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Meta-Analysis of Flipped Classroom on Students' Mathematics Abilities: Effectiveness and Heterogeneity Analysis

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Abstract

Despite numerous studies investigating whether the Flipped Classroom method is more effective in enhancing students' mathematical abilities compared to conventional teaching methods, previous research has shown inconsistent results. This study aims to examine the effectiveness of the Flipped Classroom method on students' mathematical abilities compared to conventional methods and to investigate the factors that can influence the effectiveness of using the Flipped Classroom method on students' mathematical abilities. The research design used in this study is a meta-analysis, analyzing 42 effect sizes from 31 primary studies that meet inclusion criteria. The results of the analysis, using a random-effects approach, yielded a combined effect size of ($g = 1.05$; $p < 0.01$). It can be concluded that the use of the Flipped Classroom method significantly contributes to students' mathematical abilities and is more effective compared to conventional teaching methods. Furthermore, the analysis of heterogeneity found that the effectiveness of using the flipped classroom method on mathematical abilities is influenced by moderator variables such as the type of measured abilities, platform, type of experimental group, country, and publication type. However, it was not influenced by variables such as educational level and publication year. The findings of this meta-analysis provide more accurate results regarding the inconsistent effect size variations and enrich the knowledge insights about the effectiveness of using the Flipped Classroom method in enhancing students' mathematical abilities.

Keywords: mathematical ability, flipped classroom, meta-analysis, heterogeneity

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INTRODUCTION

Mathematical abilities play an irreplaceable role in our lives, both in the fields of science, technology, economy, and daily life. Mathematics enables us to understand and apply abstract concepts, conduct quantitative analysis, and make intelligent decisions (Peng et al., 2016). In the era of digitization and technological advancements, mathematical skills form the foundation for technological development, computer programming, artificial intelligence, and other innovative fields (Drijvers, 2015; Higgins et al., 2019; Kaput et al., 2020). Additionally, mathematics is a crucial tool in modeling natural phenomena, data analysis, making economic decisions, and managing personal finances (Cragg & Gilmore, 2014). By understanding mathematics well, we can develop logical,

critical, and analytical thinking essential for success in this increasingly complex world.

In an effort to enhance mathematical abilities, various teaching approaches and methods have been developed. One method that has garnered attention in recent years is the Flipped Classroom method. This method revolutionizes the roles of teachers and students in the classroom by utilizing educational technology and learning resources that can be accessed outside the classroom. In the Flipped Classroom method, learning materials are delivered in advance through videos, readings, or online resources before students attend the class. This allows students to prepare themselves and formulate questions before they discuss and apply the learned concepts in collaborative activities during class (Limayanta et al., 2021; Abeysekera & Dawson, 2015). By combining technology with effective learning principles, the Flipped Classroom can create an adaptive, interactive, and engaging learning environment, thereby facilitating the development of mathematical skills and optimizing students' learning potential.

The Flipped Classroom provides opportunities for students to independently access learning materials, acquire foundational understanding, and build conceptual skills before engaging directly with teachers and classmates. In the classroom, time that was previously used to deliver content can be allocated to more interactive and collaborative activities (Elian & Hamaidi, 2018). Through group discussions, collaborative projects, or problem-solving activities involving critical and analytical thinking, students can apply the concepts they have learned, receive immediate feedback, and deepen their understanding (Akçayır & Akçayır, 2018; Bergmans & Sams, 2012). Thus, the Flipped Classroom method offers broader opportunities for students to actively engage and build profound comprehension.

The Flipped Classroom method encourages students to prepare before class by watching videos, while in-class time is utilized for discussions and problem-solving activities related to the topics they studied (Rotellar & Cain, 2016; Ozdamli & Asiksoy, 2016). Through pre-class activities, students are expected to independently acquire foundational knowledge and skills. In the classroom, students are encouraged to participate individually and collaboratively, receiving individual support from the teacher (Brewer & Movahedazarhouligh, 2018; Ishartono et al., 2022). Flipped Classroom shifts the focus to student-centered learning, where active learning takes center stage, and the teacher becomes not only an information deliverer but also a facilitator for students in their roles as independent learners (Bergmann & Sams, 2012; Abeysekera & Dawson, 2015). The activities used in the Flipped Classroom model are closely related to active, constructivist-based learning (Arnold-Gaza, 2014; Abeysekera & Dawson, 2015). As a result, the Flipped Classroom method can be an effective approach in enhancing students' mathematical abilities and creating a learning environment that emphasizes participation and profound understanding.

Several previous studies have investigated the effectiveness of the Flipped Classroom method in improving students' mathematics abilities. Although some studies have shown that Flipped Classroom has a significant impact on enhancing mathematical skills, for instance, the research conducted by Albawi (2018); Ario & Asra (2018); Casem (2016); Darwani et al. (2023); Khoirotunnisa & Irhadtanto

(2020); Nida et al. (2019); Nurfadillah (2022); Pinontoan and Walean (2019); and Zebidi (2021). However, there are also other studies that state no significant difference between the Flipped Classroom approach and the traditional approach (Andriani et al., 2022; Jarah & Diab, 2019; Ramadhani, 2019; Zineddine, 2018). The contradictions in these research findings may be attributed to moderator factors influencing the effectiveness of the Flipped Classroom method in the context of mathematics learning. It is essential to note that individual experiments have limitations in terms of time situations, samples, and contexts, which could be reasons for the differing research outcomes (Davies, 2000). In this context, meta-analysis becomes a relevant approach to combine findings from various previous studies to obtain a more comprehensive understanding of the effectiveness of the Flipped Classroom method on students' mathematical abilities.

Meta-analysis is a statistical approach that enables the integration of data from relevant studies and provides more objective conclusions. In a meta-analysis, researchers collect and merge results from previous studies conducted on the same topic. This technique allows for the determination of the combined effect of each study used (Cohen, Manion, & Morrison, 2007). By gathering data from various sources, meta-analysis can yield more objective and reliable conclusions than other review methods. This approach emphasizes measuring the effects of empirical findings present in the analyzed studies (Schmidt & Hunter, 2004; Retnawati et al., 2018). Thus, meta-analysis becomes a powerful tool to unify existing research findings and provide a comprehensive overview of the researched topic.

This study aims to conduct a meta-analysis of the effectiveness of the Flipped Classroom method on students' mathematical abilities and investigate moderator factors that may influence its effectiveness. Through meta-analysis, we hope to identify significant factors that affect the effectiveness of the Flipped Classroom method in the context of mathematics learning. The results of this research are expected to provide useful guidance for educators and educational practitioners in implementing the Flipped Classroom method more effectively. With a deeper understanding of the factors influencing the success of this method, appropriate strategies and approaches can be found to enhance students' mathematical learning outcomes through the use of the Flipped Classroom.

METODE

Research Design

In this study, the meta-analysis method is employed to review the results of research examining the effects of the flipped classroom model on students' mathematical abilities. Generally, the stages in meta-analysis involve establishing inclusion criteria, searching for studies, collecting and coding variable data, as well as statistical analysis (Borenstein et al., 2009; Retnawati et al., 2018).

Inclusion Criteria

Inclusion Criteria In this meta-analysis research, inclusion criteria have been established to facilitate the search for studies and evaluate those that qualify for

inclusion in the analysis. By applying these inclusion criteria, the meta-analysis research can filter relevant studies and ensure that the data used for analysis are of sufficient quality and completeness. The following are the established inclusion criteria:

1. Publication Year: Studies accepted for analysis must have been published between 2016 and 2023. This time range is chosen to ensure that the utilized studies are relatively recent and relevant to the current research context.
2. Journals/Proceedings: Studies can be published in national or international journals or proceedings. This is done to obtain a diverse range of literature sources and include research findings from various academic forums.
3. Research Method: Only studies that employ experimental or quasi-experimental research methods will be included. These methods are used to ensure clear control settings and allow drawing conclusions about the cause-and-effect relationship between the use of the flipped classroom method and students' mathematical abilities.
4. Data Reporting: Selected studies must report mean values, standard deviations, and sample sizes for each experimental and control group. If this information is not available, an alternative is studies reporting sample sizes with t-values, p-values, or F-values. This criterion is essential to ensure sufficient data for calculating effect sizes and statistically combining the results of the studies.

Data Collection and Coding

Data Collection and Coding the collection of relevant studies was carried out using online databases such as Google Scholar, ERIC, Elsevier, and others. The keywords used in the literature search were "Flipped Classroom Effectiveness" AND "Mathematics" in both Indonesian and English languages. From the search results based on the predetermined criteria, a total of 110 studies were collected, and out of these, 31 primary studies were found to meet the eligibility criteria.

After obtaining the eligible articles, the literature's characteristics were identified through coding. The coding content includes the type of mathematical ability, media platform used, educational level, type of experimental group, country, publication year, and publication type. A summary of the coding results is presented in Table 1.

Table 1. Studies Included in the Meta-analysis

Moderator Variable	Frequency	Percentage (%)
Type of Mathematical Ability		
Creative Thinking	2	4.76
Critical thinking	4	9.52
Representational Capability	1	2.38
Mathematical Literacy	3	7.14
Concept Understanding	8	19.05
Solution to problem	3	7.14
Performance	5	11.90
Learning achievement	16	38.10
Media Platfors		
Edmodo	1	2.38
google classroom	7	16.67
Khan Academy	4	9.52
Moodle	6	14.29

QQ Learning	1	2.38
WhatsApp	15	35.71
Not reported	8	19.05
Educational level		
Elementary school	2	4.76
Junior High School	13	30.95
Senior High School	19	45.24
University	8	19.05
Experiment Class Types		
Conventional FC	1	88.10
Ethnomathematics based FC	1	2.38
Gamification based FC	2	2.38
Geogebra based FC	1	4.76
PBL-based FC		2.38
Country		
Arab Saudi	2	4.76
China	1	2.38
Hongkong	1	2.38
Indonesia	28	66.67
Nigeria	1	2.38
Philipina	1	2.38
Scotlandia	1	2.38
Uni Emirat Arab	4	9.52
USA	3	7.14
Year of Publication		
2016-2019	17	40.48
2020-2023	25	59.52
Type of Publication		
Journal	39	92.86
Proceedings	3	7.14

Note: FC = Flipped classroom

Data Analysis

The data analysis was conducted using Comprehensive Meta-Analysis (CMA) software Version 3. The meta-analysis scheme employed in this article consists of several steps, namely: (1) calculating the effect size of each study; (2) testing for heterogeneity and the combined effect size; (3) analyzing moderator variables; and (4) evaluating publication bias.

The interpretation of effect sizes in this study follows the classification proposed by Cohen et al. (2018). The classification of effect sizes is presented in Table 2 as follows.

Table 2. Categories of effect size groups (g)

Classification	Interval
Ignored	$0.00 < g \leq 0.19$
Small	$0.19 < g \leq 0.49$
Medium	$0.49 < g \leq 0.79$
Large	$0.79 < g \leq 1.29$
Very large	$g > 1.29$

Heterogeneity testing in this study was performed using the Q parameter and I^2 approach. If the assumption of heterogeneity is met, then the appropriate estimation model to calculate the summary effect is the random-effect model. On the other hand, if the assumption of heterogeneity is not met, the fixed-effect estimation model is used (Borenstein et al., 2009; Retnawati et al., 2018).

To measure the extent to which the available literature covers the entire spectrum of research results, a publication bias test was conducted using the File-Safe

N (FSN) approach (Muhtadi et al., 2022; Martaputri et al., 2021; Kamsurya et al., 2022; Samritin et al., 2023; Setiawan et al., 2022).

RESULT AND DISCUSSION

Effect Size for Each Study

To determine the effect size for each study, we collected data from 31 primary studies comparing the use of flipped classroom methods with conventional teaching methods in the context of mathematics education. Table 3 presents a summary of the effect size values for each study.

Table 3. Effect Size for Each Study

No	Author	Effect Size	Std. Error	Lower Limit	Upper Limit	*z*	*P*
1	Albawi (2018)	1.97	0.25	1.47	2.46	7.78	0.00
2	Andriani et al. (2022) a	1.51	0.35	0.82	2.20	4.28	0.00
3	Andriani et al. (2022) b	0.53	0.32	-0.09	1.14	1.67	0.10
4	Arifin & Herman (2018)	1.00	0.28	0.46	1.54	3.64	0.00
5	Ario & Asra (2018)	1.71	0.51	0.72	2.71	3.39	0.00
6	Arnawa & Setiawan (2021)	0.47	0.15	0.19	0.76	3.24	0.00
7	Casem (2016)	0.78	0.41	-0.03	1.58	1.89	0.00
8	Darwani et al. (2023)	1.20	0.32	0.58	1.82	3.80	0.00
9	Esperanza et al (2016)	0.42	0.21	0.01	0.84	2.02	0.04
10	Hanifah et al. (2023) a	1.90	0.29	1.33	2.47	6.55	0.00
11	Hanifah et al. (2023) b	0.90	0.25	0.41	1.40	3.59	0.00
12	Jarah & Diab (2019) a	0.98	0.24	0.51	1.44	4.14	0.00
13	Jarah & Diab (2019) b	0.97	0.24	0.51	1.43	4.12	0.00
14	Jarah & Diab (2019) c	0.91	0.23	0.45	1.37	3.88	0.00
15	Jarah & Diab (2019) d	0.19	0.22	-0.25	0.63	0.86	0.39
16	Juniantari et al (2018)	1.20	0.26	0.68	1.72	4.53	0.00
17	Khofifah et al (2021) 1a	1.44	0.28	0.88	1.99	5.09	0.00
18	Khofifah et al (2021) 1b	0.66	0.26	0.15	1.16	2.56	0.01
19	Khofifah et al (2021) 2a	1.41	0.28	0.86	1.96	5.01	0.00
20	Khofifah et al (2021) 2b	0.98	0.27	0.46	1.50	3.69	0.00
21	Khoirotunnisa & Irhadtanto (2020)	1.60	0.28	1.04	2.16	5.62	0.00
22	Kiptiyah et al (2021) b	0.79	0.22	0.36	1.21	3.63	0.00
23	Lo & Hew (2018)	0.72	0.27	0.18	1.26	2.62	0.01
24	Makinde (2020)	0.92	0.13	0.67	1.17	7.26	0.00
25	Mubarokah et al. (2022)	0.74	0.25	0.26	1.23	3.01	0.00
26	Nida et al. (2019)	1.27	0.17	0.94	1.60	7.58	0.00
27	Nurfadillah (2022)	0.99	0.28	0.44	1.54	3.55	0.00
28	Nurhayati (2022)	0.89	0.29	0.33	1.45	3.11	0.00
29	Pinontoan & Walean (2019)	1.00	0.32	0.37	1.63	3.10	0.00
30	Pratidiana et al. (2022)	1.52	0.35	0.83	2.21	4.30	0.00
31	Pratiwi (2021)	1.79	0.29	1.22	2.37	6.10	0.00
32	Ramadhani (2019)	0.11	0.25	-0.38	0.60	0.43	0.67
33	Salsabila & Maarif (2022)	0.73	0.26	0.21	1.25	2.77	0.01
34	Saputra & Mujib (2018)	3.12	0.36	2.41	3.83	8.61	0.00
35	Sihotang et al. (2023)	0.82	0.31	0.21	1.42	2.64	0.01
36	Spotts & Blumme (2020) a	1.11	0.32	0.48	1.73	3.47	0.00
37	Spotts & Blumme (2020) b	0.70	0.31	0.10	1.30	2.28	0.02
38	Syahrul et al (2020)	0.77	0.26	0.26	1.28	2.96	0.00
39	Wei et al (2020)	0.62	0.22	0.20	1.05	2.87	0.00
40	Zatalini et (2017)	0.63	0.27	0.11	1.15	2.37	0.02
41	Zebidi (2021)	3.47	0.44	2.59	4.34	7.80	0.00
42	Zineddine (2018)	0.42	0.31	-0.18	1.03	1.37	0.17

Based on Table 3 above, it is found that out of a total of 42 effect sizes analyzed, the smallest effect size is 0.11, and the largest effect size is 3.47. Using Cohen's (2018) classification, there are eleven studies (n = 11) with a very large effect, sixteen studies (n = 16) with a large effect, ten studies (n = 10) with a moderate effect, three studies (n = 3) with a small effect, and two studies (n = 2) with a negligible effect. These findings indicate that the use of the flipped classroom method on students' mathematics abilities has a significant variation in effect sizes. Therefore, to obtain a more accurate conclusion, it is necessary to calculate the combined effect size.

Heterogeneity Test and Combined Effect Size

To test the heterogeneity among the included studies, we used the Q statistic and I^2. Furthermore, we used the results of the heterogeneity test to select the appropriate estimation model to calculate the combined effect size. Table 4 presents a summary of the heterogeneity test and the random-effect and fixed-effect estimation models.

Table 4. Summary of Heterogeneity Test and Combined Effect Size

Model	k	Effect Size (g)	Lower Limit	Uper Limit	p	df	Heterogeneity		
							Q	P	I^2
Random-Effect	42	1.05	0.89	1.02	< 0.01	41	180.21	< 0.01	77.25%
Fixed-Effect	42	0.96	0.84	1.04	< 0.01	41			

The heterogeneity test results (see Table 2) showed a Q value of 180.21; df = 41, $p < 0.05$; and I^2 of 77.25%. These results indicate a significant level of heterogeneity among the analyzed studies. Therefore, we utilized a random-effects model to calculate the combined effect size. Based on the random-effects estimation model, the obtained combined effect size is ($g = 1.05$; $p < 0.01$). This effect size falls into the category of a large effect. Thus, it can be concluded that the use of the flipped classroom method has a significant influence on students' mathematics abilities and is more effective compared to conventional methods.

Moderator Variable Analysis

Next, we conducted moderator variable analysis to identify factors that may influence the effectiveness of the flipped classroom on students' mathematics abilities. The moderator variables we considered include the type of mathematics ability, platform, educational level, type of experimental group, country, publication year, and publication type. Table 5 presents a summary of the moderator variable analysis.

Table 5. Moderator variable analysis results

Moderator Variables	Number Studies	g	Std. Error	p	Heterogeneity				
					Q	df	Qw	Qb	P
Type of Mathematical Ability									
Creative Thinking	2	1.36	0.14	0.00	0.99	7	153.58	26.63	0.00
Critical thinking	4	1.19	0.15	0.00	12.51				
Representational Capability	1	0.82	0.31	0.01	0.00				
Mathematical Literacy	3	0.80	0.14	0.00	0.17				

Concept Understanding	8	1.13	0.10	0.00	39.34				
Solution to problem	3	1.26	0.17	0.00	1.91				
Performance	5	0.65	0.12	0.00	3.34				
Learning achievement	16	0.87	0.06	0.00	95.32				
Platform Media									
Edmodo	1	1.20	0.26	0.00	0.00				
google classroom	7	0.70	0.09	0.00	23.72				
Khan Academy	4	0.75	0.12	0.00	8.49				
Moodle	6	1.06	0.11	0.00	17.44	6	158.22	21.99	0.00
QQ Learning	1	0.62	0.22	0.00	0.00				
WhatsApp	15	1.11	0.06	0.00	30.06				
Not reported	8	1.04	0.11	0.00	78.51				
Educational level									
Elementary school	2	0.86	0.19	0.00	0.51				
Junior High School	13	1.11	0.07	0.00	58.15	3	172.75	7.46	0.06
Senior High School	19	0.87	0.06	0.00	51.80				
University	8	0.99	0.09	0.00	62.29				
Experiment Class Types									
Conventional FC	37	0.97	0.04	0.00	154.37				
Ethnomathematics based FC	1	0.79	0.22	0.00	0.00				
Gamification based FC	1	0.72	0.27	0.01	0.00	4	155.09	25.12	0.00
Geogebra based FC	2	1.74	0.22	0.00	0.71				
PBL-based FC	1	0.11	0.25	0.67	0.00				
Country									
Arab Saudi	2	2.33	0.22	0.00	8.61				
China	1	0.62	0.22	0.00	0.00				
Hongkong	1	0.72	0.27	0.01	0.00				
Indonesia	28	1.01	0.05	0.00	105.68				
Nigeria	1	0.92	0.13	0.00	0.00	8	125.15	55.06	0.00
Philipina	1	0.78	0.41	0.03	0.00				
Scotlandia	1	0.42	0.21	0.04	0.00				
Uni Emirat Arab	4	0.75	0.12	0.00	8.49				
USA	3	0.74	0.18	0.00	2.37				
Year of Publication									
2016-2019	17	0.94	0.06	0.00	93.06	1	180.01	0.20	0.65
2020-2023	25	0.97	0.05	0.00	86.95				
Type of Publication									
Journal	39	0.92	0.04	0.00	165.52	1	172.26	7.95	0.01
Proceedings	3	1.30	0.13	0.00	6.74				

Note. g = effect size; Qw = Q within; Qb = Q between.

Type of Mathematical Ability

The moderator variable of mathematical ability types consists of eight groups: creative thinking, critical thinking, representation skills, mathematical literacy, conceptual understanding, problem-solving, performance, and learning achievement. The analysis results (see Table 5) indicate that the implementation of the flipped classroom method has a significant effect on creative thinking ability (g = 1.36; p = 0.00), critical thinking ability (g = 1.19; p = 0.00), representation skills (g = 0.82; p = 0.00), mathematical literacy (g = 0.80; p = 0.00), conceptual understanding (g = 1.13; p = 0.00), problem-solving skills (g =

1.26; p = 0.00), performance (g = 0.65; p = 0.00), and learning achievement (g = 0.87; p = 0.00). The heterogeneity test results found that the average effect sizes of these eight groups differ significantly (Qb = 26.63; p = 0.00). This indicates that the variable of mathematical ability types influences the impact of using the flipped classroom method on students' mathematical abilities. Although the average effect sizes of the eight groups were found to differ significantly, the use of the flipped classroom method was reported to have a significant impact on all eight groups.

Media Platforms

The moderator variable of media platforms consists of seven groups: Edmodo, Google Classroom, Khan Academy, Moodle, QQ Learning, WhatsApp, and not reported. The analysis results (see Table 5) show that the use of the flipped classroom method has a significant impact on mathematical abilities with the assistance of the Edmodo media platform (g = 1.20; p = 0.00), Google Classroom (g = 0.70; p = 0.00), Khan Academy (g = 0.75; p = 0.00), Moodle (g = 1.06; p = 0.00), QQ Learning (g = 0.62; p = 0.00), and WhatsApp (g = 1.11; p = 0.00). The heterogeneity test results found that the average effect sizes of these seven groups differ significantly (Qb = 21.99; p = 0.00). This indicates that the variable of media platforms influences the impact of using the flipped classroom method on students' mathematical abilities. Although the four groups were found to differ significantly, the use of the flipped classroom method on mathematical abilities was reported to have a significant impact on all seven groups.

Education Level

The moderator variable of education level consists of four groups, namely Elementary School (SD), High School (SMA), Junior High School (SMP), and University. The results of the analysis (see Table 5) indicate that the use of the flipped classroom method significantly influences mathematics proficiency at the Elementary School level (g = 0.86; p = 0.00), Junior High School level (g = 1.11; p = 0.00), High School level (g = 0.87; p = 0.00), and University level (g = 0.99; p = 0.00). The test of heterogeneity found that the average effect size of the four groups did not differ significantly (Qb = 7.46; p = 0.06). This result indicates that the education level variable does not affect the impact of using the flipped classroom method on students' mathematics proficiency. In other words, the use of the flipped classroom method on mathematics proficiency will be equally effective when applied at all four education levels.

Type of Experimental Group

The moderator variable of the experimental group type consists of five groups, namely Conventional Flipped Classroom (FC), Ethnomathematics-based FC, Gamification-based FC, Geogebra-based FC, and Problem-Based Learning (PBL)-based FC. The results of the analysis (see Table 5) indicate that students' mathematics proficiency significantly improved through the conventional flipped classroom method (g = 0.97; p = 0.00), Ethnomathematics-based FC (g = 0.79; p = 0.00), Gamification-based FC (g = 0.72; p = 0.01), and Geogebra-based FC (g = 1.74; p = 0.00). However, there was no significant improvement observed through the Problem-Based Learning (PBL)-based FC (g = 0.11; p = 0.67). The test of

heterogeneity found that the average effect size of the five groups differed significantly (Qb = 25.12; p = 0.00). This result indicates that the variable of experimental group type affects the impact of using the flipped classroom method on students' mathematics proficiency. Although the five groups were found to be significantly different, the use of the flipped classroom method was reported to have a significant effect on students' mathematics proficiency in all five groups.

Country

The moderator variable of country consists of nine groups: Saudi Arabia, China, Hong Kong, Indonesia, Nigeria, the Philippines, Scotland, the United Arab Emirates, and the USA. The results of the analysis (see Table 5) indicate that the use of the flipped classroom method significantly affects students' mathematics ability in Saudi Arabia (g = 2.33; p = 0.00), China (g = 0.62; p = 0.00), Hong Kong (g = 0.72; p = 0.01), Indonesia (g = 1.01; p = 0.00), Nigeria (g = 0.92; p = 0.00), the Philippines (g = 0.78; p = 0.03), Scotland (g = 0.42; p = 0.04), the United Arab Emirates (g = 0.75; p = 0.00), and the USA (g = 0.74; p = 0.00). The results of the heterogeneity test reveal that the average effect sizes of these nine groups differ significantly (Qb = 55.06; p = 0.00). These findings indicate that the country variable influences the impact of using the flipped classroom method on students' mathematics abilities. Despite significant differences among the nine groups, the use of the flipped classroom method has a significant effect on students' mathematics ability in all of them.

Publication Year

The moderator variable of publication year consists of two groups: publications from 2016 to 2019 and publications from 2020 to 2023. The results of the analysis (see Table 5) show that the use of the flipped classroom method significantly affects students' mathematics ability reported in publications from 2016 to 2019 (g = 0.94; p = 0.00) and publications from 2020 to 2023 (g = 0.97; p = 0.00). The heterogeneity test reveals that the average effect sizes of both groups do not differ significantly (Qb = 0.20; p = 0.65). These results indicate that the publication year variable does not influence the impact of using the flipped classroom method on students' mathematics ability. This means that the use of the flipped classroom method can provide significant benefits in improving students' mathematics ability, both in the earlier years (2016-2019) and in the more recent years (2020-2023).

Publication Type

The moderator variable of publication type consists of two groups: journal publications and conference proceedings. The results of the analysis (see Table 5) show that the use of technology-based learning media significantly affects students' mathematics ability in both the journal publication group (g = 0.92; p = 0.00) and the conference proceedings group (g = 1.30; p = 0.00). The heterogeneity analysis reveals that the average effect sizes of the two groups differ significantly (Qb = 7.95; p = 0.00). These results indicate that the publication type variable influences the impact of using the flipped classroom method on students' mathematics ability. Despite the confirmed significant differences in the average

effect sizes of the two groups, the use of the flipped classroom method has a significant effect on students' mathematics ability in both groups.

Publication Bias Evaluation

We also conducted an evaluation of the potential publication bias in the studies we included. We utilized the file-safe N (FSN) method to assess the likelihood of publication bias. Table 6 presents the results of the Fail-Safe N analysis.

Table 6. Fail-Safe N Analysis

z-value	25.17
p-value	0.00
Alpha	0.05
Z for Alpha	1.96
N	42
P > number of missing studies	6888

Based on the analysis presented in Table 6, it was found that the obtained p-value is smaller than the predetermined alpha value. This indicates that the research can be considered reliable and valid (Borenstein et al., 2009). Additionally, according to the fail-safe N analysis, it is estimated that 5783 undisclosed studies would be needed to change the p-value to be larger than alpha = 0.05. With such a substantial number of studies, the results of this analysis can be considered dependable, and there is no indication of significant publication bias.

Discussion

The results of the meta-analysis conducted on 42 effect sizes indicate that the use of the flipped classroom method has a significant positive impact on students' overall mathematics abilities ($g = 1.05$; $p = 0.00$). These findings consistently show that the flipped classroom method is more effective than conventional teaching methods in improving students' mathematics abilities. These results align with previous meta-analyses conducted by Cheng et al. (2019), Güler et al. (2023), Purnomo et al. (2022), Shi et al. (2020), Wagner et al. (2020), and Yakar (2021), which also found that the use of the flipped classroom method significantly improves students' learning outcomes. These consistent findings provide more strength and credibility in recommending the use of the flipped classroom method as an effective approach to enhance students' mathematics abilities. In this context, the flipped classroom approach can be considered a successful strategy in providing a more interactive, participatory learning experience, allowing students to access materials independently before class. This can help students build a stronger conceptual understanding and improve their mathematics abilities.

Furthermore, we investigated heterogeneity to explore factors that may influence the effectiveness of using the flipped classroom method on students' mathematics abilities. Our meta-analysis results also show that the effectiveness of the flipped classroom method can be significantly influenced by several moderator variables, including the type of mathematics ability, media platform, experimental group type, country, and publication type. However, our research

indicates that moderator variables such as educational level and publication year do not affect the effectiveness of the flipped classroom method on students' mathematics abilities.

Firstly, we found that the type of mathematics ability studied as a moderator variable has a significant influence on the impact of using the flipped classroom method on students' mathematics abilities. This suggests that the effectiveness of the flipped classroom method may vary depending on the specific type of mathematics ability being observed. This finding is consistent with the research conducted by Lusa et al. (2021) and Mawardi et al. (2023), who found that the type of ability being studied can influence the effect size. Despite significant differences among these groups, we found that the flipped classroom method can be effective in enhancing various types of students' mathematics abilities, including creative thinking, critical thinking, representation, mathematical literacy, conceptual understanding, problem-solving, performance, and learning achievements. This method facilitates active, reflective, and interactive learning between students and the learning materials (Hwang et al., 2019). Therefore, the flipped classroom method can be a relevant and effective choice for educators to strengthen students' mathematics learning.

Secondly, the moderator variable of the type of media platform used has a significant influence on the impact of using the flipped classroom method on students' mathematical abilities. This indicates that the effectiveness of using the flipped classroom method can vary depending on the type of media platform used. This finding is consistent with the research by Purnomo et al. (2022) and Mawardi et al. (2023), who found that the type of media platform used can affect the effectiveness of distance learning. Despite the significant differences between these groups, we found that the use of the flipped classroom method still had a significant impact on all types of media platforms studied, including Edmodo, Google Classroom, Khan Academy, Moodle, QQ Learning, and WhatsApp. This finding provides evidence that the use of the flipped classroom method with various media platforms can be effective in improving students' mathematical abilities. Each media platform has its own role and characteristics in supporting effective mathematics learning. Thus, selecting a media platform that suits the needs and learning context can enhance the effectiveness of using the flipped classroom method.

Thirdly, the moderator variable of educational level does not have a significant influence on the impact of using the flipped classroom method on students' mathematical abilities. This indicates that the use of the flipped classroom method has a similar impact on students' mathematical abilities at all educational levels studied. In other words, the method's effectiveness in improving students' mathematical abilities remains consistent, regardless of the educational level being pursued. This finding is in line with the research by Cheng et al. (2018); Güler et al. (2023); Låg and Sæle (2019); Vitta and Al-Hoorie (2020); and Yakar et al. (2021), who found that the educational level variable does not significantly affect the effectiveness of using the flipped classroom method. This finding has important implications that the flipped classroom method can be an effective strategy in improving students' mathematical abilities at various educational levels, including primary schools, middle schools, high

schools, and universities. The method can be adapted and applied effectively in the context of mathematics learning at different educational levels.

Fourthly, the moderator variable of the type of experimental group has a significant influence on the impact of using the flipped classroom method on students' mathematical abilities. This indicates that the impact of using the flipped classroom method can vary depending on the type of experimental group used. Our findings show that the use of the flipped classroom method has a significant impact on improving students' mathematical abilities in several types of experimental groups, such as conventional flipped classroom, Ethnomathematics-based flipped classroom, Gamification-based flipped classroom, and Geogebra-based flipped classroom. However, this is not the case for PBL-based flipped classroom. This finding provides evidence that the use of the flipped classroom method with different types of experimental groups can be effective in improving students' mathematical abilities. Each type of experimental group has its own approach and strategies in helping students better understand and master mathematical concepts. However, it should be noted that our findings indicate that the use of PBL-based flipped classroom did not show a significant improvement in students' mathematical abilities. Therefore, selecting an appropriate type of experimental group based on the needs and characteristics of the students can enhance the effectiveness of using the flipped classroom method in improving students' mathematical abilities.

Fifthly, the moderator variable of country groups has a significant influence on the impact of using the flipped classroom method on students' mathematics abilities. This indicates that the influence of using the flipped classroom method may vary depending on the country under study. This finding is also consistent with Güler et al. (2023) research, which found that the country group variable affects the effectiveness of using the flipped classroom. Despite significant differences among the nine country groups studied, we found that the use of the flipped classroom method significantly influences the improvement of students' mathematics abilities in various countries, including Saudi Arabia, China, Hong Kong, Indonesia, Nigeria, the Philippines, Scotland, the United Arab Emirates, and the USA. This finding provides evidence that the use of the flipped classroom method across different countries can be effective in enhancing students' mathematics abilities. Each country has its unique educational context, and the flipped classroom method can be adapted to the needs and characteristics of education in each country.

Sixthly, the moderator variable of publication year has a significant influence on the impact of using the flipped classroom method on students' mathematics abilities. This indicates that the influence of using the flipped classroom method is not affected by the publication year of the research. This method continues to have a significant impact on improving students' mathematics abilities, both in early years and in more recent years. This finding aligns with Vo et al. (2017) research, which found that the publication year variable affects the effectiveness of distance learning. This finding has important implications, suggesting that the use of the flipped classroom method remains relevant and effective in improving students' mathematics abilities, regardless of the publication year of the research. The method can be implemented successfully at

various times and educational contexts. Therefore, it can be considered an effective approach to enhance students' mathematics abilities across different research periods.

Seventhly, the moderator variable of publication type has a significant influence on the impact of using the flipped classroom method on students' mathematics abilities. This indicates that the influence of using the flipped classroom method may vary depending on the type of publication. This finding is consistent with the research by Güler et al. (2023), Mwardi et al. (2023), and Purnomo et al. (2022), which found that the publication type variable affects the effectiveness of using the flipped classroom in mathematics education. Despite significant differences between the two publication groups studied (journals and proceedings), we found that the use of the flipped classroom method significantly influences the improvement of students' mathematics abilities in both journal and proceedings publications. This finding has important implications, indicating that the use of the flipped classroom method in mathematics education can be effective, regardless of whether it is published in journals or proceedings. Therefore, the method can be considered an effective approach to enhancing mathematics learning in various research and publication contexts.

CONCLUSION

Based on the findings of this meta-analysis, it can be concluded that the use of the flipped classroom method significantly contributes to improving students' mathematics abilities and is more effective compared to conventional teaching methods. The analysis results show inconsistent variations in effect sizes, but overall, the flipped classroom method provides a significant positive impact on students' mathematics abilities. Furthermore, the heterogeneity analysis found that certain factors such as the measured ability type, platform, experimental group type, country, and publication type can influence the effectiveness of the flipped classroom method on students' mathematics abilities. This suggests that in implementing the flipped classroom method, it is essential to consider these factors to maximize its impact. However, the findings also indicate that factors such as educational level and publication year do not significantly influence the effectiveness of the flipped classroom method. Therefore, this research provides a deeper understanding of the factors that influence the effectiveness of using the flipped classroom method to enhance students' mathematics abilities.

The results of this study have important implications for curriculum development and mathematics teaching practices. The use of the flipped classroom method can be an effective strategy to improve students' mathematics abilities. However, it is essential to consider factors such as the measured ability type, platform, experimental group type, country, and publication type to maximize its effectiveness. These findings also make valuable contributions to the literature on mathematics education by combining and analyzing findings from previous research. However, there are limitations in this study that need to be considered, such as limited primary data, heterogeneity of primary studies, potential publication bias, limited generalizability, and the absence of primary

study quality analysis. Further research is recommended to broaden the scope of including primary studies, address more detailed heterogeneity, conduct primary study quality evaluation, and consider other factors that may influence the effectiveness of using the flipped classroom method. These findings are expected to provide useful guidance for education practitioners and researchers in developing effective mathematics teaching methods.

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