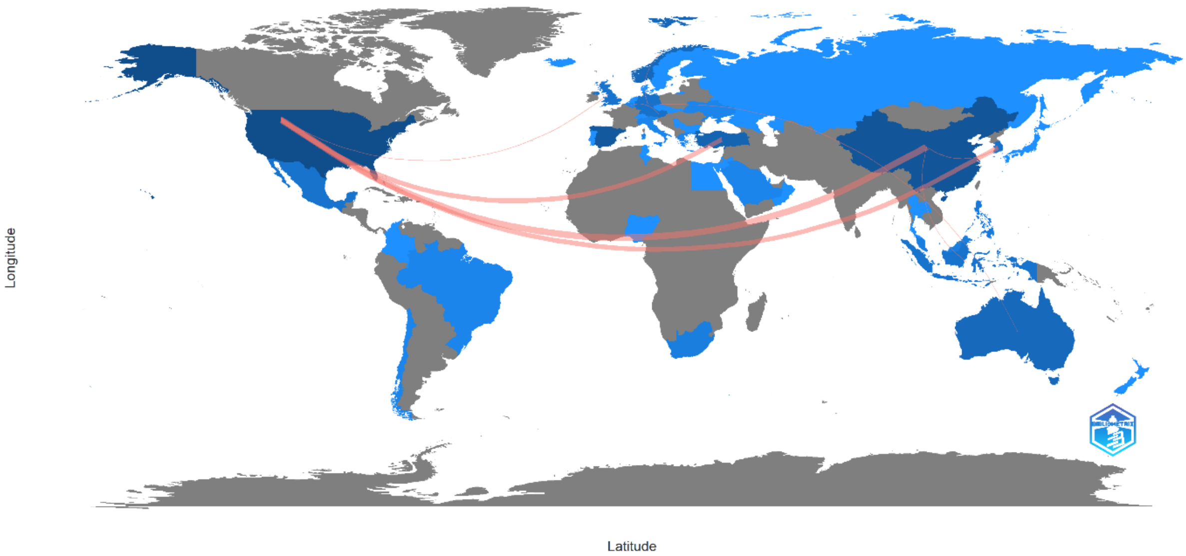


Figure 6 presents a map illustrating the analysis of countries' cooperation in research. The intensity of the blue color on the map corresponds to the number of publications produced by each country. A darker shade of blue indicates a higher number of publications. Notably, the countries appearing as the darkest blue on the map align with the top five countries regarding publication output.

The red lines on the map represent collaborations between researchers from different countries. The analysis revealed several instances of international cooperation, such as six publications resulting from collaboration between the USA and China, four publications involving the USA and Türkiye, and four publications involving the USA and South Korea. When the data set is examined, the international co-authorship result reached 21.7%.

Overall, the map visually represents the collaborative efforts between countries, with the blue color reflecting publication output and the red lines highlighting research collaborations across borders.

Findings Regarding the Research Question: Most Cited Publications

The most influential publications on flipped classroom in mathematics are shown in Table 4, along with their citation numbers and average citations per year (Data obtained from R Bibliometrix). This table shows that the researchers who made the most cited publications were Lai and Hwang (2016), with 311 citations. Love et al. (2014) are the owners of the second (194) and Cheng et al. (2019) the third (154) most cited works.

Table 4

The 5 Most Cited Documents in The Field of Flipped Classroom in Mathematics

Rank	Title	Authors	PY	TC	ACP
1	A self-regulated flipped classroom approach to improving students' learning performance in a mathematics course.	Lai, C. L., & Hwang, G. J.	2016	311	38.88
2	Student learning and perceptions in a flipped linear algebra course.	Love, B., Hodge, A., Grandgenett, N., & Swift, A. W.	2014	194	19.40
3	Effects of the flipped classroom instructional strategy on students' learning outcomes: a meta-analysis.	Cheng, L., Ritzhaupt, A.D. & Antonenko, P.	2019	154	30.80
4	Toward a set of design principles for mathematics flipped classrooms: A synthesis of research in mathematics education.	Lo, C. K., Hew, K. F., & Chen, G.	2017	140	20.00
5	The role of self-regulated learning in students' success in flipped undergraduate math courses	Sun, Z., Xie, K., & Anderman, L. H.	2018	117	19.50

Note. PY = publication year; TC = total citations; ACP = average citations per year.

Findings Regarding the Research Question: Bibliographic Coupling of Publications

The concept of bibliographic relationship analysis, which examines the connections between items based on shared references, first emerged in the 1960s (Kessler, 1963b; 1965; Van Eck & Waltman, 2021). This analysis considers the inclusion of a common third article in the bibliographies of two articles as an indication that they may be researching related topics (Jarneving, 2007; Kessler, 1963a; Martyn, 1964). Bibliographic matching aims to assess the similarity between two studies by comparing their bibliographic references. The extent of overlap in the bibliographies of these studies determines the strength of the connections between them (Zan, 2019; Zupic & Čater, 2015). A higher overlap ratio indicates a stronger relationship between the studies. In summary, bibliographic relationship analysis and matching involve examining shared references to identify potential connections between items. This approach provides insights into the similarity and relatedness of studies based on their bibliographic characteristics.

The bibliographic relationship analysis of the articles revealed that 174 out of the 177 articles, meeting the minimum one citation criteria, were found to have connections with each other from the total of 226 articles (Data obtained from VOSviewer 1.6.19). These findings are visually represented in Figure 7, which illustrates a map of bibliographic matching. The map showcases distinct groups characterized by different colours and densities, highlighting the interconnectedness between the articles.

Figure 7

Bibliographic Coupling Analysis of the Most Cited Publications

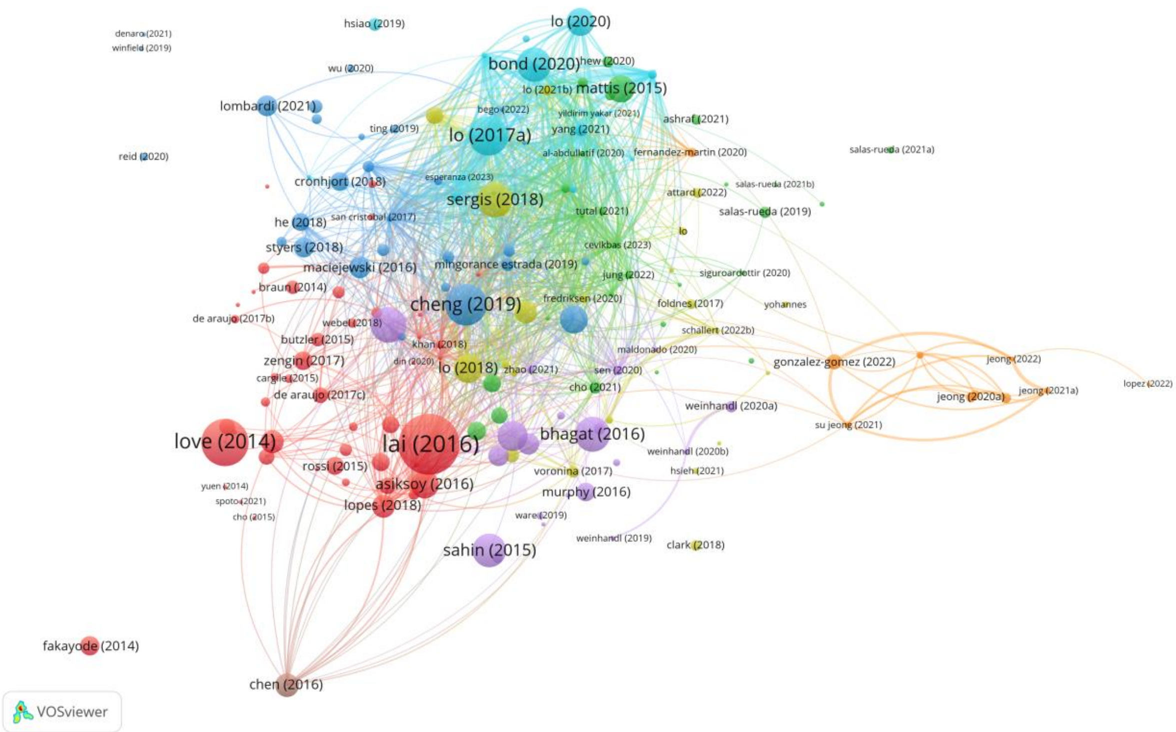


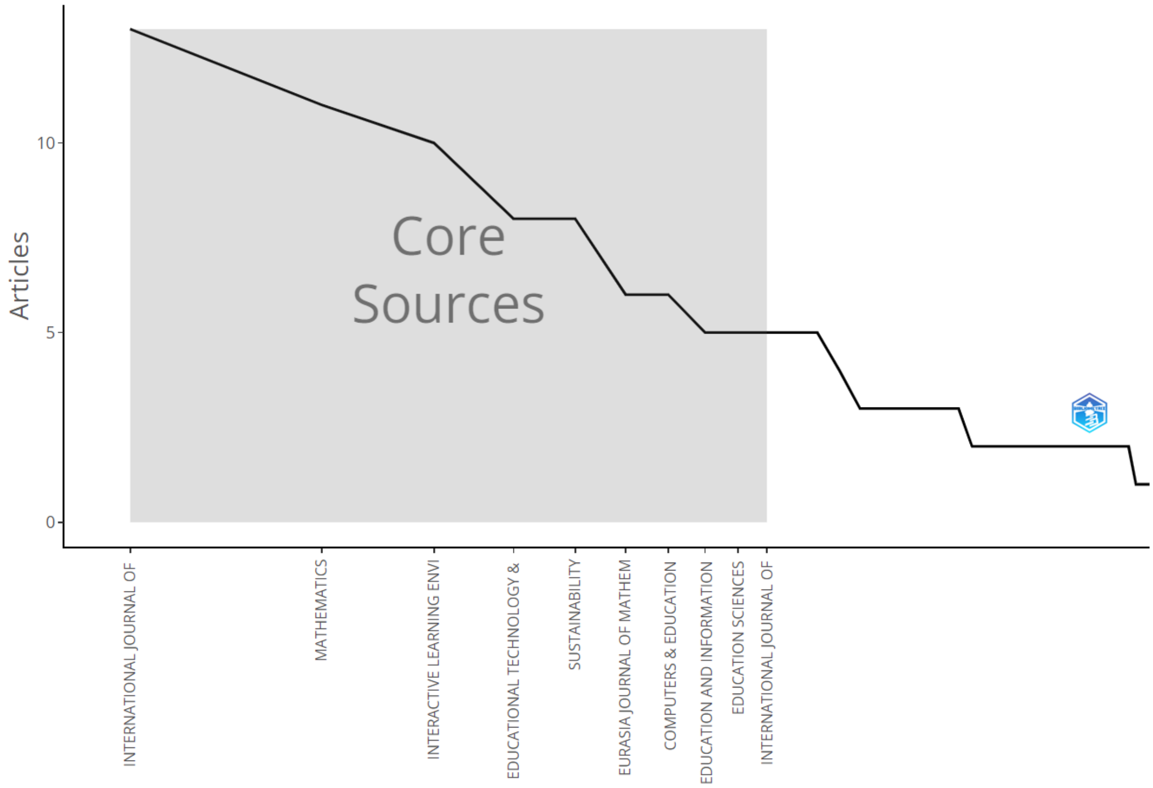
Figure 7 shows that the 174 articles analyzed using bibliographic coupling analysis are divided into eight clusters. The analysis results show that there are eight clusters, 8019 link, and 19757 total link strengths. The study by Lo et al. (2017) has the highest total link strength of 829 and 145 links.

Findings Regarding the Research Question: Bradford's Law

Bradford's Law, introduced by Bradford in 1985, serves as a measure to identify the core impact of journals within a specific field. In the context of this study, the purpose of employing Bradford's Law is to determine the primary journals where research on flipped classroom in mathematics education is predominantly published. The analysis encompassed 226 publications within the study's scope, which constituted the dataset, and these publications were distributed across 117 different journals. Figure 4 illustrates that ten journals accounted for 77 articles, followed by 33 journals with 75 articles and 74 journals with 74 articles. Based on the application of Bradford's Law, these journals were categorized into three distinct regions. Notably, the first region comprised ten key journals that serve as primary sources for research on flipped classroom in mathematics education. The outcomes pertaining to Bradford's Law are depicted in Figure 8.

Figure 8

Bradford Law Results



The 10 journals given in Figure 8 and the total publication, total citation, h-index, and CPP values of these journals are as in Table 5 (Data obtained from R Bibliometrix). Analysis discovered that the International Journal of Mathematical Education in Science and Technology was the most prolific journal in terms of publications, with 13 articles dedicated to the topic of flipped classroom in mathematics education. Following closely behind is the journal Mathematics, with 11 articles. Evaluating the results based on citation counts, Computers & Education emerged as the most frequently cited journal, accumulating 801 citations. Additionally, Educational Technology & Society ranked second with 454 citations.

Table 5

Ranking of the Journals Publishing Research on Mathematical Giftedness

Rank	Journals	TP	TC	h-index	CPP
1	International Journal of Mathematical Education in Science and Technology	13	334	7	25.69
2	Mathematics	11	75	5	6.82
3	Interactive Learning Environments	10	194	7	19.40
4	Educational Technology & Society	8	454	8	56.75
5	Sustainability	8	53	3	6.63

Table 5

(Continue)

Rank	Journals	TP	TC	h-index	CPP
6	Eurasia Journal of Mathematics Science and Technology Education	6	114	5	19.00
7	Computers & Education	5	801	5	160.20
8	Education and Information Technologies	5	32	3	6.40
9	Education Sciences	5	38	4	7.60
10	International Journal of Science and Mathematics Education	5	38	3	7.60

Note. TP = total publications; TC = total citations; CPP (TC/TP) = total citations per publication.

Findings Regarding the Research Question: Hot Terms

To address our research question, we examined citations to articles encompassing relevant terms and concepts and their interrelationships. Cluster names were derived from the most frequently occurring terms in the abstracts of each article, thereby capturing the essence of each cluster. Various algorithms were employed to characterize these clusters, with the LLR algorithm proving particularly effective in term analysis (Chen, 2014; Rousseeuw, 1987). We utilized the CiteSpace 6.2.R2 Advanced (64-bit) program to visualize and obtain values. In Table 6, the LLR algorithm presents the significant terms within each cluster, while Figure 9 showcases the feature words associated with each cluster. The results revealed the presence of six clusters in the timeline view of the network, consisting of 201 nodes and 624 lines, with a density value of 0.031. These values indicate that the articles were not predominantly concentrated within a single cluster, thus supporting multiple cluster analyses.

Table 6

Core Terms of Clusters of Hot Topics (LLR algorithm)

Cluster Label	Size	SLH	Mean Year	Top Terms (log-likelihood ratio, p-level)
#0	6	0.993	2017	classroom approach (6.22, 0.05); case study (6.22, 0.05); classroom approaches (4.07, 0.05); professional mathematics teacher development courses (4.07, 0.05); exploring essential aspect (4.07, 0.05)
#1	2	0.986	2018	receptivity (4.72, 0.05); motivation (4.72, 0.05); learning (4.72, 0.05); exploring university student (4.72, 0.05); mathematics class (1.16, 0.5)
#3	2	0.894	2022	design principle (1.67, 0.5); mathematics education (1.67, 0.5); engineering mathematics course (1.67, 0.5); mathematics class (0.68, 0.5); classroom approach (0.4, 1.0)

Table 6

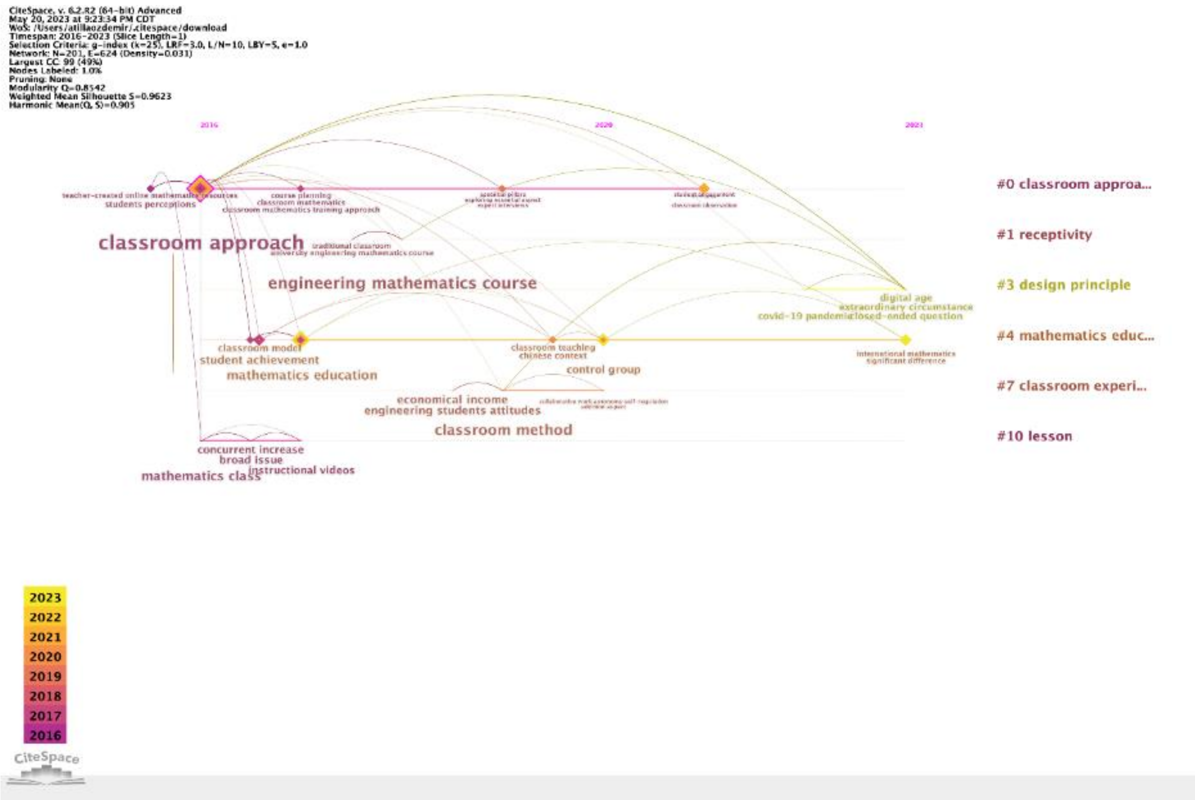
(Continue)

Cluster Label	Size	SLH	Mean Year	Top Terms (log-likelihood ratio, p-level)
#4	5	0.938	2018	design principle (6.07, 0.05); mathematics education (6.07, 0.05); middle school student (3.22, 0.1); mathematics performance (3.22, 0.1); mathematics class (2.48, 0.5)
#7	3	0.977	2019	classroom experience (5.9, 0.05); engineering students attitude (5.9, 0.05); university-level mathematics (5.9, 0.05); mathematics class (0.68, 0.5); design principle (0.54, 0.5)
#10	3	0.974	2016	lesson (7.09, 0.01); digital curriculum material (7.09, 0.01); teacher-created video (7.09, 0.01); mathematics classes (3.44, 0.1); design principle (1.74, 0.5)

Note. SLH = Silhouette.

Figure 9

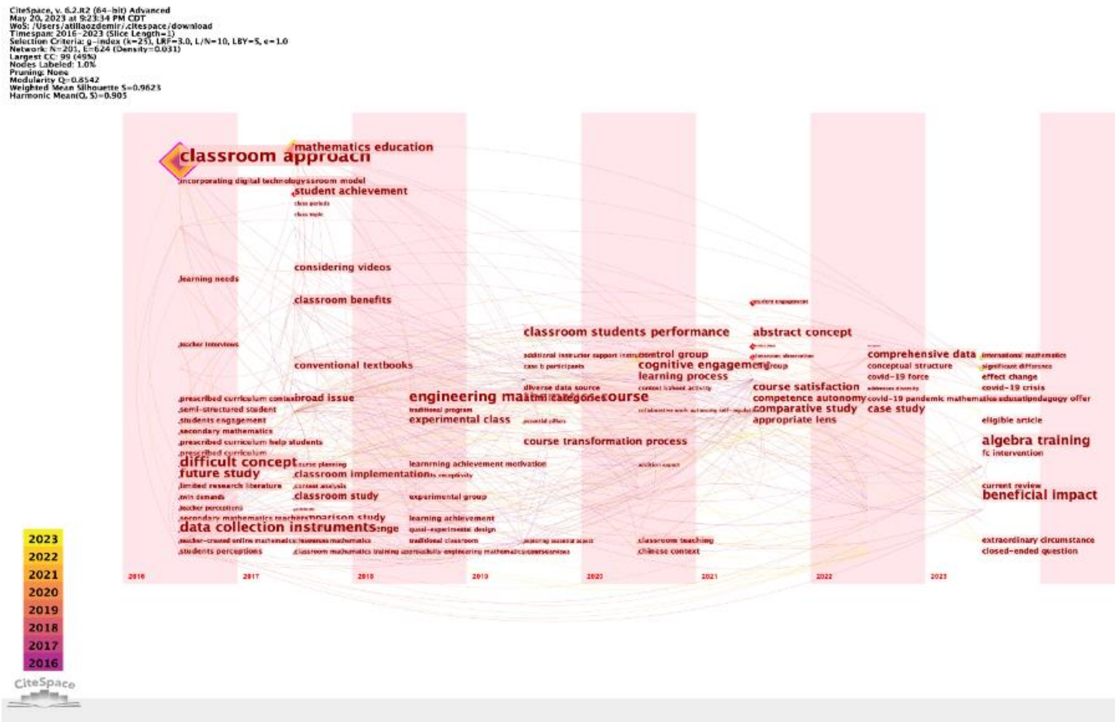
Cluster Analysis of the Most Significant Terms



To explore the evolution of research on flipped learning in mathematics education, we used a bibliometric analysis approach that combines time zone maps and burst terms. We used the software tool CiteSpace 6.2.R2 Advanced (64-bit) to generate a time zone map that illustrates the evolution of terms over time. The resulting visualization can be seen in Figure 10.

Figure 10

Timezone Map of Term Evolution



According to our findings, Cluster #0 emerged as the most extensive cluster in the co-occurring phrase analysis, comprising six studies focused on the classroom approach (6.22, 0.05). The average publication year of the references cited by the studies within this cluster was 2017. The silhouette values obtained in this analysis confirmed the homogeneity of the clusters while also indicating a wide range of values within the structure. Notably, the cluster exhibited a silhouette value of 0.993, indicating a homogeneous structure, considered a desirable network analysis indicator (Song et al., 2016). A silhouette value above 0.5 is generally considered a favorable network structure indicator. Higher silhouette values suggest more stable structures within the cluster, and clusters with homogeneity tend to have elevated silhouette values. However, it is essential to note that a high silhouette value does not necessarily imply high homogeneity, mainly when the cluster size is small (Chen, 2014). In conclusion, the academic studies examined in this study exhibited strong clustering characteristics (Chen, 2014; Song et al., 2016).

Discussion

This study aimed to review and explore the existing literature on flipped classrooms in mathematics education and to assess the general research trends in the field. The findings of this study provided extensive insights into the intellectual structure of the existing literature on flipped classrooms in mathematics education. These insights included information on the leading journals, articles, countries, authors, institutions, and networks among researchers and the key research topics investigated in the literature. In this context, in the research conducted between 2014 and 2023, 226 articles were reached in line with the search criteria for the flipped classroom in mathematics education. In line with the analysis of citation and publication trends, it was determined that the number of relevant articles and citations to these articles showed an increasing trend within the specified period. This upward trend will continue with the polynomial regression model analysis results. The fact that the annual growth rate is 14.57% and the study was conducted before the end of 2023 supports my expectation that there will be an increase in the studies on this subject. One of the most important reasons is the absence of an accepted model or plan for mathematics education (Yığ, 2022). Many studies on flipped classroom in mathematics education reveal the curiosity and effort in this field (Lo&Hew, 2021; Özdemir & Şentürk, 2021).

Lo is the author who ranks first in productivity due to his most publications on flipped classroom in mathematics education. The countries that show the most interest in flipped classroom in mathematics education and have publications on this subject are USA, China, and Spain. In addition, international co-authorship results of 21.7% of the publications were reached. The collaboration of authors from different countries is of great importance in bringing the subject of the flipped classroom in mathematics education to the literature with the perspectives of other cultures. The most cited work among all publications was by Lai and Hwang (2016). In the study, the institutions with the most publications were "The University of Hong Kong," "The University of Granada," and "The University of Extremadura."

As a result of the research, the first three journals with the highest number of publications on the flipped classroom in mathematics education, it is listed International Journal of Mathematical Education in Science and Technology (TP=13), Mathematics (TP=11), and Interactive Learning Environments (TP=10). According to Bradford Law, these journals are in the first region among the journals collected in three different areas.

The findings from analysis using the LLR algorithm for clustering have provided valuable insights into the current trends and prominent areas of focus within research on the flipped classroom in mathematics education. These findings are significant in shaping future research priorities and informing policy decisions. Table 5 presents the identified clusters of hot topics, including classroom approach, motivation, digital curriculum materials, exploration of essential aspects, and teacher-created videos. It is recommended that academics pay attention to these research topics for various reasons, such as their relationship with citation bursts, the authors who contribute to these topics, the terms with the highest frequency and centrality values, and related terms.

Firstly, working on these hot research topics may increase the likelihood of securing grants and funding, as funding agencies often prioritize them. Moreover, these topics often address critical issues within the field and potentially influence theory and practice significantly. Researchers who study these topics can actively contribute to meaningful conversations and shape the field's future direction. Additionally, these topics will likely attract researchers from various disciplines and institutions, presenting opportunities for networking and collaboration.

Limitations

Before delving into the discussion of the results, it is essential to acknowledge certain limitations to the readers. These limitations are vital to consider, providing a comprehensive understanding of the study's scope and potential implications. Firstly, my analysis predominantly relied on data obtained from the Web of Science, which primarily encompasses global databases. Consequently, there is a possibility that we may have overlooked studies published in non-global databases or those that are not indexed in the Web of Science. Secondly, my analysis was constrained to studies accessible online, which implies that we may have missed out on studies exclusively available in print or those that are yet to be published. It is essential to approach my analyses with caution, considering these limitations. Understanding that the Web of Science (WoS) database interrogation system is directed toward authors' first names is a crucial consideration. When contrasted with other citation databases that process the full names of authors, this approach presents a limitation for the study. However, the authors' names were double-checked using a thesaurus file, and no overlapping names were identified. Nonetheless, this thorough verification process opens opportunities for future researchers to further investigate the topic. Despite these constraints, I firmly believe that my findings retain their value and can provide valuable insights into the present research landscape on this subject.

Conclusion and Recommendations

The comprehensive examination of the literature about the flipped classroom in mathematics education has yielded significant insights encompassing various aspects, such as prominent journals, publications, countries, researchers, institutions, academic collaborations, and active research fields. While flipped classroom research in mathematics education is relatively nascent, it is progressively growing. Exploring uncharted territories and dimensions within this subject matter remains a viable avenue for scholars to pursue.

However, it is worth noting that the strength of the connections between researchers and institutions may shape the diversity and breadth of studies conducted on the flipped classroom in mathematics education across multiple domains. This underscores the significance of collaborative endeavors and adequate financial resources to foster a more comprehensive research landscape.

The limited diversity observed among notable researchers and institutions engaged in research on flipped classroom in mathematics education can potentially impact the range of topics addressed and the allocation of resources. Therefore, it is crucial to encourage new researchers to focus on various areas of interest within flipped classroom in mathematics education and foster partnerships with diverse institutions to broaden the scope of exploration and collaboration.

Statement of Conflict of Interest

There is no conflict of interest between the authors.

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