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Flipped Classrooms in Higher Education: A Meta-Analysis of Their Impact on Mathematics Performance

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Abstract

This study aims to identify the impact of flipped classrooms on students' performance in mathematics at higher levels of education, including universities and colleges. The flipped classroom is classified as blended learning, in which the content of a subject is delivered through both face-to-face classroom activities and online learning. Blended learning, also known as hybrid learning, focuses on a mixed-mode type of education in which the medium of instruction is delivered with technology integration. Numerous studies have been conducted to compare the efficiency of traditional learning methods versus the flipped classroom in terms of how well students learn mathematics. The Preferred Reporting Items for Systematic Reviews and Meta-Analysis (PRISMA) guidelines have been referred to in conducting this study. A total of 25 selected studies were searched through Scopus, ScienceDirect, and the Web of Science (WoS) database from 2017 to 2023. Moreover, Jefreys' Amazing Statistical Programme (JASP) version 0.17.1.0 has been utilised to analyse the data collected from the previous studies. The findings suggest that the average effect size using a random-effects model was (Cohen's $d = 0.474$; $p < 0.001$), demonstrating a medium effect size that is statistically significant.

Keywords: flipped classroom; blended learning; mathematics education; higher education; meta-analysis; effect sizes.

1 Introduction

Educational institutions have developed new teaching and learning strategies that involve the use of technology to deliver instructional materials due to the tremendous technological advancements that have taken place in recent years. Note that technology plays an important part in every element of an individual's life, including education, to generate learners with twenty-first-century abilities, which should be integrated into the teaching and learning process. This implementation can provide a substantial framework for students to use their classroom knowledge to adapt to rapid changes in society all around the globe. As a result, new learning techniques are included in the educational system to foster an atmosphere in which students can remember mathematics concepts in the classroom. According to Zhao and Watterson [63], new teaching techniques should promote students' competences and talents rather than merely their topic knowledge. Moreover, students' knowledge acquisition abilities, as well as their social and emotional well-being, should be recognised in order to foster good connections and concrete educational engagements.

Furthermore, innovative learning strategies that include technology should be capable of establishing a link between students' educational experiences and learning environments. For example, incorporating Sustainable Development Goals (SDG) into the teaching and learning process is critical in order to equip a person with essential information and abilities. Thus, an effective educational strategy can attain the SDG's scope, which is the course of action to eradicate poverty and inequality, to safeguard the environment, and to provide prosperity and justice for all people worldwide. Consequently, the education system is the primary key to meeting the needs and desires of people, communities, and society within an egalitarian framework. However, conventional teaching methods do not support students for a sustainable future since they focus on conceptual understanding [22]. According to Buil-Fabregá et al. [9] a flipped classroom is an excellent approach that can engage students in understanding the importance of a sustainable development. Therefore, implementing a flipped classroom that is connected with a sustainable development is capable of equipping students with various talents and skills. This aligns well with the primary aim of the hybrid learning implementation.

2 Background of Study

2.1 Flipped classroom

Flipped classrooms in higher education provide students with improved knowledge and learning experiences in the twenty-first century. A flipped classroom is a mixed learning strategy in which topic knowledge is conducted via face-to-face and online classroom activities. The flipped classroom Model, as defined by Baker [8], is an instructional strategy that involves conducting advanced coursework in the classroom and using educational technology to help students understand the basic and theoretical components of a subject outside of class. Blended learning, also known as hybrid learning, involves students in a mixed-mode type of education in which the medium of teaching is performed through technology. Incorporating technology into an educational system can potentially improve students' required abilities in the present digital age. In other words, a flipped classroom is the inverse of a typical classroom. It encourages students to expand the lessons outside of class using tools supplied by lecturers, such as recorded videos, forums, quizzes, and others. Furthermore, since prior educational patterns restrict students' views on thinking, the new approach of giving educational instructions should be incorporated concurrently in instructional methods [48]. As a result of this new academic pattern, students are anticipated to be more competent since they will be exposed to an atmosphere that will assist them in being well-prepared for their future vocations.

According to Say and Yildirim [43], deploying a flipped classroom may consider variances in students' capacity to retain information and increase their ability to acquire knowledge quickly since this learning environment is relevant to current individuals' requirements. Furthermore, in contrast to conventional teaching methods, this innovative strategy may provide students with an atmosphere of active learning, encouraging them in using newly gained information in a real-life context. Additionally, the flipped classroom's key aspects are to promote critical thinking and encourage students to be engaged with sophisticated ways of thinking compared to the conventional teaching technique, which is inappropriate for the present speed of society [34]. Divjak et al. [18] stated that the diversity of instructional materials for the teaching and learning process is more than just a difference that can be recognised by building a flipped classroom. However, it also relies on integrating information into an entire strategy.

In addition, the deployment of flipped classrooms may develop students' involvement with learning materials at a higher level of education, notably in mathematics topics, since this subject requires them to anticipate mathematical knowledge beyond the basic. According to Singh et al. [51], students at the tertiary level of education, such as colleges and universities, need to be introduced to a novel approach to absorb mathematical information, which is possible via flipped classrooms. Thus, a novel educational technique, such as a flipped classroom, may enable students to acquire and apply mathematical ideas in various settings, including non-typical and real-life scenarios related to mathematics topic. Note that the pillars of a flipped classroom must be addressed by educators in generating active learners based on a flipped learning network to establish a suitable environment for teaching and learning in mathematics. The flipped classroom's four key pillars are provided in Table 1 below, introduced by the flipped learning network in 2014.

Table 1: Four pillars of flipped classroom.

4 Pillars of Flipped Classroom	
F	Flexible Environment
L	Learning Culture
I	Intentional Content
P	Professional Educator

According to Villegas [58], a flexible environment refers to spaces and methods of learning that allow students to learn in ways that suit their needs and learning styles. Learning culture refers to the values, attitudes, and practices that foster active learning and student engagement. Intentional content refers to the selection and delivery of learning materials that are carefully planned to achieve specific learning goals. Professional educators are teachers who are trained and skilled in managing and implementing flipped classroom models, as well as in planning and providing quality learning experiences.

As a result, a successful mathematics flipped classroom may be created as long as educators can build a flexible learning mode. This includes the timing and platform for delivering the teaching content and for promoting student-centred learning throughout the learning process. Furthermore, educators' ability to optimise students' interactions using the learning materials and manage the classroom skilfully in terms of observing, assessing, and providing feedback to students can generate interactive learning by implementing a flipped classroom, which is aligned with the development of an educational progress [29].

2.2 The implementation of a flipped classroom in mathematics

Mathematics is an important component of existence since it allows people to comprehend the patterns of life and find global links. However, the students face difficulties in understanding mathematics since the lessons are provided in a conventional manner. Some educators still use direct learning in the process of learning mathematics. According to Yeh et al. [62], the traditional teaching method that emphasises teacher-centred learning still predominates in the mathematics classroom pedagogy. This can result in a significant number of low-achiever students and thus obstructing the development of mathematical skills among students. Furthermore, in contrast to interactive learning, the fundamental mathematical principles provided by educators in the conventional classroom require students to discover the answers independently for problem-solving issues. Since students are solely concentrated on completing problems individually, this conventional style of teaching mathematics does not foster students' participation in obtaining new information in the classroom. On the other hand, the progressive teaching method emphasises an active learning environment throughout the process of learning mathematics, allowing students to develop the necessary skills for current demands while promoting a conducive educational environment in the classroom.

As a result, the deployment of flipped classrooms for mathematics topics should be promoted, as students will be armed with a stronger comprehension of mathematical ideas since this learning technique allows flexibility in studying mathematics. Indeed, students with a wider variety of knowledge that matches the demands of mathematics may increase their grasp of mathematical ideas. According to Toivola et al. [55], the three major goals of educators in adopting the flipped classroom across the whole teaching and learning process are to foster an atmosphere of personalised learning, to enhance students' engagement, and to develop students' self-regulation. Furthermore, using flipped classrooms in mathematics subjects can improve students' abilities to connect existing information with new information of mathematical knowledge. Note that this type of learning encourages students' transformation in terms of knowledge and experience, which can improve their performance in higher-level outcomes [11, 4].

Meanwhile, active learning for mathematics classes may be conducted through engaging in peer learning activities such as collaborative assignments to foster mathematical interests and promote inductive as well as deductive thinking. As a result, the precise approaches that educators utilise in developing mathematical knowledge in children can connect them with real-life circumstances. Furthermore, when they apply their mathematics knowledge to their judgements and conclusions, they can strengthen their analytical thinking and logical reasoning. Trust et al. [56] stated that a novel pedagogical approach should be integrated into teaching and learning to encourage students to engage in an interactive learning environment and to stimulate twenty-first-century skills such as creativity, problem-solving and collaboration. These are in line with the demand for higher education in preparing individuals to adapt to rapid changes. As a result, implementing flipped learning in mathematics disciplines has the potential to produce persons with high proficiency in making judgements and arguments using a mathematical method. According to Güler et al. [20], the notion of a flipped classroom, which was established at the beginning of twenty-first-century learning, can provide a new viewpoint on teaching and learning mathematics, which may motivate students to participate. Therefore, this study aims to examine the impact of flipped classrooms on students' performance in mathematics at the higher education level through systematic reviews and meta-analysis.

3 Research Methodology

3.1 Research design

This is a quantitative study in which the data was synthesised using a meta-analysis process. The meta-analysis approach was used in this research to examine the usefulness of the flipped classroom, which is being used in mathematics disciplines at the higher education level. According to Paul and Barari [39], the meta-analysis study is defined as quantitative since the data is being evaluated and synthesised from quantitative research. Quantitative research data may be obtained using one of five different study designs; descriptive, survey, correlational, quasi-experimental, or experimental. As a result, prior research was mostly being gathered based on a quantitative design before undergoing a systematic approach that was utilised for meta-analysis.

The researchers then used the Preferred Reporting Items for Systematic and Meta-Analysis (PRISMA) to select prior studies in the meta-analysis by following the inclusion and exclusion criteria. Previous studies were analysed per these criteria to provide trustworthy findings capable of concluding the deployment of flipped classrooms in mathematical disciplines at higher education levels, such as universities and colleges. Furthermore, past studies were examined using a systematic process known as a systematic literature review, which aided the researchers in examining the relevant materials. Consequently, the meta-analysis comprised the entire number of prior research included in this study after going through a methodical selection procedure. The meta-analysis findings helped the researchers determine the efficacy of flipped classes in mathematical topics at the higher education level. Based on the findings acquired, the researcher formed a conclusion.

To conduct a systematic review and meta-analysis, the literature from the previous research was searched from 2017 to 2023 using Scopus, ScienceDirect, and Web of Science (WoS) database. The keywords used in identifying 30 potential articles relevant to the research title were being searched using combinations of Boolean operators. The keywords with the Boolean operators used in this study were as follows: (flip* OR active* OR blended* OR inverted* OR technology* OR video*) AND (learning* OR classroom* OR instruction* OR pedagogy*) AND (mathematics* OR calculus* OR linear algebra* OR statistic*) AND (education* OR teaching*) AND (undergraduate* OR higher-level* OR post-secondary* OR tertiary*). In addition, the symbol of an asterisk was utilised to explain the keywords for searching literature studies to represent the possible expression for the flipped mathematics classroom for higher-education students.

3.2 PRISMA flow diagram

In this systematic review, the researchers followed the PRISMA framework Moher et al. [35] guidelines for selecting the number of studies to include in the meta-analyses. PRISMA was employed in this study in analysing the efficacy of flipped classrooms in mathematics for higher education students within the research topic that was suggested to create a meaningful review. As observed in Figure 1, a total of 25 papers were included in the meta-analysis. Consequently, the identification and screening stages, which entailed the record of database recognition as well as the inclusion and exclusion criteria, necessitated the selection of earlier studies that were included in this study. As a result, the researchers followed the PRISMA flow diagram when choosing prior studies in order to maximise the transparency of systematic literature reviews and meta-analyses.

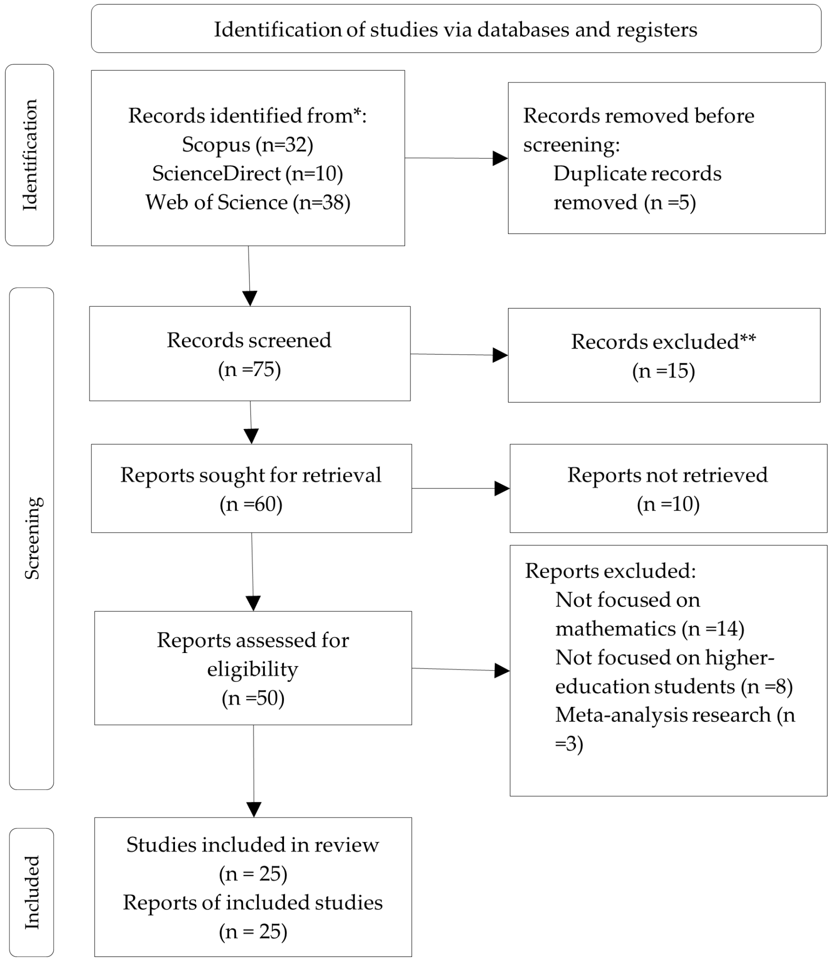

Figure 1: PRISMA flow diagram.

3.3 Inclusion and exclusion criteria

To address the research question, the articles were filtered using inclusion and exclusion criteria. The included articles used quantitative data, including descriptive, quasi-experimental, and experimental research. Other than that, the articles also encompassed higher education levels, such as universities and colleges. The articles also explicitly described the mathematical topics and courses used in the flipped classroom. Furthermore, the metrics and variables used in the articles were carefully stated. The articles adhered to the whole flipped classroom pattern used in the study. Therefore, the articles offered significant information, such as the mean value, standard deviations, and sample size, to determine each study's effect size. The omitted requirements were articles unrelated to the mathematical topic. As a result, the search did not specify the higher education level. Since the articles were gathered through systematic review analyses rather than actual research, they were omitted. In addition, some articles were eliminated if the sample size and significant information were not indicated. The inclusion and exclusion criteria for choosing the articles are shown in Table 2.

Table 2: Inclusion and exclusion criteria for the selection process.

Type of Criteria	Inclusion Criteria	Exclusion Criteria
Type of articles	Journal articles and peer-reviewed publications	Books and non-peer-reviewed publications
Accessibility to the publication sites	Articles being published in open access	Articles are not being published in open access
Publication year	Articles being published within $2015-2023$	Articles are not being published within $2015-2023$
Education level	Articles emphasise higher education level	Articles did not emphasise higher education level
Subject area	Articles cover the content area of mathematics	Articles do not cover the content area of mathematics
Data	Quantitative data that provide the statistical value like mean, standard deviation and sample size	Not quantitative data
Language	English articles	Non-English articles

3.4 Screening procedures

The screening procedures are summarised in Figure 1, representing the PRISMA figures. The researchers reviewed the abstracts of 80 articles. Due to record duplication, five abstracts were deleted. Note that only 50 out of 75 articles were evaluated for eligibility. As a result, 25 articles were omitted since they did not focus on mathematical topics and did not explicitly include higher education students, as well as meta-analysis studies. Finally, 25 remaining articles were included in the review that fit the research questions of the current study.

3.5 Coding procedures

The 25 articles selected for the systematic review and meta-analysis followed the coding guidelines by Gaur and Kumar [19]. As listed in Table 3, the articles were coded based on the research design, including experimental and quasi-experimental studies for the quantitative data. Thus, the articles were coded based on the research focus, which identified the mathematical subjects at the higher education level

Table 3: List of 25 studies included in the meta-analysis.

No.	Author(s), (year)	Research Design	Research Focus	Sample (Number of participants)
1.	Sickle [57]	EX	Algebra	2000
2.	Turner [14]	EX	Introductory Statistic	78
3.	Kennedy et al. [27]	EX	Calculus	173
4.	Petrillo [41]	EX	Calculus	530
5.	Wasserman et al. [59]	QEX	Calculus	151
6.	Schroeder et al. [44]	EX	Calculus	112
7.	Gundlanch et al. [21]	QEX	Statistic	462
8.	Overmyer [37]	QEX	Algebra	210
9.	Anderson and Brennan [3]	EX	Calculus	1000
10.	Peterson [40]	QEX	Statistic	43
11.	Scott et al. [45]	EX	Calculus	100
12.	Li et al. [32]	QEX	Statistic	120
13.	Heuett [23]	EX	Statistic	82
14.	Kostaris et al. [28]	QEX	Algebra	46
15.	Asarta and Schmidt [5]	EX	Calculus	604
16.	Sergis et al. [46]	EX	Algebra	46
17.	Chien and Hsieh [12]	EX	Engineering Mathematics	60
18.	Reyneke et al. [42]	EX	Statistic	4294
19.	Collins [16]	EX	Calculus	57
20.	Carter et al. [10]	QEX	Mathematics	632
21.	Amstelveen [2]	EX	Algebra	77
22.	Karjanto and Simon [26]	EX	Calculus	310
23.	Sun and Xie [53]	EX	Calculus	104
24.	Lewin and Barzilai [30]	EX	Numerical Method	117
25.	Atta and Bonyah [6]	QEX	Mathematics	101

*Note: EX: Experimental, QEX: Quasi-experimental.

The features of the coding process for the moderator analysis are presented in Table 4. The variables included for this moderator analysis are the content area, sample size of the study, type of region, types of flipped classrooms, characteristics of flipped classrooms, and other relevant components for calculating the effect size. Li et al. [31] stated that the study characteristics assigned as moderators could describe the variability in effect sizes in order to evaluate the efficacy of current interventions. Therefore, the researchers were able to create a potential intervention that could increase the reliability of the study conducted.

Table 4: Inclusion and exclusion criteria for the selection process.

Type of features	Code
Content area	Mathematics subjects for higher education levels are Algebra, Statistics and Introductory Statistics, Calculus, Engineering Mathematics, Mathematical Modelling, Numerical Methods and Mathematics
Sample size	N of study which had been classified into $1-50$, $51-100$, $101-150$, $151-200$ and more
Type of region	Midwest USA, North eastern US, Southwest US, Southern US, Southeast Europe, Eastern Asia, Southeast Asia, South Africa, West Africa and South eastern Florida
Type of Flipped Classroom	T-Typical type of flipped classroom which not only focus on group orientation, GB-Group-based flipped classroom

3.6 Meta-analysis

In this study, the Jefreys' Amazing Statistic Programme (JASP) version 0.17.1.0 was employed to assess prior experiments' data. The data was evaluated using this programme, including the computation of effect size, detecting the existence of heterogeneity, and assessing the probability of publication bias. Prior to the meta-analysis, the articles were calculated in Microsoft Excel depending on the mean and standard deviation of each article. In addition, depending on the researchers' evaluation, the mean, standard deviation, and number of participants for the control and experimental groups were determined. To generate the results for meta-analysis in the JASP programme, the researchers needed to determine each study's pooled standard deviation, effect size, and standard error.

The value of Cohen's d was applied in calculating the effect size for each selected study. According to Cohen et al. [15], the classification of effect size included four groups based on the value of effect size. Note that the values 0 to 0.20, 0.21 to 0.50, 0.51 to 1.00, and greater than 1.00 were classified as weak, modest, moderate, and strong, respectively. The present study evaluates the possibility of publication bias by performing the funnel plot. It describes that there is publication bias if the distribution in the funnel plot is asymmetric and skewed. At the same time, there is no publication bias if the distribution in the funnel plot is symmetrical.

4 Data Analysis

The results of each study were reported along with the calculation of the effect size based on students' performance in mathematics subjects, using JASP software version 0.17.1. Furthermore, the total impact size was estimated when the heterogeneity test was run. As a result, assuming the heterogeneity assumptions were fulfilled, the random effects model was employed to determine the total impact size. Moreover, publication bias was evaluated to select papers utilised in the meta-analyses that could address specific research objectives [47]. In addition, Table 5 displays the categorisation of effect sizes using Cohen et al. [15] value to identify the category for effect size.

Table 5: Classification of effect size.

No.	Category	Interval
1.	No effect	$0.00 < ES \leq 0.19$
2.	Small effect	$0.19 < ES \leq 0.49$
3.	Moderate effect	$0.49 < ES \leq 0.79$
4.	Large effect	$0.79 < ES \leq 1.29$
5.	Very large effect	$ES > 1.29$

4.1 The effect of size on students' performance

In this analysis, a total of 25 articles were selected to determine the effect of flipped classrooms on students' performance in mathematics at the higher education level. The mean, standard deviation, number of students, and pooled standard deviation of the experimental and control groups were used to compute the effect size value. Furthermore, the standard error value was acquired when the effect size was computed. Note that each study's impact size was calculated using components that indicated the variable of students' performance, such as examination scores, final exams, and other associated scores. Hence, the derived value of the effect size of each study was utilised to determine if the study demonstrated the influence of the flipped classroom on students' mathematical performance. Table 6 indicates the impact size of each study depending on the variable of students' performance.

The value of effect size for the 25 articles chosen to investigate the effects of flipped classrooms on students' performance in mathematical disciplines at the higher education level is shown in Table 6. It can be seen that the range of impact sizes for all studies ranged from 0.03 to 2.59, classifying the studies as having no effect to having a very significant effect. Five studies Scott et al. [45], Asarta and Schmidt [5], Chien and Hsieh [12], Amstelveen [2], Lewin and Barzilai [30] were classified as having "no effect size", with effect sizes of 0.03, 0.07, 0.16, 0.12, and 0.14, respectively. In addition, eight out of 24 studies had small effect sizes, which are Sickle [57], Petrillo [41], Wasserman et al. [59], Schroeder et al. [44], Reyneke et al. [42], Carter et al. [10], Karjanto and Simon [26], Sun and Xie, [53] as the values of effect sizes were 0.43, 0.41, 0.28, 0.32, 0.41, 0.27, 0.27, and 0.25, respectively.

Furthermore, four studies were classified as having a moderate effect size of 0.56, 0.74, 0.51, or 0.80, as reported by Anderson and Brennan [3], Peterson [40], Heuett [23], and Collins [16] respectively. Turner [14], Li et al. [32], Sergis et al. [46], and Kostaris et al. [28], on the other hand, were classified as having a high impact size, with effect sizes of 1.15, 1.12, 0.83, and 0.93, respectively. Meanwhile, Atta and Bonyah [6] demonstrated an impact size of 2.59, the highest effect size value among the 25 studies that measured this variable. As a result, compared to previous research, Atta and Bonyah [6] had a very strong influence of the flipped classroom on students' performance in mathematics at the higher education level. Gundlanch et al. [21] and Overmyer [37], on the other hand, demonstrated the importance of negative impact size. This suggests that the variables of students' performance and the mathematics flipped classroom in these three experiments have an inverse connection.

Table 6: The effect size of each study based on the student's performance.

Author/s (year)	Mean Ctrl	SD Ctrl	N Ctrl	Mean Ex	SD Ex	N Ex	Pooled SD	ES	SE
Sickle [57]	70.5	19.43	54	77.20	10.80	58	15.57	0.43	0.191
Turner [14]	64.1	16.70	56	80.20	11.80	78	14.05	1.15	0.189
Kennedy et al. [27]	80.4	16.56	76	78.50	16.67	77	16.62	-0.11	0.162
Petrillo [41]	73.6	17.60	65	79.80	13.30	93	15.21	0.41	0.163
Wasserman et al. [59]	68.8 19.92	77	73.79	15.65	74	17.96	0.28	0.164	
Schroeder et al. [44]	69.2	18.80	49	74.90	17.50	63	18.08	0.32	0.192
Gundlanch et al. [21]	73.3	4.42	331	70.93	12.32	56	14.14	-0.16	0.145
Overmyer [37]	19.2	5.09	30	19.14	5.51	28	5.29	-0.01	0.263
Anderson and Brennan [3]	62.9	18.70	103	71.90	12.00	76	16.20	0.56	0.154
Peterson [40])	72.0	13.20	19	82.30	14.30	24	13.83	0.74	0.317
Scott et al. [45]	13.3	2.28	45	13.33	2.68	51	2.50	0.03	0.205
Li et al. [32]	77.9	5.26	45	83.79	5.33	75	5.30	1.12	0.202
Sergis at al. [46]	15.4	3.11	22	17.50	1.64	20	2.52	0.83	0.322
Heuett [23]	60.7	18.70	30	71.00	20.80	52	20.06	0.51	0.233
Kostaris et al. [28]	16.9	1.32	23	18.10	1.25	23	1.29	0.93	0.311
Asarta and Schmidt [5]	128.2	17.50	108	129.50	18.20	149	17.91	0.07	0.126
Chien and Hsieh [12]	56.4	24.90	24	60.69	27.60	36	26.56	0.16	0.264
Reyneke et al. [42]	59.2	13.93	1343	65.15	14.63	1466	14.30	0.41	0.038
Collins [16]	25.7	7.28	24	31.00	6.01	23	6.69	0.80	0.303
Carter et al. [10]	49.8	15.80	295	54.01	15.90	284	15.85	0.27	0.084
Amstelveen [2]	66.0	14.15	38	67.71	15.30	39	14.75	0.12	0.228
Karjanto and Simon [26]	47.5	15.94	85	54.45	33.42	81	25.98	0.27	0.156
Sun and Xie [53]	19.1	6.75	66	20.76	5.95	26	6.54	0.25	0.232
Lewin and Barzilai [30]	69.6	17.90	79	71.90	14.70	111	16.11	0.14	0.147
Atta and Bonyah [6]	46.9	10.75	101	73.48	9.77	101	10.27	2.59	0.191

*Note: Ex: Experimental, Ctrl: Control, N: Number of participants, SD: Standard deviations, ES: Effect size, SE: Effect size standard error.

4.2 The combined effect size for students' performance

As a total of 25 studies were used in analysing the impact of flipped classrooms on students' performance in mathematics subjects at the higher education level, the effect size for each study was combined to obtain the value of the combined effect size. Subsequently, the value of the combined effect size was measured through JASP software in order to identify the category of combined effect size for the variable of students' performance. Indeed, the obtained value of the combined effect size was used in determining the impact of flipped classrooms on students' performance in mathematics subjects at the higher education level. The output for the coefficient estimation using a random-effect model for students' performance is presented in Table 7.

Table 7: Coefficient estimation using the random-effect model for students' performance.

	Effect Size (Cohen's d)	SE	$z-$value	$p-$value	95% Confidence Interval	
					Lower limit	Upper limit
Overall	0.474	0.115	4.129	<0.001	0.249	0.699

*Note: SE: Standard Error.

As shown in Table 7 above, the value of the combined effect size for the variable of students' performance was 0.474, which was categorised under the moderate effect size category. In addition, the standard error and $z-$value were 0.115 and 4.129, respectively. Meanwhile, the obtained $p-$value for the variable of students' performance was found to be statistically significant as the value was less than 0.05 at the 95% confidence interval. Therefore, it can be concluded that the combined effect size exhibited a moderate effect, which can be interpreted as the implementation of flipped classrooms having a moderate effect on students' performance in mathematics subjects at the higher education level.

4.3 Heterogeneity test

The heterogeneity test should be addressed while doing meta-analysis research since it evaluates the variability of the data utilised in prior studies. Furthermore, heterogeneity refers to the diversity of data within each research or main study in which the test is performed to determine the effect size estimate model. According to Yakar [61], the goal of the heterogeneity test is to decide the kind of impact model to be employed based on the determined effect size. The random effects model was produced for heterogeneous effect size, while the fixed effects model was created for homogeneous effect size. The value of I-squared was employed to assess the heterogeneity of the data in this study. Additionally, the I-squared value demonstrates the percentage variance in the chosen studies due to heterogeneity rather than sampling error [25]. As a result, the largest value of percentage variation across the research shows that the data is heterogeneous, implying greater variability between the studies. Because of its practical application in determining the fraction of variable attributable to heterogeneity and its ease of comprehension, the I-squared statistic is preferred over Cochrane's Q. It offers a lucid, percentage-based measure of heterogeneity that is frequently more helpful for summarizing and comprehending meta-analysis findings. Moreover, the recommendations for evaluating the value of I-squared were based on the Cochrane partnerships, as indicated in Table 8.

Table 8: The effect size of each study based on the student's performance.

t^2 (%)	Potential Level of Heterogeneity
0 - 40	Minimal
30 - 60	Moderate
50 - 90	Substantail
90 - 100	Considerable

Meanwhile, Table 9 displays an overview of the residual heterogeneity estimates from the JASP output.

Table 9: Summary of residual heterogeneity estimates.

	Estimate	95% Confidence Interval	
		Lower	Upper
I^2 (%)	93.004	89.573	96.256

According to Table 9 above, the value achieved for this study was 93%, which indicated the data's variability. Thus, according to Cochran's recommendations, the data in the present study had the maximum conceivable degree of heterogeneity, suggesting that it experienced a significant amount of heterogeneity. As a result, we may deduce that the random effects model was used since the data was diverse. Furthermore, Table 10 below presents the JASP output for fixed and random effects models. As a consequence of the $p-$value, the result was statistically significant, indicating that the data variation between the main studies was likewise diverse.

Table 10: Fixed and Random Effects.

	Q	df	p
Omnibus test of Model Coefficients	31.546	1	$<$ .001
Test of Residual Heterogeneity	312.428	38	$<$ .001

*Note: $p-$values are approximate.
*Note: The model was estimated using the Restricted ML method.

4.4 The evaluation of publication bias

Meta-analysis research should be evaluated for publication bias to develop a study that can establish the study's neutrality. The study's findings that were not published may contribute to publication bias [17]. As a result, Nair [36] indicated that studies with negative and statistically insignificant results would not be published, but those with positive and statistically significant findings would be published. As a result, publication bias will arise in research considering that studies with positive and statistically significant results vary from studies with negative findings. Furthermore, publication bias explains why research with good results is more likely to be published than unpublished.

4.5 Funnel plot

Regarding the total effect size of this research, the funnel plot supplied in the JASP output was used to assess the publication bias in this study. Lin and Chu [33] proposed that the publication bias in the research may be quantified using funnel-plot-based methodologies. This methodology allows for the visual examination of a funnel plot, regressions, rank tests, and non-parametric trim and fill procedures. Other than that, the interpretation of the funnel plot was utilised in this research to determine the presence of publication bias in the chosen studies. Furthermore, since the funnel plot reflected the relationship of the effect sizes within the standard errors, the visualisation of the plot indicated the composition of the data, including symmetrical and asymmetrical factors. Figure 2 illustrates the funnel plot of the effect sizes for students' performance in the flipped classroom.

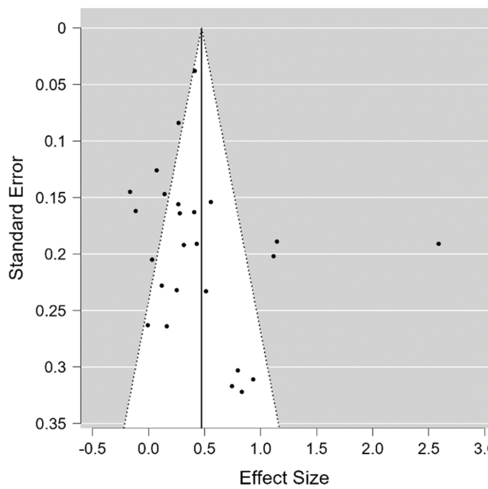

Figure 2: Funnel plot of students' performance in mathematics flipped classroom.

Note that the scatterplot for the effect sizes was asymmetrical. It did not approach the weighted mean of effect sizes based on a visual evaluation of the funnel plot. The assessment of publication bias was then tested using the fail-safe N test technique for the variable. Therefore, the traditional fail-safe N was computed for the variable, and the derived number should be more than $5k + 10$ to verify that the studies utilised were free of publication bias. As a result, Table 11 provides the results of file drawer analysis for students' performance in mathematical disciplines at the higher education level.

Table 11: File drawer analysis for both variables used in this study.

	Variable	Fail-safe N	Target Significance	Observed Significance
Rosenthal	Students' performance	1657	0.050	$< .001$

5 Discussion

The present study entails a meta-analytical examination of prior research to scrutinise students' academic achievement in mathematics courses in the context of the flipped classroom approach.

Furthermore, given the emphasis of this study on a particular level of education, the meta-analysis was restricted to prior studies that focused on higher education levels, characterised by a rigorous curriculum in mathematics. In contrast, Güler et al. [20] discovered that adopting the flipped classroom approach in mathematics education yielded a statistically significant impact across various educational levels, namely primary, secondary, and high school. Consequently, the impact of the flipped classroom approach in mathematics is primarily evident in primary education, with only a marginal effect observed in other educational levels following its adoption.

Alternatively, Strelan et al. [52] demonstrated a correlation between students' performance and the flipped classroom model across various educational levels, including higher education. However, the impact was discovered to be modest. Furthermore, Wei et al. [60] reported that incorporating the flipped classroom approach in mathematics courses yielded superior academic outcomes for students at the intermediate educational level relative to other educational stages. Wei et al. [60] stated that integrating the flipped classroom approach in mathematics has significantly enhanced students' academic performance. Therefore, the flipped classroom was recommended as an effective instructional strategy for educators to deliver the lesson. On the other hand, Talan and Gulsecen [54] asserted that the evaluation of students' mathematical performance was conducted subsequently in a post-test. This test was administered in both a conventional classroom setting and a flipped classroom setting. The results indicate that students in the experimental group, who were exposed to the flipped classroom model, exhibited higher levels of academic achievement relative to their counterparts in the controlled group. This was evidenced by statistically significant differences in test scores between the two groups. Therefore, it is evident that incorporating the flipped classroom model in mathematics courses can potentially improve academic attainment and outcomes in higher education compared to traditional lecture-based instruction. Moreover, Shahzadi et al. [49] performed a study comparing students' academic performance in mathematics subjects between traditional and flipped classrooms. The results indicated a significant difference in outcomes, with the integration of flipped classrooms yielding superior results compared to the traditional classroom.

Apart from that, Li et al. [32] reported that the academic performance of students who underwent the flipped classroom technique surpassed that of students who underwent the traditional classroom technique. Wei et al. [60] conducted a study to evaluate the academic achievement of students in mathematics across different levels of education, namely low, middle, and high, by analysing their learning outcomes. The research on implementing the flipped classroom model in mathematics education has revealed that students at intermediate and advanced educational levels achieved noteworthy academic achievement. This suggests that these two levels of education have a statistically significant impact on students' mathematics performance compared to those with a lower level of mathematical proficiency. In the traditional classroom setting, students at the high mathematical level exhibited superior academic performance compared to their middle and low-mathematical-level counterparts. Thus, it can be inferred that students who possess advanced mathematical skills and are enrolled in higher education programmes exhibit superior academic performance in a flipped classroom setting compared to a conventional classroom environment.

Furthermore, concerning the impact magnitudes on the academic achievement of students in mathematics courses at the tertiary level, 25 articles were chosen to investigate the variations in effect sizes obtained subsequent to the statistical computations. Five out of 25 articles were singled out for obtaining significant effect sizes. These studies indicate that students in the experimental group, as observed in the flipped classroom context, exhibit superior mathematical performance compared to their counterparts in the lecture-based classroom. Moreover, it was observed that the cohort of students who participated in the flipped classroom approach exhibited a propensity for academic excellence. This is evidenced by their exceptional performance in math test scores, final examinations, assessments, and other metrics utilised to evaluate their mathematical proficiency.

Other than that, this serves to underscore the efficacy of the flipped classroom model in the context of mathematics education. Consequently, the researchers utilised the interpretation of effect sizes derived from the 25 chosen studies to ascertain the studies that significantly influenced students' academic performance in relation to the adoption of the flipped classroom approach. Turner [14] demonstrated a large effect size of 1.146, as determined by the effect size classification table. This indicates a significant mean-score increase between the control and experimental groups.

Furthermore, Li et al. [32] exhibited a substantial effect size of 1.116, signifying the practical significance of this study for enhancing students' mathematical performance through implementing a flipped instructional approach. Sergis et al. [46] was classified as belonging to the group with a large effect size, as their study yielded an effect size value of 0.833. This shows that the standardised mean difference observed in their study is considerably larger than the variability or pooled standard deviation value. Kostaris et al. [28] reported a substantial effect size of 0.934. In contrast, Atta and Bonyah [6] demonstrated the highest effect size among the investigated studies, which amounted to 2.589. Therefore, it can be inferred that the flipped classroom approach's effect size significantly impacts students' academic performance in mathematics subjects at the tertiary level. Hence, it can be inferred that nearly 97% of the participants in the experimental cohort exhibited a greater likelihood of achieving elevated grades due to their mathematical aptitude rather than their engagement in conventional classroom settings. It can be inferred that a higher effect size observed between the control and experimental groups corresponds to an increased likelihood of a randomly selected student from the experimental group achieving superior performance in mathematics compared to their counterparts in the control group. A larger effect size indicates a minimal probability of students from the control group being randomly selected to achieve high mathematics scores.

Conversely, the meta-analysis findings pertaining to the aggregate effect size of students' academic performance in prior research studies exhibited diverse effect size estimates. The present study yielded an effect size of 0.47 for the variable of students' performance, indicating that it falls within the small effect category. This suggests that there is only a modest level of statistical significance with respect to students' performance. Based on the integration of the flipped classroom approach into the teaching and learning process, it can be inferred that a mere 63% of students from the experimental group were afforded the chance to be randomly selected for achieving high scores in mathematics in comparison to the control group. Subsequently, the results were corroborated by Algarni [1] study, which reported a Cohen's d value of 0.27 for the performance variable of the 34 studies analysed. This value falls under the category of a small effect. This recommends that there is limited statistical significance in relation to the academic achievement of students, which aligns with the findings of the current study.

Özdemir and Senturk [38] observed a substantial effect size of 1.223 concerning the academic achievement of students. This suggests that the impact of flipped classrooms on mathematics performance is statistically significant. Moreover, Shi et al. [50] established that students' academic achievement in mathematics can be viewed as a manifestation of their cognitive learning, signifying the enhancement of their measurable academic outcomes. Shi et al. [50] discovered that the implementation of a flipped classroom model in mathematics education resulted in a significant improvement in students' performance. The researchers analysed 33 effect sizes and determined that the fit effect size was optimal. In summary, the incorporation of flipped learning methodologies within mathematics education has demonstrated the potential to enhance students' academic achievements in higher education institutions.

6 Conclusions

Adopting the flipped classroom model has replaced the traditional pedagogical methods in higher education mathematics courses, resulting in a shift from teacher-centred to student-centred learning approaches. Contemporary learning instruction prioritises student-centred learning over the traditional teacher-centred approach. In addition, integrating technology into the pedagogical approach is a contemporary imperative in the educational system, allowing educators to foster skills relevant to twenty-first-century learning. According to Avery et al. [7], the flipped classroom is a contemporary pedagogical approach that facilitates twenty-first-century learning by fostering essential skills and competencies among students. This includes collaborative, critical, and creative thinking and communication skills. In addition, using flipped classrooms can facilitate interactive learning by promoting students' involvement in self-directed learning through technological resources to access educational content. The present study indicates that adopting flipped classrooms in mathematics courses at the tertiary level significantly enhanced students' academic performance compared to the conventional classroom approach.

According to Chou et al. [13] and Hidayat et al. [24], the flipped classroom has been discovered to enhance learning effectiveness by promoting active engagement among students, particularly those with lower academic performances. This is attributed to the opportunity for interactive learning during class time, allowing for immediate feedback and guidance from educators in addressing challenges. Hence, the inclination and receptivity of students towards the novel pedagogical approach in mathematics can facilitate their individualised acquisition of mathematical proficiency. This can be done by utilising video lectures and supplementary educational resources beyond the confines of the classroom, thereby fostering their engagement in interactive learning within the classroom setting. The aforementioned suggests that the flipped classroom model is characterised by a high degree of adaptability, as it allows students to engage in convenient and more efficacious learning experiences in contrast to conventional pedagogical approaches. From the perspective of SDG 4, the flipped classroom model impacts several aspects, including improving the quality of teaching and learning, student engagement and motivation, the use of technology in education, academic performance, and the development of critical thinking skills.

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Conflicts of Interest The authors declare no conflict of interest.

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