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A review of flipped learning in innovative math education

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ABSTRACT

Many systematic reviews have examined flipped learning models in various fields. However, there is little research on the use of the flipped learning model in mathematics education, which could help researchers and practitioners use and develop a model to implement mathematics learning processes. To fill this gap, this study aimed to analyze and synthesize current knowledge and practices in the implementation of flipped learning in mathematics education. Systematic literature review was adopted as the research method following an article selection and screening process using the preferred reporting items for systematic review and meta-analysis (PRISMA) protocol. Articles published from 2012 to 2021 in some reputable databases (Web of Science, Scopus, and ERIC) were reviewed, and 17 of 137 articles were included for detailed analysis and synthesis. The findings of this study showed that research in the implementation of the flipped learning model in mathematics education focused on documenting the affectivity of the implementation of the flipped learning model, developing learning processes, and sharing preliminary findings and student feedback. Future research is highly recommended to examine different aspects of flipped learning implementation, promote longitudinal data based on multi-year research for implementing flipped learning, and review various learning media to strengthen students' understanding of mathematics.

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1. INTRODUCTION

There is still no agreement among experts on the definition of mathematics. Some experts define mathematics as a study of quantity, structure, space, logic, connectedness, and change [1]–[4]. Some others define mathematics as a study of abstract objects [5]–[7]. From those opinions, the common thread that can be drawn is that mathematics is purely a brain activity; by having good mathematical skills, one will be able to analyze abstract objects in the forms of quantity, structure, space, logic, connectedness, and change. This is in line with the study by Velazquez [8], who states that mathematical mastery enables one to decipher the activity of the human brain. If drawn in the context of education, mastery of mathematics can only occur if the learning process is done by fully involving students to maximize their thinking skills, such as convergent analytical thinking, divergent thinking, critical thinking, and creative thinking skills [9]. Therefore, choosing the right learning model can help and actively involve students in using their thinking skills during the mathematics learning process. One such model is the flipped learning model. According to Cevikbas and Kaiser [10], a well-designed flipped learning model provides an excellent opportunity to foster students' mathematical thinking and comprehension.

The flipped learning model—also known as inverted learning—is a learning model that expands the focus of the conventional learning process on just one classroom learning session into three learning sessions: pre-class, in-class, and post-class [11], [12]. Each session has its role. Pre-class activities provide space for students to learn materials given by their teacher in the form of learning videos. In-class activities become phases of the learning process with a focus on deepening students' material mastery that is gained in the pre-class activity phase. Finally, post-class activities consist of students' knowledge enrichment with exercises and assignments by the teacher as a form of learning evaluation [13].

Since the introduction of the concept of flipped learning in 2012 [14] until at least 2017, implementation of the flipped learning model in learning processes has increased drastically in various educational institutions worldwide, specifically in higher education settings. This improvement is inextricably linked to the benefits of implementing the flipped learning model during the learning process. Several previous studies have applied the flipped learning model to mathematics learning with different results. Ishartono *et al*. [15] used the GeoGebra-integrated flipped learning model to improve students' self-regulated learning on algebraic topic materials, while Belmonte *et al*. [16] used the flipped learning model to establish attitudinal and mathematical indicators. Next, Yorganci [17] used the flipped learning model to improve Turkish students' mathematics self-regulated learning, learning achievement, and self-efficacy. Lastly, Yorganci's [17] research finding strengthened the study by Hwang and Lai [18], which showed that the flipped learning model could strengthen students' self-efficacy in learning mathematics. From these studies, it can be seen that the flipped learning model can be an alternative solution in the mathematics learning process through active student involvement in constructing the mathematical concepts they learn.

In principle, the flipped learning model lies under the umbrella of active learning, where students are conditioned to be more active in the construction of their knowledge [19], [20]. This is reinforced by previous studies showing that the implementation of the flipped learning model could increase students' activeness in learning [21], [22]. In addition, the syntax of the flipped learning model points out that it provides ample space for teachers or lecturers to apply various pedagogical models during class time. In line with this, McLaughlin [23] argues that applying the flipped learning model allows teachers to explore the most suitable learning models. Previous studies also showed that implementing the flipped learning model provides personalized guidance and different learning experiences for students [11], [24], [25].

Despite those benefits, however, the flipped learning model has some problems that should be addressed. To begin with, this model largely depends on how well students can complete tasks in the pre-class activity phase [26]. This phase is dedicated to students' constructing their knowledge through any learning materials and media the teacher provides. Besides, students are also expected to develop their thinking skills during the pre-class activity phase. Thus, a failure in this phase can affect the learning process in the next stage. Teachers may state that students' task completion is the motivational aspect of student learning.

The number of stages that students must go through in a flipped-learning-model-based learning process—in conjunction with many tasks given—requires students to be highly motivated in learning, or they will fail to complete all stages in the learning process [27], [28]. Besides, previous studies showed that failures in the implementation of flipped learning occur due to technical reasons, such as i) videos that are less engaging; ii) teachers who do not master technologies such as learning management systems; iii) curricula and syllabi that do not support the flipped learning ecosystem; iv) student disobedience of online learning technology; and v) facilities that are barely accessible to both teachers and students [29]–[31]. Indeed, it is still possible to overcome all these obstacles as they are in the realm of technical constraints. However, the flipped learning model emphasizes student-centered activities and involves the full activeness of students.

In pedagogy, mathematics is considered one of unique subjects because of its abstract work objects. It takes liveliness and good thinking skills to learn all the mathematical concepts that need to be learned [32], [33]. In addition, it is also necessary for students to be physically active to gain an understanding of mathematical concepts through trials and errors while solving mathematical problems [34]. To accommodate those aspects, the flipped learning model may come up as an alternative learning model that can maximize aspects of thinking skills and physical activity through the three phases. McLaughlin's study [23] supports this, showing that the flipped learning model may theoretically provide a vast space for students to explore, strengthen, and deepen the understanding of mathematical concepts that they gain through the phases in the flipped learning model [23].

Despite the potential application of the flipped learning model in mathematics education, there has been no agreement on how to apply the flipped learning model in mathematics education technically. Therefore, it is time to analyze and synthesize research findings to describe the state of knowledge to inform future research and development efforts. One of the ways in which they can be achieved is by reviewing previous empirical studies on the implementation of flipped learning in mathematics education.

There are a plethora of review studies on the implementation of the flipped learning model in various fields, such as engineering education, gamification, dental education, computer education, and English education [12], [35]–[39]. However, not many reviews focused on the implementation of the flipped learning model in mathematics education, among which are those conducted by several studies [40], [41]. However, both of the aforementioned studies focused on empirical studies about implementing flipped classrooms—instead of flipped learning—in mathematics education. Although many education practitioners consider that flipped learning and flipped classroom are the same [13], the two models theoretically have different conditions. Flipped classroom is a learning model where teachers record their lectures in a video that is to be given to their students to be studied outside the class later and dedicate class time to homework.

On the other hand, flipped learning is a pedagogical model that moves group learning into individual learning space, in which case the group learning space transforms into a space of more active and deep learning [42]. Therefore, this strengthens the urgency of systematically reviewing, analyzing, and synthesizing previous empirical studies about the implementation of flipped learning in mathematics education. Besides, the study's findings may enrich researchers' insight in optimizing mathematics learning processes through flipped learning as an innovative model, specifically in the situation of an online learning, blended learning, or hybrid learning mode [43]. The finding of this study may become an initial step towards a more profound understanding of the way to implement the flipped learning model—including its challenges—in mathematics education.

Based on the aforementioned, the research problem is how previous research integrated the flipped learning model in mathematics learning. Thus, the present study aimed to systematically review literature in previous research articles that integrated flipped learning in various aspects of the mathematics learning process. Therefore, the research questions (RQ) proposed in this study are: i) What is the research trend related to the application of the flipped learning model in mathematics education? (RQ1); ii) Is the application of the flipped learning model effective in mathematics education? (RQ2); iii) What are the benefits of applying the flipped learning model in mathematics education? (RQ3); iv) What kind of learning media is integrated into the application of the flipped learning model in mathematics education? (RQ4).

2. RESEARCH METHOD

The present study is a systematic literature review that employed the preferred reporting items for systematic review and meta-analysis (PRISMA) protocol to obtain references that were to be studied in depth [38]. The protocol consists of four steps: identification, screening, eligibility, and inclusion. Table 1 informs the detail of the article selection process by using PRISMA protocol.

Table 1. The article selection process based on the PRISMA protocol

PRISMA protocol steps	Activity	n
Identification	Web of Science	50
	Scopus	44
	ERIC	43
	Total	137
Screening	Language (exclusion: non-English)	7
	Publication type (exclusion: literature reviews, books, book chapters)	48
	Duplicated papers	38
	Total	44
Eligibility	Title selection	19
	Abstract selection	6
	Total	19
Inclusion	Poor quality of the paper	2
	Final total	17

2.1. Identification

This stage defines keywords based on the participants, interventions, comparisons, and outcomes (PICO) framework [44]. However, in this study, the researchers did not specify the participant and outcome aspects because they did not focus on student levels and specific outcomes from applying flipped learning in the mathematics learning process. The definition applies to the aspect of interventions, in reference to the implementation of the flipped learning model, and the aspect of comparisons, in reference to the subject used, namely, mathematics education (Table 2). These keywords were then combined with Boolean operators such as "AND" and "OR" to assist in the reference search process; Figure 1 shows the search query sample [45].

The next step of the identification stage is to determine the database as the reference search source to be used, followed by determining the year range. The authors used the Web of Science, Scopus, and ERIC databases in this study. The Web of Science is a database developed by Clarivate, and Scopus is a database developed by Elsevier. Both databases have rigorous selection rates where only journals that have good quality can be indexed by the databases [46]. Meanwhile, ERIC is a database developed by the Department of Education of the United States. Although ERIC is not as strict as Scopus and the Web of Science, the articles published in ERIC-indexed journals are also considered of good quality [47]. Collection of articles was carried out using the Publish or Perish software for the Scopus and the Web of Science databases [48]. Some previous studies have also used this application because of its facility support in the reference search process [49]–[52]. The search for articles in the ERIC database was carried out manually through the ERIC website. The years used in the article collection process were between 2012 and 2021. From the entire identification stage-based article collection process, 137 articles were obtained.

Table 2. Keywords

PICO framework	Categories	Keywords
Intervention	Flipped learning	"Flipped learning", "Inverted learning"
Comparison	Mathematics education	"Mathematics", "Math", "Education", "Instruction", "Calculus", "Geometry", "Algebra", "Statistic"

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TITLE-ABS-KEY ( ( "Flipped Learning" OR "Flipped Classroom" OR "Inverted Classroom" ) AND ( "Mathematics" OR "Calculus" OR "Algebra" OR "Geometry" OR "Statistic" ) ) AND ( LIMIT-TO ( PUBYEAR , 2021 ) OR LIMIT-TO ( PUBYEAR , 2020 ) OR LIMIT-TO ( PUBYEAR , 2019 ) OR LIMIT-TO ( PUBYEAR , 2018 ) OR LIMIT-TO ( PUBYEAR , 2017 ) OR LIMIT-TO ( PUBYEAR , 2016 ) OR LIMIT-TO ( PUBYEAR , 2015 ) OR LIMIT-TO ( PUBYEAR , 2014 ) OR LIMIT-TO ( PUBYEAR , 2013 ) OR LIMIT-TO ( PUBYEAR , 2012 ) ) AND ( LIMIT-TO ( DOCTYPE , "ar" ) ) AND ( LIMIT-TO ( LANGUAGE , "English" ) )
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Figure 1. Example of the search query in the Scopus database

2.2. Screening

The screening stage began with selecting articles collected in the identification stage by aspects of language, publication type, and duplicated papers. For ease of data analysis, this study only used English references. In the language-based selection step, as many as seven articles were found to use a non-English language, namely, the Spanish language. Furthermore, the study only used the research article type of publication. A total of 48 articles were eliminated because they did not meet the required article type criteria. For example, some references were categorized as systematic literature review articles [53], [54]. The following selection step was to eliminate duplicates of articles. In this step, 38 articles were omitted. Finally, 44 articles were considered fit to enter the eligibility stage.

2.3. Eligibility

This stage aims to select articles in terms of title and abstract. Based on the title, as many as nineteen articles were eliminated because, in addition to not representing the application of flipped learning in mathematics learning, the articles used the concept of flipped classroom instead of flipped learning. Meanwhile, based on the abstract, as many as six articles were eliminated because the research purposes were not related to the application of flipped learning in mathematics learning. A total of 19 articles were fit for further analysis in the next stage.

2.4. Inclusion

This stage was carried out by selecting articles more strictly in terms of the quality of the article's authorship. This stage was carried out using an evaluation form containing each article's intended questions. The scoring system used the concept of multiple choice, where 0=No, 1=Partially, and 2=Yes. The form was then given to two people, namely, the first author and an expert from one of the universities in Indonesia. This is based on the recommendation by Kitchenham and Charters [55] that two evaluators are appropriate to conduct data extraction. The results of the assessment of the two experts were then analyzed for the degree of agreement using Cohen's Kappa formula [56]. Using SPSS 23, a Kappa score of 87%, which was categorized as "strong", was obtained. Due to their poor quality, two articles were eliminated from the list, leaving as many as 17 articles for analysis using NVivo 12. The assessment aspects are as: i) Did the paper state its purpose clearly?; ii) Is the method of the study suitable for this study?; iii) Was the research process sufficiently documented?; iv) Were the research questions adequately answered?; v) Were the key findings clearly articulated?; and Was the flipped learning model implemented in mathematics education? [38].

3. RESULTS

3.1. Trend in flipped learning and mathematics education (RQ 1)

Figure 2 shows the publication trend of journal articles and proceedings from 2012 to 2021. Research on flipped learning first appeared in 2003 by the term inverted learning, and since then, research related to this topic remained minimal and limited until 2012, when the flipped learning concept was introduced by Bergmann and Sams [11]. However, studies integrating the flipped learning model in mathematics education only began to emerge in 2017, when there were two research results from a conference published by MERGA [57] and from a journal published by JSTOR [18]. From then on, the number of research publications on the topic fluctuated, and in 2018, there were three research results found.

In 2019, the number of publications decreased to just one publication. However, in 2020, the number skyrocketed to six articles. Until 2021, five papers were recorded to have examined the topic. The drastic increase in 2020 was closely linked to the spread of COVID-19 worldwide, forcing the learning process to be carried out entirely online or at least by blended learning [18]. Therefore, most researchers in the field of mathematics education see the need for a mathematical learning model that can be run effectively and efficiently, and one such model is the flipped learning model [18]. As for publication venues, most of the study results were published in reputable journals—94% of the articles were published on the indexed Web of Science, Scopus, and ERIC, while the remaining 6% were published in ERIC-indexed international conference proceedings as presented in Figure 3.

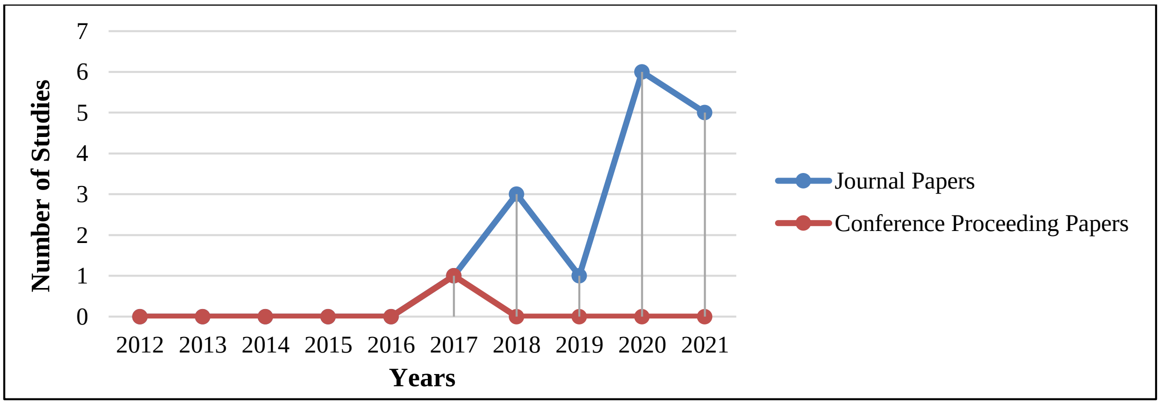

Figure 1. The number of studies related to the implementation of flipped learning in mathematics education published from 2012 to 2021

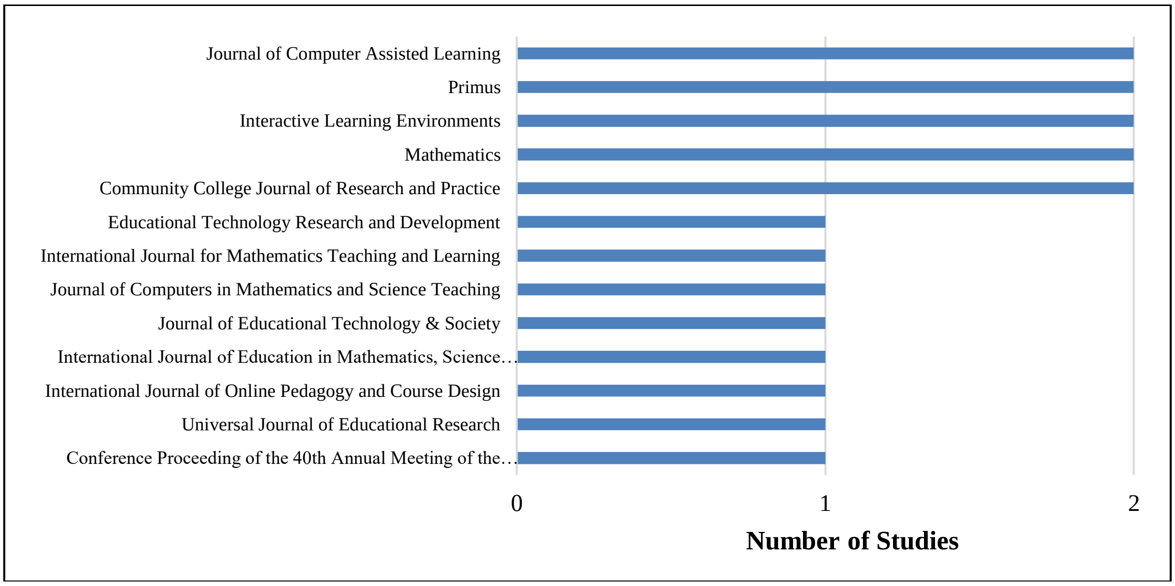

Figure 3. The list of publication venues

In terms of research theme, from the 17 research results that have been studied, three research themes related to flipped learning were found to be a trend during 2012–2021, namely i) The implementation of the flipped learning approach to improve mathematics teaching and learning quality from the student's or teacher's side; ii) The integration of the flipped learning approach with technology to improve mathematics teaching and learning quality; and iii) Designing flipped learning resources to improve the mathematics learning process. Figure 4 shows that of the three research themes, the first dominates every year. This is because explorations related to the impact of applying the flipped learning model in mathematics learning are still widely needed to enrich references. An example of such research is one conducted by Adams and Dove [58], who reviewed the application of the flipped learning approach in improving the quality of calculus learning. Based on the results of their research, classes applying the flipped learning approach tended to have a high level of participation and liveliness. In addition, the application also helped students improve their achievements in learning calculus.

Another research work on this topic was conducted by Yorganci [17], who quantitatively reviewed the application of the flipped learning approach in the mathematics learning process. By involving as many as 163 first-year students of a public university and dividing them into three groups, namely the groups receiving e-learning (EL), blended learning (BL), and flipped learning (FL) treatments. It was found that the mathematics achievements of students in the FL group were much higher than those of students in the BL and EL groups. In addition, it was also found that students from the FL group demonstrated better self-regulated learning and self-efficacy than those in the EL and BL groups. Besides these two research results, there are still other research results that have similar research themes [57], [59]–[67].

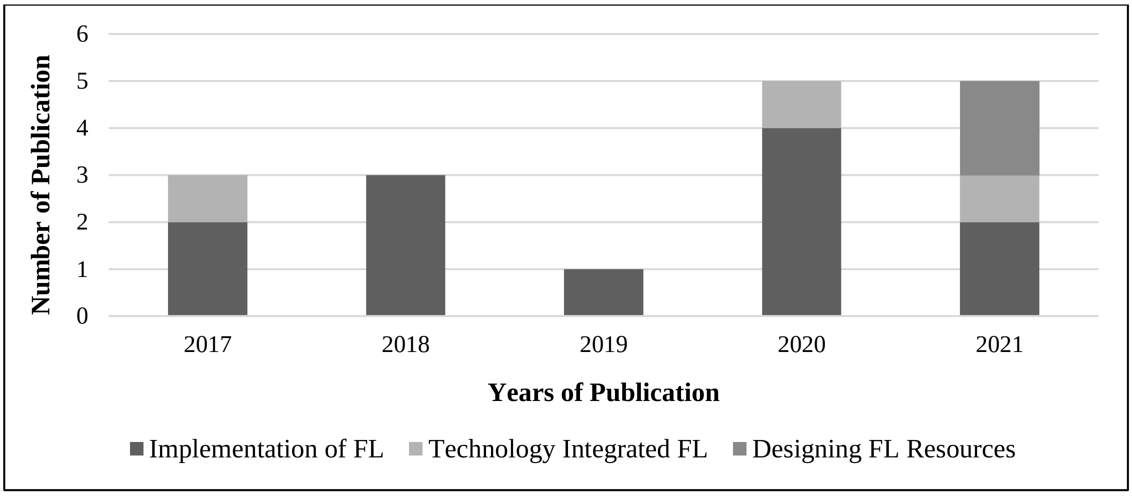

Figure 4. Trend based on research theme

There are three research works that took the theme of the integration of digital technology in mathematics learning based on the flipped learning approach, one of which was conducted by Weinhandl *et al.* [68], who qualitatively reviewed the application and integration of GeoGebra in the flipped-learning-based mathematics learning process. The finding of the study was that to integrate GeoGebra in the process of mathematics learning based on the flipped learning approach it requires clear task definition and task design; feedback; contexts and benefits; and a single-source learning environment. There were two other research results that had similar themes carried out by other researchers [18], [69].

Finally, there are two research results related to designing flipped learning approach and resources in the mathematics learning process, the first of which was by Lo, who in 2021 developed open-access flipped learning resources as an inventory of online learning needs during the COVID-19 pandemic [70]. Later in the same year, Lo also developed a flipped-learning-based approach to math learning, whose result was that student's engagement during mathematics learning increased after the implementation of the flipped learning approach that had been developed [71].

3.2. Effectiveness of implementing flipped learning models in mathematics education (RQ 2)

Based on the study results of the 17 articles, only seven empirical studies examined the comparison of flipped learning model implementation with conventional models as presented in Table 3. Of the studies that have been conducted, six stated that the flipped learning model was more effective in improving aspects of learning in mathematics education than conventional models. For example, findings from a study conducted by Zhao *et al*. [69] showed that the flipped learning model was more effective in improving students' understanding of mathematics compared to conventional models. In contrast, two articles showed that implementing the flipped learning model did not significantly affect mathematics education compared to the conventional teaching and learning model. One of the two studies is the study by Romaker [67], which showed that the application of flipped learning did not make a big difference in the mathematics learning process, especially in student engagement.

Table 1. Findings of articles comparing the flipped learning approach with the traditional approach in mathematics education

Findings	Studies
Flipped learning was effective	[17], [18], [59], [65], [66], [69]
Flipped learning caused no difference	[65], [67]

3.3. The benefits of implementing flipped learning in mathematics education (RQ 3)

From the analysis of the 17 articles that have been collected, it was found that the application of the flipped learning model in mathematics education provided many benefits for students during the learning process. The benefits obtained from the application of this learning model in the student learning process are increased learning motivation, student achievement, self-efficacy, and cognitive engagement. Having a relation to the management of the mathematics learning process, the application of flipped learning increased student collaboration and made learning more effective and efficient.

One of the most cited benefits of implementing the flipped learning model is increased students' learning motivation. An example was revealed by the results of the research conducted by Zhao *et al*. [69], in which a questionnaire was distributed to 130 students in a public primary school in Chengdu, China, and it was found that students who were involved in the flipped-learning-based math learning process experienced a significant increase in motivation. Other research also found similar results that students' learning motivation tended to rise during the flipped-learning-model-based mathematics learning process [59], [61].

The next benefit most widely cited is that the application of the flipped learning model can increase student achievement. One of the studies discussing this benefit is by Hwang and Lai [72], which involved 45 students who were divided into control and experimental groups. It was found that the application of the flipped learning model in the mathematics learning process could positively impact student achievement in mathematics learning. This finding is supported by other studies [59], [60].

With the impact of the application of the flipped learning model on mathematics learning management, the level of learning collaboration of students was found to be increased during the flipped-learning-based math learning process. Research by Patterson, McBride, and Gieger [61] involved 1,200 college students in the United States. The finding was that during the application of the flipped learning model, students tended to be able to work with their peers in solving a given math problem. This finding is also supported by Naidoo [63], who found similar conditions where student learning collaboration increased during the flipped-learning-model-based mathematics learning process. In the same study, Naidoo also found that applying the flipped learning model could make learning more effective and efficient. When these results are attributed to other studies applying the same model to different subjects, it was found that the application of the flipped learning model helped teachers efficiently use time during the learning process, so that the quality of learning became further improved [73]–[76]. Other benefits can be seen in Table 4.

Table 2. Benefits of the implementation of flipped learning in mathematics education

Benefits	Studies
Improved collaborative learning	[61], [63]
Improved time efficiency	[48]
Improved student's achievement	[18], [59], [60], [71]
Improved student's motivation	[59], [61], [69]
Improved student's self-efficacy	[17], [18]
Improved cognitive engagement	[58], [71], [74]

3.4. Learning media used in the implementation of flipped learning in mathematics education (RQ 4)

Learning media in a learning process play a significant role in helping students understand the material they want to learn [77], [78]. In applying the flipped learning model, the role of learning media is huge and even becomes part of the flipped learning model syntax [11]. Based on the review of the studies, it was found that the learning media used in the integration of flipped learning in mathematics education took the form of learning videos, mobile apps, e-books, and gamification.

According to the study results obtained, most researchers used learning videos as media to help students understand the materials used. For instance, Yorganci [17] attempted to apply the flipped learning model based on the "first principle of instruction" in mathematical learning. In the application of the flipped learning model, Yorganci [17] used lecture and question and answer videos to explain the concept of sets in mathematics. The same medium was also used by other researchers in improving students' understanding in the flipped-learning-model-based mathematics learning process [57], [59], [62], [71].

In addition to videos, e-books were also empirically proven to assist students in understanding mathematical concepts during the flipped-learning-model-based mathematics learning process. For instance, a study conducted by Zhao *et al*. [69] found that using e-books could help students understand the concept of fractions. In addition, Zhao *et al*. [69] also found that students' motivation also increased during the learning process using e-books [79]. This condition is in line with the findings of Hwang and Lai [18], where e-books significantly improved student learning performance during the flipped-learning-model-based mathematics learning process. Other types of learning media can be seen in Table 5.

Table 3. Learning media in the implementation of the flipped learning model in mathematics education

Learning media	Studies
Learning videos	[17], [57], [59], [62], [70], [71]
Mobile apps	[63]
E-books	[18], [69]
Gamification	[60]

4. DISCUSSION

4.1. Trends in flipped learning and mathematics education

The publication trend indicates that until 2021 the research interest in the flipped learning model in mathematics education had increased significantly. This is attributed to the benefits related to time-wise efficiency in learning obtained from applying the flipped learning model. However, the number of research works that focused on applying the flipped learning model in mathematics education is still deficient compared to the number of works applying flipped classroom models. This could be due to a misconception that the flipped classroom model is the same as the flipped learning model [42]. The most frequent research is related to the application of the flipped learning approach in mathematics learning, followed by research related to the integration of flipped learning with technology and designing flipped learning resources.

4.2. Effectiveness of implementing flipped learning models in mathematics education

This systematic review indicates that, in some cases, flipped learning in mathematics education was more effective than conventional learning models. Therefore, it is ideal to conduct a meta-analysis to see if there are significant differences related to the effectiveness of the flipped learning model compared to conventional learning in improving the quality of mathematical learning. Nevertheless, the small number of studies testing the effectiveness of the flipped learning model makes the meta-analysis process challenging. In addition, differences in the data retrieval techniques and instruments used in the reviewed studies make it difficult to compare the studies. However, based on the statistical data from analysis of variance (ANOVA), analysis of covariance (ANCOVA), and even T-test, the flipped learning model could improve the quality of mathematics learning in terms of learning management and aspects of student mastery of the materials studied.

4.3. The benefits of implementing flipped learning in mathematics education

Applying the flipped learning model in learning mathematics is seen as promising enough to benefit both teachers and students. However, the results showed that some studies only focused on testing the effectiveness of applying the flipped learning model in mathematical learning. The benefits found were categorized as "other findings" in the studies. In other words, efforts to review these benefits are still considered peripheral. Therefore, further research needs to focus more on identifying benefits related to the application of the flipped learning model in the mathematics learning process, especially in terms of learning management, which still has a vast room to explore.

For example, this study only reviewed one paper related to the impact of flipped learning in terms of time efficiency in the mathematics learning process [63]. This is considered vital because the COVID-19 pandemic has undeniably changed the order of the learning process with an inclination towards online learning or blended learning and with space and time limits for teachers to carry out the learning process comprehensively [79], [80]. Therefore, learning, especially mathematics learning that has its uniqueness, must be implemented effectively and efficiently where in the face-to-face learning process with very limited time can improve the quality of learning to the level of higher order thinking skills (HOTS) [15]. Through the implementation of flipped learning models, students have a wide space to explore mathematical media both in the pre-class activity phase and in the in-class activity phase [20].

4.4. Learning media used in the implementation of flipped learning in mathematics education

According to the results, the learning media used are mostly learning videos. It is not a wrong idea to use learning videos as they are part of the flipped-learning-based learning package suggested by Bergmann and Sams [11]. However, due to the uniqueness of mathematics, which has abstract work objects, mathematics knowledge construction must involve students' cognitive and psychomotor activities [80]. Therefore, it is necessary to vary the use of learning media, with the criteria to increase the role of cognitive activities, such as reasoning and critical thinking, and actively involve students in manipulating learning media. The studies' results mentioned the use of e-books, mobile apps, and gamification as an alternative to learning videos. However, these media are not enough to better fulfill the criteria mentioned earlier.

4.5. Recommendations for future research and practice

4.5.1. Expansion of research coverage on the impact of implementing the flipped learning model in mathematics education

The present study found the research theme related to implementing the flipped learning model in mathematics learning as dominant. Flipped learning was an object of trial in previous research in the effort to improve students' mathematical performance. Previous researchers were of the view that flipped learning is a variable that can be integrated with mathematics learning environments, mathematics learning media, mathematics learning curricula, and mathematics instructional designs. This is important because with the increasing number of education practitioners choosing the online learning mode as the main alternative to offline learning, the role of the flipped learning model has increased in significance. To implement the flipped learning model, institutional support, teachers, and systems must be in place in schools or universities [13]. Therefore, future research into the flipped learning model as a variable that can be integrated into mathematics learning curricula in schools or colleges is critical.

4.5.2. Using more qualitative and longitudinal data to gain a holistic understanding

The synthesis results showed that few studies still used qualitative data to measure the depth of mathematical understanding in the flipped-learning-based learning process. This is added to the fact that there is a lack of research with longitudinal data for comparison that will support a more holistic understanding related to applying the flipped learning model in mathematical learning. The reviewed studies were mainly carried out in a short time, in which case the longest time taken for a study was only one semester when the flipped learning model became a new model. Indeed, good learning is not new, but a series of evaluations remain necessary to carry out in order to achieve an effective and comprehensive learning process. Hence, the authors recommend that a multi-year study on flipped learning model application be carried out to gain longitudinal data that can be used as a reference for other research for improvement.

4.5.3. Employing more mathematics-based multimedia as learning media

The results showed that the learning media used during the flipped-learning-based math learning process were generic media—i.e., videos—with no focus on the uniqueness of mathematics as a subject that students must learn. Although learning videos can increase flexibility in the learning process [79], their application is still considered not enough for students to study mathematics comprehensively. This is because the use of learning videos only allows one-directional communication patterns, depriving students of the opportunity to be creative cognitively and kinesthetically during the learning process. Hence, the authors consider the need for further and in-depth research on using mathematics-based learning media such as GeoGebra, SPSS, Microsoft Excel, and many more, both qualitatively and quantitatively [81].

Recently, a learning method based on flipped learning named the Flop Methodology has been developed by Ogawa [82]. In principle, the method consists of the same stages as the flipped learning approach; the difference lies in the use of videos—which lays a groundwork for the conventional flipped learning approach—where these videos are integrated with several facilities that can make students interact more with them. In the context of this study, the authors suggest that the video-based Flip Flop Method be modified with mathematics-based learning media such as GeoGebra, SPSS, Microsoft Excel, or MathLab, among others. This will allow the student's math learning experience to be more condensed and developed with the needs of mathematical materials taught to students.

4.6. Limitation

Using Scopus, Web of Science, and ERIC databases could reduce the chances of getting low-quality articles. However, under the same conditions, the scope of the articles under study became narrowed. Departing from this limitation of the study, expansion of the scope of the databases used may be considered for further research. The results of this systematic review become the basis for further research in the context of efforts to implement flipped learning in mathematics education.

5. CONCLUSION

This systematic review showed an increase in the application of flipped learning in mathematics education. It is imperative to understand the trend of current practice to inform future research and implementation. The review of 17 articles included in this synthesis was based on four research questions. The findings obtained from this systematic review are as: i) There is a considerable number of research works that examined the application of flipped learning in mathematics education, some of which were specific to certain topics such as calculus; ii) Most of the research results showed the effectiveness of the flipped learning model in improving the quality of mathematical learning in both the learning management and student aspects; iii) Improvement on student motivation, self-efficacy, and achievement was the most widely generated benefit identified from the results of the reviewed studies; and iv) Videos were the most widely used learning media to improve students' understanding in the mathematics learning process. Based on the results of existing research, this study provides recommendations that can be used by practitioners, researchers, stakeholders, and policymakers in the field of mathematics education as a reference to create research-based action plans to develop and evaluate the implementation of the flipped learning model in mathematics education.

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