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GoSET2025Malacca
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Global Conference on Social Science, Education and Technology 2025
Mudzaffar Hotel, Melaka, Malaysia, 1-2 Feb 2025
Organised by: Maths Proofread and Iman Excellence Center, Malaysia

Revolutionizing Science Education: A bibliometric exploration of the flipped classroom model

Nurashikin Muzafar, Nur Jahan Ahmad*
**Corresponding Author*

School of Educational Studies,
Universiti Sains Malaysia, Penang, Malaysia

auroraike@gmail.com, jahan@usm.my
Tel: 0194809923

Abstract
The flipped classroom model has emerged as a revolutionary pedagogical technique in science education. To map the research landscape, this study uses VOSviewer and Scopus Analyser to perform a bibliometric analysis of 798 publications from the Scopus database. Key study areas include learning outcomes, technology integration, and student engagement, specifically in higher education. The findings reveal a notable increase in interest and publications over the past decade. This study emphasises how the flipped classroom is reshaping scientific education and urges more empirical research to address underexplored areas and expand its applications.

Keywords: flipped classroom; science education; technology; engagement

DOI: https://doi.org/10.21834/e-bpj.v10iSI32.7054

1.0 Introduction

Significant changes in educational methods, particularly in scientific education, have occurred over the last decade due to the rapid advancement of digital technology and the increasing demand for active, student-centered learning (Tunggyshbay et al., 2023; Turan, 2023). A promising strategy to enhance student engagement, critical thinking, and learning outcomes is the flipped classroom model, which relocates direct instruction outside the classroom and utilizes in-class time for interactive, collaborative activities (Rincon-Flores et al., 2024; Suwardika et al., 2024). Recent studies highlight the effectiveness of the flipped classroom model in improving academic achievement and fostering critical 21st-century skills, despite challenges such as digital divides and the need for teacher training, particularly in resource-limited settings (Nkanyani et al., 2024).

The flipped classroom is an instructional approach in which students access instructional content outside of the classroom and engage in interactive activities during class time. This innovative method has gained popularity in various scientific disciplines, including physics, chemistry, and biology. Research has shown that it effectively enhances student learning outcomes. Findings from meta-analyses indicate that flipped classrooms positively influence academic achievement, particularly in scientific subjects, evidenced by moderate to large effect sizes (Tunggyshbay et al., 2023; Turan, 2023). More than that, some research has also suggested the model's effectiveness in smaller classes and at the primary level, indicating its versatile nature with respect to implementation (Doğan et al., 2021).

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DOI: https://doi.org/10.21834/e-bpj.v10iSI32.7054

This study systematically maps and analyzes the research landscape of the flipped classroom model in science education using bibliometric methods.

2.0 Objectives of this study

1. To identify research trends in the flipped classroom model in science education based on publication years
2. To determine the most productive authors contributing to this field
3. To analyze the most popular keywords and research themes related to the flipped classroom in science education
4. To examine patterns of international collaboration among authors in this research area.

3.0 Research Question

1. How have studies on flipped classroom approaches within science education evolved over different publication years?
2. Who are the most productive authors of research?
3. Which keywords are most frequently associated with this research?
4. How do different countries collaborate through co-authorship in this research area?

4.0 Literature Review

Over the past several years, the flipped classroom model has surfaced as a significant advancement to conventional learning methods and has turned science education towards an active student-centered pedagogy. As previously discussed (Rincon-Flores et al., 2024), this model possesses the benefits of adaptive learning techniques, along with those from flipped classroom elements, to increase student engagement and enhance academic performance. The study conducted in Tecnologico de Monterrey has shown that integrating adaptive learning in flipped classrooms, a micro-learning approach, further increases student disciplinary and transversal competencies. Likewise, Suwardika et al., 2024 provided an instance of importance, which was where the flipped classroom course could increase levels of teacher self-regulation skills and communication skills in primary schools, as well as critical thinking levels. On the other hand, according to Nkanyani et al., 2024 challenges in rural settings (i.e., digital divides and lack of teacher training) hinder the successful implementation of flipped classrooms. This is how the flipped classroom model may revolutionize science education using these examples of studies.

Recent research has demonstrated the flipped classroom model's increasing popularity and efficacy in science education, especially when it comes to improving learning outcomes and student engagement (Tunggyshbay et al., 2023; Turan, 2023). Although earlier studies have concentrated on the application and immediate effects of the flipped classroom in diverse educational settings, a thorough assessment of worldwide research patterns, influential figures, and cooperative networks in this area is still required (Rincon-Flores et al., 2024; Suwardika et al., 2024). This work adds to the body of literature by performing a bibliometric analysis, which maps the evolution of flipped classroom research in scientific education methodically, identifies gaps, and recommends future research possibilities.

5.0 Methodology

Bibliometrics encompasses the collection, management, and analysis of bibliographic data from scholarly publications (Alves et al., 2021; Assyakur & Rosa, 2022; Verbeek et al., 2002). This includes basic descriptive statistics such as the journals in which articles are published, the publication year, and the classification of primary authors (Wu & Wu, 2017). Furthermore, the analysis incorporates advanced methods such as document co-citation analysis. This research prioritised reputable publications, as they offer valuable insights into the theoretical perspectives shaping the evolution of the field. To guarantee data accuracy, information was sourced from the Scopus database (Al-Khoury et al., 2022).

5.1 Data search strategy

The tables detail the methodology of a bibliometric search regarding the flipped classroom model in science education through the Scopus database. Keywords (e.g., flipped, classroom, education, science) are shown in Table 1. The search was limited to publications in English from 2012 to 2024. Selection criteria are indicated in Table 2: only English-language books, journal articles, and proceedings published from 2012 to 2024 were considered, while non-English publications and reviews were excluded. This approach ensures a relevant and focused dataset for analysing trends and developments in the flipped classroom model in science education.

Table 1. The search string

Scopus	TITLE-ABS-KEY ((flipped) AND (classroom) AND (education) AND (science)) AND PUBYEAR > 2011 AND PUBYEAR < 2025 AND (LIMIT-TO (LANGUAGE , “English”))

Table 2. The selection criterion is searching

Criterion	Inclusion	Exclusion
Language	English	Non-English
Timeline	2012 – 2024	> 2024
Literature type	Article, Journal, Proceeding, Book	Review

(Source:) Scopus

5.2 *Data analysis*

VOSviewer is a widely used bibliometric tool with powerful features and an intuitive interface, developed by Nees Jan van Eck and Ludo Waltman at Leiden University, Netherlands (Van Eck & Waltman, 2010, 2017). Moreover, this software is extensively utilised for scientific literature visualization and analysis. Special features include item clustering, network display with arc diagram layout, and density map generation. Furthermore, it supports an enterprise profile for research landscapes using co-citation or keyword-specific networks. Each of these has a unique faceplate that often changes to adapt to the higher interaction with big data. This makes VOSviewer a valuable tool for researchers working with complex data, advanced metrics, customized visualizations, and diverse bibliometric sources. The tool focuses on network visualization, clustering similar objects, discovering keyword co-occurrence patterns, and building density maps. Hence, researchers can make sense of metrics and visualize outputs in an adjustable plane. VOSviewer is an essential tool for researchers seeking a deeper understanding and practical insights across different fields. Its versatility allows users to analyze various types of bibliometric data, such as co-authorship and citation networks. PlainText data regarding title, publication year, journal, author name, keywords, and citation were gathered from the Scopus database, spanning the years 2012 to 2024. The datasets were examined using VOSviewer software version 1.6.19, which enabled the creation of visual maps and clusters through its specialised VOS techniques. In contrast to the Multidimensional Scaling (MDS) method, VOSviewer arranges items in a low-dimensional space so that the proximity between any two items precisely represents their level of similarity and relatedness (Van Eck & Waltman, 2010). In this respect, VOSviewer shares certain characteristics with the MDS method (Appio et al., 2014). Nevertheless, while MDS typically relies on similarity measures such as cosine and Jaccard indices, VOSviewer adopts a more effective strategy for normalising co-occurrence data specifically, by utilising Association Strength (ASij), which is determined as described by Van Eck & Waltman (2007):

$$ASij = \frac{cij}{wiwj},$$

The value is determined by the ratio of the actual co-occurrence count for items i and j to the expected count, under the assumption that their co-occurrences are statistically independent (Van Eck & Waltman, 2007).

6.0 Results and Discussion

6.1 How have studies on flipped classroom approaches within science education evolved over different publication years?

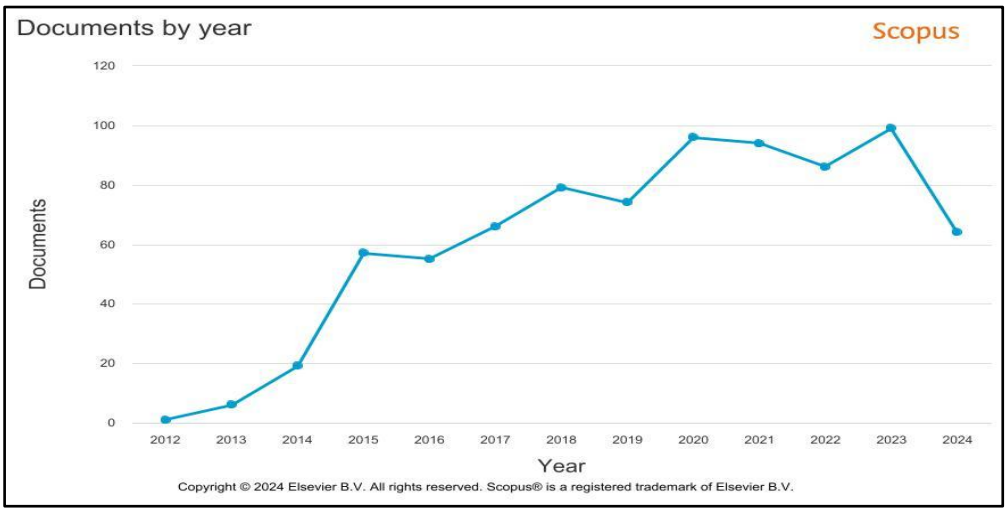

Fig. 1: The number of documents released each year.

The trend of publications on the flipped classroom model from 2012 to 2024, as depicted in the Scopus data, reveals significant interest and research output growth over the years. Initially, from 2012 to 2015, there was a steady rise in publications, reflecting the nascent phases of academic exploration into this educational approach. This period likely reflects the initial adoption and experimentation with

the flipped classroom model in various educational settings. The sharp rise in publications from 2015 to 2018 suggests a growing recognition of its potential benefits, possibly driven by positive outcomes reported in early studies and the increasing integration of technology in education. From 2018 onwards, the publication trend indicates fluctuations, with peaks in 2020 and 2023. These trends may indicate periods of more intense research, likely in response to global events such as the COVID-19 pandemic. These necessitated innovative teaching methods and could have spurred further interest in flipped classrooms. The decrease for 2024 could indicate saturation in the research arena or a focus on new emerging educational technologies. The data highlights the fluidity of educational research and the previous interest in teaching strategies such as the flipped classroom model. The treatise also noted that the most severe problem is the digital gap, which poses a greater challenge to learners located in rural or underdeveloped socioeconomic zones (Nkanyani et al., 2024). The absence of digital instruments, the lack of trained educators, and the poor internet connection make it extremely difficult to implement flipped classrooms successfully. This challenge is palpable in many developing countries where resources and infrastructure are often inadequate.

6.2 Who are the most productive authors of research?

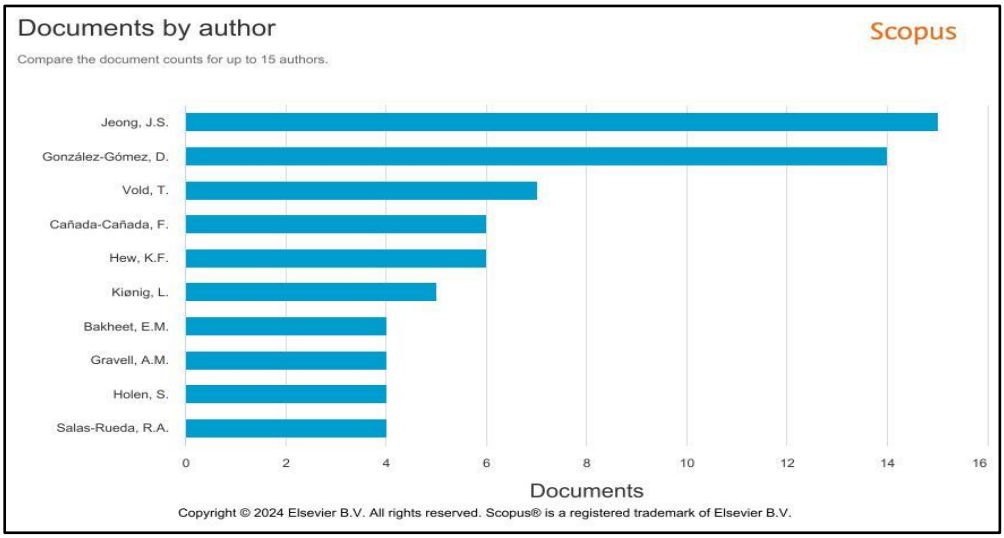

Fig. 2: Most productive authors of research.

Table 3. The most productive authors of research.

Author name	Number of Documents	Percentage (%)
Jeong, J.S.	15	1.884
Gonzalez-Gomez, D.	14	1.759
Vold, T.	7	0.879
Canada-Canada, F.	6	0.754
Hew, K.F.	6	0.754
Kionig, L.	5	0.628
Bakheet, E.M.	4	0.503
Gravell, A.M.	4	0.503
Holen, S.	4	0.503
Salas-Rueda, R.A.	4	0.503

(Source:) Scopus

Ultimately, their work probably expands on what the top few authors were doing by zooming into niche topics or niche applications of the flipped classroom model, which collectively help fill gaps in the overall evidence base and inform practical implementations. The moderate number of publications, for example, Hew, K.F., and Kionig, L., reiterates the extent of interest in this educational innovation. The diverse authorship is indicative of research perspectives that are broadening and necessary to address the heterogeneity of challenges faced and benefits being gained from the flipped classroom approach. The number of publications by these authors indicates a good and dynamic research area, which is when both established and emerging scholars contribute to the conversation. This participatory structure promotes creativity and innovation and guarantees a holistic examination of the potential of the flipped classroom

model. Moreover, the ongoing evolution of the field highlights the essential contributions of these authors in guiding future research directions and educational practices, ultimately revolutionising science education through innovative pedagogical strategies. The complication of the flipped classroom approach seems to work only in certain subjects and student populations. The fact that it seems to be a popular approach to education does not mean it can fit any classroom context. For example, the model would not address the requirement for in-class practice for students with hands-on practical courses like science laboratories or other vocational practices.

6.3 Which keywords are most frequently associated with this research?

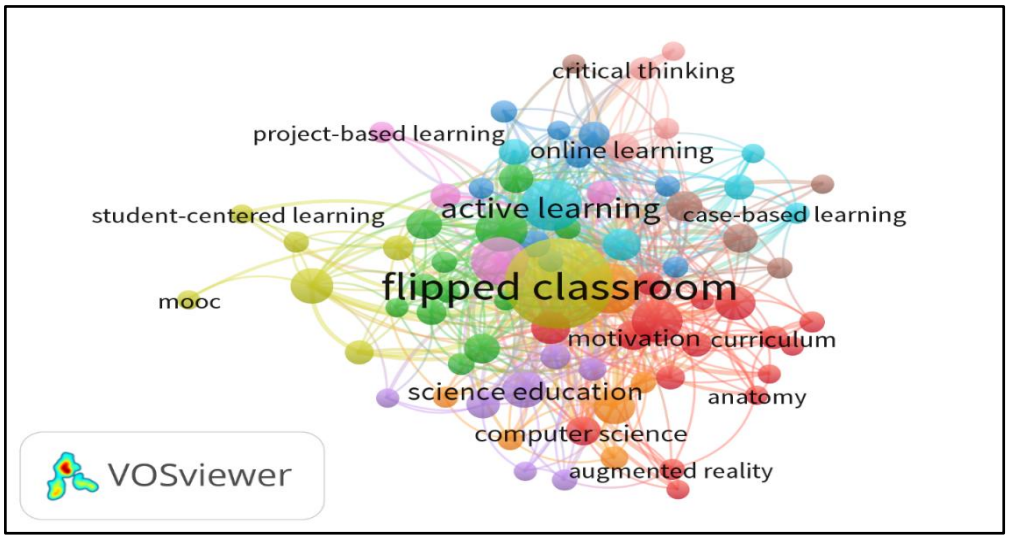

Fig. 3: Network visualization map of keywords' co-occurrence.

This bibliometric analysis gives a thorough overview of the various concerns linked to the flipped classroom model within the context of science education. Moreover, the literature indicates that the topic of "flipped classroom" appears with the highest frequency (331) and total link strength (471), indicating both the centrality of the topic as well as its prominence within the scholarly literature. This indicates that a flipped classroom is one of the transformative approaches in the learning context. Analysis of associated search texts' most popular keywords, such as "flipped learning" (44 occurrences and 70 link strength) and "flipped classrooms" (12 occurrences and 18 link strength), highlights the practice and extensive experimentation with the model. A strength that strongly links from there into the rest of the educational graph tends to accentuate its role as a revolutionary element (flipped classroom) to change minds about pedagogical approaches. Active learning (67 occurrences, 123 link strength) and blended learning (64 occurrences, 117 link strength) are also frequent, signifying their essential position in the flipped classroom. Altogether, these concepts regard the flipped classroom model. Hence, they auscultate the active participation of students and the application of technology to enhance educational experiences. The relatively high frequency of keywords like higher education (57 occurrences, 101 link strength) as well as educational technology (10 occurrences, 16 link strength) suggests that the flipped classroom method is being implemented in higher education settings, where technology is an integral part of pedagogy. This means that education will be very interactive and technology-driven.

Moreover, the primary analysis demonstrates the widespread applicability of flipped classrooms in different disciplines, as shown in keywords like "medical education" (22 occurrences, with a link strength of 37), "engineering education" (16 occurrences, with a link strength of 25), and "computer science education" (25 occurrences, with link strength of 41). Such diversity indicates the model's applicability and success across different education sectors. The current term "critical thinking" (8 occurrences with 12 link strength), whereas "student engagement" (15 occurrences, 35 link strength), indicating a flip-based classroom is a tool for delivering content, also enriches the foundation skills and activities of students. The bibliometric data highlights the significance of the flipped classroom approach in influencing modern educational methodologies, encouraging a transition to more student-oriented and participatory learning settings. Supportive educational policies that place a high priority on teacher preparation, technology integration, and fair access to resources are frequently necessary for the effective adoption of flipped classrooms.

6.4 How do different countries collaborate through co-authorship in this research area?

The bibliometric examination of the flipped classroom model reveals significant international collaboration and research output, with the United States at the forefront in terms of document count and citation frequency. The U.S. has produced 207 documents and received 5,128 citations, indicating its central role in advancing research on this educational model. The total link strength of 31 suggests robust collaborative networks with other countries. China and Spain rank as the second and third highest contributors, with 67 and 60 documents, respectively. Spain contributed with 1,874 citations, registering the highest impact and quality of research in the world. China comes in with a total link strength of 24, while Spain demonstrates a total link strength of 19, suggesting a somewhat less robust but still

active collaboration than the United States. Some countries have made significant contributions, including Canada, Australia, and Germany. A total link strength of 22 signifies a strong collaborative presence. A total link strength of 22 signifies a strong collaborative presence. Australia has produced 33 documents and garnered 545 citations, reflecting a total link strength of 26, which signifies robust international collaboration. Germany has 32 documents and 245 citations, as well as a link strength of 20, indicating that Germany has a relatively good presence overall but a less robust impact than Canada and Australia. These countries represent a significant but balanced proportion of publications on the global map in terms of publication and citation impact and collaborative efforts.

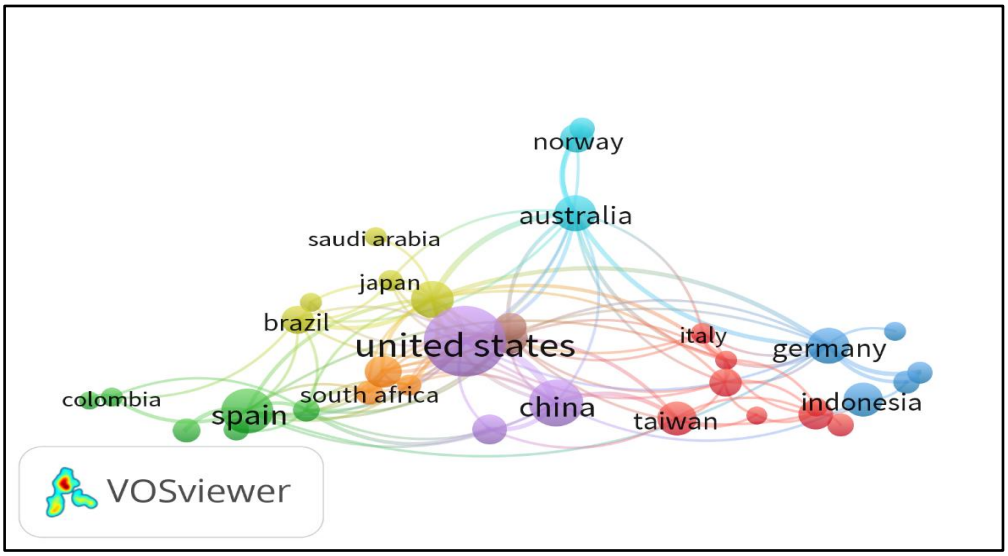

Fig. 4. Network visualisation map of countries whose authors collaborate on flipped classrooms in science education.

Hong Kong, Norway, and Taiwan are a few more countries with high citation counts relative to their document output, showcasing their impactful research. With 19 documents and 594 citations, the total link strength of Hong Kong is 7, indicating that the research in Hong Kong is robust despite the fewer collaborative links, and the higher influence of the research. Norway and Taiwan have, respectively, 18 documents and 291 citations and 27 documents and 572 citations, with intermediate strengths of 6 and 9. This indicates that those countries that do not have wider connected international collaboration networks still produce high-quality and highly cited research work on flipped classrooms.

7.0 Conclusion

The literature review of the flipped classroom model provides a detailed overview of an emerging area of research. From 2012 to 2024, there has been an increasing emphasis within the academic community, particularly marked by a significant rise in publications between 2015 and 2018. This surge likely indicates that the flipped classroom is being increasingly recognized as a beneficial pedagogical approach, supported by positive early findings and the growing integration of technology in educational settings. Following 2018, the rise in publications peaked in both 2020 and 2023, influenced by global events such as the COVID-19 pandemic, which necessitated innovative teaching methods. The decline in publications in 2024 may represent a saturation point in research on this topic, reflecting a shift towards other emerging educational technologies. This illustrates that the field of education research is continually evolving in search of improved pedagogical strategies. The review also identifies important publications in this discipline based on their citation counts, including foundational works like Strayer (2012) and Gilboy et al. (2015). These studies address a variety of themes related to the flipped classroom, such as technology adoption, instructional practices and effects, and specific learning outcomes. This diversity enriches the academic dialogue and offers a comprehensive view of the advantages and challenges associated with the flipped classroom model. The citation counts highlight the ongoing relevance of these studies and their potential contributions to future research and implementation efforts in science education through innovative pedagogies.

The bibliometric analysis of flipped-classroom studies on science education reveals a multifaceted network of associated themes and ideas. The word “flipped classroom” is the core node in the network of co-words after extensive analysis, which highlights the common claim on changing education practices. Other popular concepts, such as “flipped learning,” also emphasize how the model is more widely accepted and experimented with. The flipped classroom model relies on active learning as well as blended learning, in which students interact with information before class, using technology as a supplement. The use of terms like “higher education” and even the term for educational technology shows that this model is likely most applicable, where changes to teaching are more easily implemented through tech. The analysis, however, also highlights the model’s translatability to other domains, given the appearance of keywords such as ‘medical education,’ engineering education,’ and ‘computer science education’ in the results, indicative of the model’s

utility in a range of fields. Terms such as "critical thinking" and "student engagement" propose that the flipped classroom model enhances content delivery, fosters the establishment of critical skills, and encourages student participation in the learning method. Globally, the analysis indicates a robust international collaboration, with the United States clearly being the most active producer of documents and producing the most citations, indicating that the advancement of research on the flipped classroom approach is, in fact, a global issue. Spain contributes significantly, too, particularly in the form of impactful research, as does China. For instance, nations like Canada, Australia, and Germany show a healthy balance of output, citation impact, and collaborative work, playing a crucial role in the global scientific dialogue. They show up with high citation counts per paper relative to their planned output, meaning their papers have a high impact.

This study has some limitations. To begin with, the bibliometric analysis was restricted to certain databases, which may have omitted relevant studies on the flipped classroom model in science education. Furthermore, the study did not analyze qualitatively any of the components or impact of the flipped classroom model in different educational contexts, focusing solely on publication counts. More recent publications or novel research may also have been left out due to the time frame set for the analysis. Finally, there is likely a bias concerning language since only English publications were considered. Other researchers are encouraged to address these issues by broadening their scope and methodologies while interpreting these findings, bearing the noted limitations in mind.

Lastly, there are still questions about the flipped classroom model's long-term viability. There is no data on the model's long-term effects on academic performance, student engagement, and skill development despite the fact that short-term research has produced encouraging results. How the flipped classroom approach may be modified and maintained over time, especially in varied educational contexts, requires more investigation. Future research must concentrate on establishing strategies to overcome these challenges, like focused teacher preparation courses, laws to close the digital gap, and frameworks for modifying the model to fit various cultural and financial settings. There are still issues, including digital inequalities, inadequate teacher preparation, and a paucity of studies on its long-term impacts and use in various educational settings. In order to fully realise the model's potential to transform scientific education, the research emphasizes the need for further empirical study, especially in understudied areas like elementary education, rural settings, and integration with other cutting-edge teaching models like STEM education.

Acknowledgement

I want to express my sincere appreciation to the School of Educational Studies at Universiti Sains Malaysia, my supervisor, and all the experts for their invaluable support and resources that made this research possible.

Paper Contribution to Related Field of Study

This research significantly advances science education by examining how the flipped classroom approach enhances student participation, elevates academic achievement, and facilitates the incorporation of technology into teaching methods. Through the analysis of 798 relevant publications, the research uncovers major trends and persistent challenges, such as the ongoing need to enhance technological access in rural communities. The findings highlight the growing adoption of this pedagogical approach and underscore the necessity for additional research to expand its implementation and assess its long-term impact. Ultimately, the insights provided offer valuable direction for both educators and policymakers seeking to advance effective teaching strategies.

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