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Effectiveness of Flipped Classroom Pedagogy in Programming Education: A Meta-Analysis

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The flipped classroom has generated considerable interest in programming education in recent years. This meta-analysis aimed to assess the effectiveness of a flipped classroom and traditional methods in teaching programming courses and the impact on students' performance, problem-solving abilities, and behavioural outcomes, and to analyse the specific discipline, students' type, students' level, and publication sources in the relevant studies. Articles published between 2010 and 2021 were searched carefully in six academic databases, comprising Web of Science, IEEE Xplore Digital Library, ScienceDirect, NCBI Databases, and Springer Link. Peer-reviewed articles written in English were selected and screened according to the inclusion criteria. All the vital data were extracted and stored in Microsoft Excel and meta-analysis was performed using the Comprehensive Meta-analysis (CMA) software. A total of 101 articles were retrieved while 27 of them met the inclusion criteria and were subjected to the meta-analysis. Flipped classroom improved students' achievement in programming courses with statistically significant effect size (g = 0.56; p < 0.001, 95% confidence interval; 0.33-0.79) compared to traditional teaching method. The flipped classroom also favoured behavioural outcome (satisfaction) in programming education. Programming subject areas had a significant moderating impact on the effect sizes. Overall, evidence of publication bias was lacking in this study. The findings and implications of implementing flipped classrooms in programming education were highlighted. More studies are needed to elucidate the effect of flipped classroom model on various dimensions of programming students' learning outcomes to support comparative research in future.

Keywords: flipped classroom, student learning outcomes, lecture-based learning, programming, meta-analysis

INTRODUCTION

Programming education remains one of the most difficult subjects for students at various institutional levels (Sobral, 2021). Programming is not only challenging and complex,

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students in science, engineering, and mathematics departments need to pass programming courses at certain stages in their curriculum (Siti Rosminah & Ahmad Zamzuri, 2012). To address this issue, several researchers have advocated for a radical transformation in programming education (Threekunprapa & Yasri, 2020).

The challenges in comprehending computer programming can be classified into three broad aspects: nature of the subject, student-related issues, and teaching-related issues (Karaca & Ocak, 2017). In terms of the nature of the subject, there are two main aspects in learning programming: programming strategies and programming knowledge (Davies et al., 2013). Learning syntax and semantics of programming language are embedded in programming knowledge, whereas the applications of such knowledge to innovate and fabricate new programmes is regarded as programming strategies (Bayman & Mayer, 1988). Additionally, an algorithm-based solution can only be achieved when students develop problem-solving skills, which is subsequently required for implementing a computer programme. Thereafter, debugging codes and fixing syntax and semantic errors are conditions to be met by students.

According to Hsu and Lin (2016), programming students are most times unaware of their deficiencies and they rely mostly on reading textbooks and understanding language syntax instead of practising to develop new programmes. Other researchers reported that students are generally impatient to debug the errors in their codes, hence, they are unable to create correct versions and error-free contents (Turan & Goktas, 2018). Regarding teaching-related issues, instructors tend to spend time concentrating on syntactic details instead of equipping students on how to create new programmes. Meanwhile, traditional teaching methods or lecture-based instruction is only effective for teaching language syntax, other vital aspects such as problem-solving, creation of new programmes, debugging and fixing code bugs, and comprehending complete programmes require more advanced teaching techniques (Davies et al., 2013).

A flipped classroom is a form of the blended learning platform (Atwa et al., 2022), where students are exposed to and learn instructional content by watching video lectures at the comfort of their homes, where lecturers or teachers provide personalised interaction and guidance with other students, rather than in a typical classroom setting (Al-zoubi, 2021). The definition by Lage (2000) simplified flipped or inverted classroom as “Inverting the classroom signifies that events that traditionally occur within the classroom now take place outside the classroom and vice versa”. Bishop and Verleger (2013) posited that flipped classroom comprises two parts, namely, direct computer-based individual instruction taking place outside the classroom and interactive group learning activities within the classroom.

A flipped classroom model is more advantageous and suitable for teaching programming courses by maximising the support provided for students learning (Turan & Goktas, 2018). This is achieved by freeing up class time for in-class activities, thereby helping to shift the instructor’s role from teaching programming syntax to training students on creating programming strategies. The broad components of learning programming: strategies and knowledge, could be targeted by using the two phases of flipped class model: out-class and in-class. Students could be taught programming language based on online recorded lectures with such knowledge serving as background and mandatory programming skills, including programme comprehension, problem-solving, debugging and correcting errors, building algorithm-based solutions, and writing new programmes (Pattanaphanchai, 2019).

Several attempts have been made in implementing flipped classroom learning in programming education and other related courses. For instance, flipped classrooms were employed in computer science to teach introductory programming courses (Alhazbi, 2016; Antti et al., 2016; Elmaleh & Shankararaman, 2017; Marasco, Moshirpour, & Moussavi, 2017) and advanced topics in software engineering (Paez, 2017). In these studies, specific sessions within a course were flipped while some involved the entire course. Nevertheless, contradicting outcomes were reported regarding the effectiveness, as some researchers found positive learning impacts, whereas others reported either -neutral or non-significant improvements when compared to traditional learning methods (Elmaleh & Shankararaman, 2017).

Despite acknowledging the positive contributions of flipped classrooms in delivering programming courses, only a few articles employed robust scientific techniques or study designs to verify students' learning (academic achievement and performance, problem-solving abilities e.t.c.) and behavioural (i.e., motivation and satisfaction) outcomes. In other words, robust experimental studies on the flipped classroom in programming education are limited. A few systematic reviews have been performed to address flipped classroom models in programming education, but meta-analysis was not conducted probably due to data paucity and heterogeneity of studies. Nevertheless, a considerable number of studies have been published recently, thus indicating the need and feasibility to perform a meta-analysis to elucidate the effectiveness of flipped classroom approach in programming education. This study aims to evaluate the effectiveness of flipped classrooms in teaching programming courses in comparison to traditional or lecture-based learning methods and the enhance on students' performance, problem-solving abilities, and behavioural outcomes and identify the subject area, student's type, students' level and type of publication. The following research questions are addressed in this article:

- What effects of the flipped classroom compared with the traditional lecture (lecture-based learning) have been reported in programming education?
- How effective is using the flipped classroom in student achievement or performance in programming courses?
- Is there a significant difference between the effect size in programming students' achievement in relation to discipline, students' type, students' level, and publication sources?

Theoretical Background

The first application of the flipped classroom model was in 2007 by a group of chemistry teachers: Aaron Sams and Jonathan Bergmann. The main reason for applying the model was to record video courses and make them available online. Thus, high school students could watch the lesson at their convenience. Thereafter, the flipped classroom model began to receive exceptional interest from several fields and students in which courses were made available in downloadable format (Al Mulhim, 2020). Besides, the technique was well-recognised as efficient in allocating the duration needed to teach theoretical knowledge in combination with practical learning activities in the traditional classroom (Bergmann & Sams, 2012).

Flipped classroom model is a form of blended learning model, whereby learning aligns and considers the students' learning levels and pace (Ayçiçek & Yelken, 2018). Essentially, the responsibility to learn is transferred to the student. Hence, the term "blended learning" is widely employed in describing flipped classroom model, which comprises of the integration of traditional learning and technology. Yavuz et al. (2016) posits that flipped learning entails the combination of traditional or face-to-face and electronic teaching (online). Additionally, the model encourages problem-based, inquiry-based, collaborative, and active learning theories. The weaknesses inherent in the learning environment is removed to a certain degree, as documented in mobile learning theory.

The social constructivist approach (SCA) has been used in elucidated the flipped learning model. The SCA posits that social and culturally regulated experiences play vital role in the structuring knowledge (Torun & Dargut, 2015). Furthermore, the Bloom's Taxonomy developed by Willian (2013) and Brame (2013) has been associated with the flipped classroom model. This is based on the significance of "remembering" and "understanding" the steps explained by the teacher via the theoretical knowledge outside the classroom, meanwhile, concepts such as "Analysing", "Applying", "Evaluating", and "Creating" are delivered within the traditional classroom.

METHOD

Research Design

This meta-analysis research design applied to explore the effectiveness of flipped classroom in teaching programming courses in comparison to traditional or lecture-based learning methods. The study employed the following meta-analytic procedures: retrieval of relevant articles, coding the articles features, estimating the effect sizes of outcome measures in each study, and determining the moderating impacts of the study's features on the outcome measures.

Literature Search

The flipped classroom concept has been described using several terms in the context of programming education, thus the researchers used all the related terms when searching for relevant articles on the topic. The keywords used for the literature research included

language", "computer science", "computer programming", "programming course", "introductory programming", "novice programming", "computer programming education".

Articles published between 2010 and 2022 were searched carefully in seven academic databases, comprising Web of Science, IEEE Xplore Digital Library, ScienceDirect, NCBI Databases (PubMed and PMC), and Springer Link. Apart from the primary search engines, references from the retrieved articles were also assessed if considered relevant to the research topic.

Inclusion and Exclusion Criteria

A comprehensive set of inclusion and exclusion criteria were developed in this meta-analysis. As shown in Table 1, all the articles included in this study were published between 2010 and 2022, written in English, and focused on utilising flipped classroom models in delivering programming courses in any discipline. Additionally, the studies utilised either empirical, quasi-experimental, experimental, randomised control trials (RCT), or longitudinal study designs in comparing flipped classroom and lecture-based teaching methods. The student learning outcomes measures were either between or within-subjects conditions. Articles providing detailed data (mean, standard deviations (SD), sample size and corresponding inferential statistical test values such as t-value) to compute the effect sizes were also considered. Studies were included if the student learning or behavioural outcomes were clearly defined and described quantitatively for the experimental or observational groups.

Table 1
Article inclusion and exclusion criteria

Criteria	
Learning content	Involving flipped classroom in programming education
Language	English
Timeframe	Articles published between 2010 and 2021
Literature type	Peer-reviewed articles, dissertation/theses, conferences and proceedings
Research design	Experimental, quasi-experimental, RCT, observational (longitudinal and prospective cohort)
Implementation	Flipped classroom
Accessibility	Full texts are available either as open access articles or via library repository
Research outcomes/results	Basic statistical data to estimate the effect size (mean, standard deviation, sample size, statistical test values)
Educational outcomes/results	Well-described educational outcomes

Articles Identification and Selection

The identification and selection of articles in this study involved three phases. The titles and abstracts were first screened to ensure they were related to flipped classrooms in programming education. Several publications including journal articles, conferences and proceedings. Meanwhile, reviews, online articles, and articles reporting flipped classroom models in other disciplines besides programming were excluded. Thereafter, all the relevant studies were imported into a Microsoft Excel spreadsheet. Duplicates in various databases were removed and upon completing the data screening process, a total of 101 articles were available for consideration (See Figure 1).

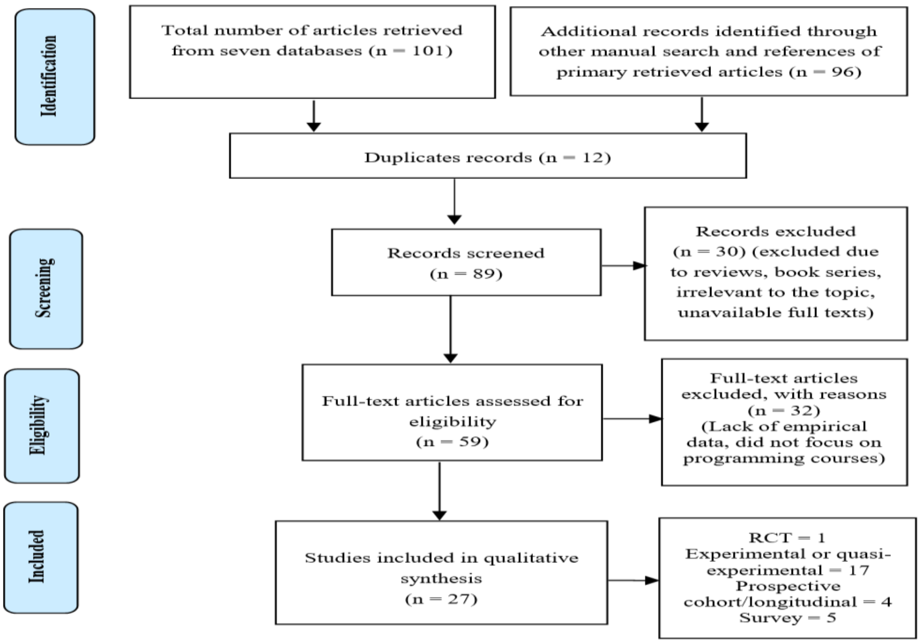

Figure 1
Study selection process and flow diagram using the PRISMA guideline

Coding features and procedures

A set of relevant variables such as subject areas, study duration, and types of publication were used to code all the included articles. All the data available in computing the effect size were extracted from each study. Attempts were made to code for the instructional media, pre-class activities, and in-class activities but the data were inadequate to facilitate a consistent coding system.

All the authors of this review participated in developing the coding scheme upon reading a given number of articles that were randomly allocated. In instances where opinions differed on how the variables should be coded, a discussion was held among the authors to reach a consensus and resolve the differences. Although inter-rater reliability (Kappa coefficient) was not conducted in this study, this would not affect the meta-analysis results since the final coding process was performed consistently by three authors of this review. Moreover, frequent discussions and communication were held to reach a consensus on the coding process. Coding related to the quantitative data was also examined for errors and corrected. The final coding comprised information on subject areas (engineering, computer, and ‘others’) student groups (undergraduates or post-graduates), and publication types (research articles and conference proceedings). The following details were coded in the Microsoft Excel spreadsheet: year of publication, author details, the title of the articles, type of publication, subject area or discipline, study duration, and available data for effect size calculation.

Extraction and Estimation of Effects Sizes

The effect sizes for the 27 articles included in the final analysis were estimated using the Comprehensive Meta-analysis (CMA) version 3.0. Descriptive statistics of the data set was performed using the Statistical Package for Social Science (IBM SPSS, Version 24). The effect sizes were extracted based on three domains namely, student overall achievement or performance (final examination scores), problem-solving abilities, and behavioural outcome (i.e., satisfaction). Notably, these domains were reported in a good number of the included studies. However, other outcomes such as motivation, competency acquisition, attentiveness, self-efficacy, and attitude were also reported in a few articles.

Each of the studies reporting sufficient data for effect size estimation was analysed following the suggestion by Lipsey and Wilson (2001). Only one effect size was estimated for each study to prevent statistical dependence and bias in the overall results. The averages in the CMA was employed to combine the effect size comparisons. Several researchers have described various effect size comparison methods and addressed the associated issues in the meta-analysis (Scammacca et al., 2014; López-López et al. 2018). While the method employed in this study is considered divergent and integrative, each method has its cons and pros as elaborated in the discussion session.

All the effect sizes were standardised in Hedge's g before performing the meta-analysis. The Hedge's g is considered a standardised measure of effect size when dealing with continuous data. Moreover, Borenstein et al. (2010) reported that Hedge's *g* is more effective than Cohen's *d* when adjusting for bias relating to small sample size.

Both the fix and random model effects were compared in the meta-analysis. According to Borenstein et al. (2010), random-effects models are best conducted when effect sizes in reviewed studies differ from each other. Additionally, mixed-effects analysis in the CMA software was employed to perform the post-hoc subgroup analyses. Effect sizes of 0.2 and below were considered small, values between 0.3 and 0.7 were considered medium, and values of 0.8 and above were classified as large (Cohen, 1992). Visual inspection of funnel plots, Orwin's fail N test and fail-safe N procedure were used to evaluate publication bias (Orwin, 1983).

FINDINGS

A meta-analysis was performed on 27 articles identified from the systematic literature search and extracting process. These flipped classroom studies focused on the delivery of programming courses and they were published mostly in conferences/proceedings (n = 12) and journal articles (n = 15). Table 2 shows the summary of the articles in terms of study designs, subject areas, students involved and their levels, main studied variables, and articles reporting sufficient data for effect size estimation. The majority of studies were quasi-experimental (17/27; 62.9%), followed by surveys (5/27; 18.5%), observational (4/27; 14.8%) and only a single randomised control trial (RCT). As expected, the main studied subject area was computer science (18/27; 66.7%) and 24 articles focused on undergraduates (88.9%). Meanwhile, 15 articles (55.6%) did not state the students' level. Overall, 18 studies provided sufficient data for effect size estimation.

A higher number of articles (n = 18) reported student learning (performance/ achievement) and behavioural outcomes (satisfaction; n = 4). Other aspects investigated in the reviewed studies included students' problem-solving ability (Lin, 2019; Hsu & Lin, 2016), attention, confidence (Chang et al., 2018), competencies acquisition (Pattanaphanchai, 2019; Elmaleh & Shankararaman, 2019), learning motivation (Lin, 2019; Abdallah et al., 2020), and learning attitude (Lin, 2019).

Table 2
Descriptive analysis of the studies included in this meta-analysis

Variables	Number of studies (n)	%
Study designs		
Quasi-experimental	17	62.9
Observational (prospective and longitudinal)	4	14.8
Survey	5	18.5
RCT	1	3.7
Subject areas		
Computer science	18	66.7
Engineering	3	11.1
Computer science and engineering	3	11.1
Others	3	11.1
Student type		
Undergraduates	24	88.9
Post-graduates	0	0.0
Unspecific	3	11.1
Student level		
First-year	5	18.5
Second-year and above	7	25.9
NA	15	55.6
Main studied variables		
Students' performance/achievement	18	66.7
Satisfaction	4	14.8
Problem-solving abilities	3	11.1
Learning motivation	3	11.1
Competencies acquisition	2	7.4
Attitude	2	7.4
Attentiveness	1	3.7
Confidence	1	3.7
Self-efficacy	1	3.7
Articles reporting sufficient data for effect size estimation		
Student performance	14	77.7
Satisfaction	2	16.1
Problem-solving abilities	2	16.1

Effectiveness of Flipped Classroom and Lecture-Based Teaching (Traditional Method)

These results are divided into three main areas based on the areas investigated, namely, student's achievement or performance, problem-solving ability, and satisfaction with flipped classrooms. Other aspects in a few studies included attentiveness, confidence, competencies acquisition, learning motivation, and learning attitude.

Students' performance and achievement

A total of 14 articles compared the effects of flipped classrooms and lecture-based methods on students' achievement or performance in programming courses. Figure 2 presents the combined effect size of the 14 articles in terms of authors' name, year of publication, and statistic parameters such as the standard error, Hedge's g, variance, confidence interval, Z-value, and *p*-value. Each study contributed a specific effect size that is indicated by the small boxes. Meanwhile, the confidence interval of the estimate from each study is represented by the horizontal line that crosses each box. Upon pooling all the studies combined with a confidence interval, the average effect size is depicted by the diamond at the bottom of the plot.

Study name	Statistics for each study						
	Hedges's g	Standard error	Variance	Lower limit	Upper limit	Z-Value	p-Value
Hakan Jonsson, 2015	0.944	0.187	0.035	0.578	1.310	5.049	0.000
Emine Cabi, 2016	-0.058	0.257	0.066	-0.562	0.447	-0.224	0.822
Wang et al., 2019	0.866	0.182	0.033	0.510	1.222	4.764	0.000
Elmaleh and Shankaraman, 2017	0.043	0.085	0.007	-0.123	0.210	0.507	0.612
Yeh-Ting Lin, 2019	0.707	0.348	0.121	0.025	1.389	2.032	0.042
Pattanaphanchai, 2019	0.261	0.179	0.032	-0.089	0.611	1.460	0.144
Patrick, 2016	0.416	0.183	0.034	0.057	0.776	2.270	0.023
Wen-Chun Hsu and Hao-Chiang, 2016	1.020	0.323	0.104	0.387	1.653	3.160	0.002
Ruiz de Miras et al. 2022	1.105	0.087	0.008	0.936	1.275	12.750	0.000
Taspolat et al. 2021	0.929	0.261	0.068	0.418	1.440	3.564	0.000
Amira et al. 2019	0.819	0.290	0.084	0.250	1.389	2.821	0.005
McCord and Jeldes, 2019	0.182	0.053	0.003	0.077	0.286	3.405	0.001
Mithun and Evans, 2018	0.264	0.215	0.046	-0.157	0.685	1.229	0.219
Chang et al. 2018	0.627	0.201	0.041	0.232	1.021	3.111	0.002
	0.412	0.034	0.001	0.345	0.480	12.011	0.000

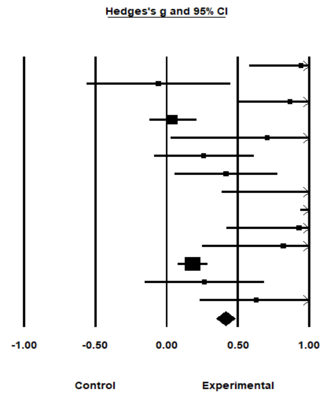

Figure 2
Effect sizes of each study comparing student achievement/performance in programming courses using flipped classroom and lecture-based learning

The forest plot revealed that 12 studies favoured the application of flipped classrooms (experimental group) and their corresponding effect sizes were statistically significant (Figure 2). Only one study was neither in favour of the flipped classroom nor lecture-based method and the effect size was not statistically significant since the confidence interval overlapped with zero (Cabi, 2018). The effect size differed between studies, with those conducted by Chang et al. (2018), Elmaleh and Shankararaman (2017), and McCord and Jeldes (2019) contributing the highest effect size, which could be attributed to the large sample size. Nevertheless, sampling error might also be responsible for the variation in effect sizes observed in the included studies.

Table 3 depicts the overall effect size of the fixed and random-effects model, with a g-value of 0.41 and 0.56, respectively. These values are trivial to small effect size (Cohen, 1992), and they were both statistically significant at Z-values of 12.01 (CI 0.35-0.48) and 4.45 (CI 0.32-0.81), respectively. The Q-statistic was checked to determine if the studies included in the meta-analysis are homogeneous and characterised by common effect sizes. In other words, the Q-statistic tests the null hypothesis regarding the studies homogeneity (Borestein et al., 2010). The Q-value was 131.6 with a degree of freedom (df) of 14 and was statistically significant at $P < 0.001$. Hence, the null hypothesis that the actual effect size is identical in all of the studies was rejected. Meanwhile, a high heterogeneity level of 90.1% (I-squared value) was detected (Higgins and Thompson, 2002). This result suggests that other moderators aside from the sampling error might be responsible for this high heterogeneity (Borenstein et al., 2010). However, this is unlikely as only one study found no significant difference in students' performance in programming courses between flipped classrooms and traditional teaching methods. In other words, no study reported that students in the traditional room flipped classroom performed worse than the lecture-based method.

Table 3
Overall effect size of the fixed and random-effects model for studies comparing student achievement/performance in programming courses and satisfaction with using flipped classroom and lecture-based or traditional teaching method

					95% CI				Heterogeneity		
Achievement/Performance											
Model	K	ES	SE	Variance	Lower	Upper	Z	P	Q	Df (Q)	P
Fixed	14	0.41	0.03	0.001	0.35	0.48	12.01	0.000	131.62	13	0.000
Random	14	0.56	0.13	0.01	0.32	0.81	4.45	0.000			
Satisfaction											
Fixed	2	0.91	0.17	0.03	0.56	1.25	5.19	0.000	9.35	1	0.002
Random	2	1.22	0.64	0.41	-0.03	2.47	1.92	0.05			

K = number of studies, SE = standard error, df = degree of freedom

Apart from the aforementioned studies, four other articles reported students' performance using different study designs and methodologies. Wang et al. (2019) found that the students obtaining good grades in the flipped classroom increased significantly by 15% in two successive years, whereas no significant difference was detected in students subjected to lecture-based methods. A similar study by Pattanaphanchai (2019) reported an overall improvement in students' examination scores in various programming courses upon changing from traditional to flipped classroom pedagogy. Meanwhile, the final exam scores of students subjected to flipped classrooms improved significantly compared to the scores obtained in previous two years (Hayashi et al., 2015).

Students' satisfaction with flipped classrooms

Effect sizes were only estimated for two studies (Chang et al., 2018; Hsu & Lin, 2016) comparing students' satisfaction with flipped classroom and lecture-based methods in delivering programming courses. As expected, the effect size contributed by Chang et al. (2018) was much higher compared to Hsu and Lin (2016), which is clearly due to the larger sample size. Both studies favoured students' satisfaction with flipped classrooms compared to lecture-based methods, and the effect sizes were statistically significant. The overall effect size of the fixed and random-effects models are shown in Table 3, with g values of 0.91 and 1.22, respectively. These values are also trivial to small effect size and both were statistically significant at Z-values of 5.19 (CI 0.56-1.26) and 1.92 (CI -0.02-2.47), respectively. The Q-value was 9.35 and P = 0.002. Likewise, the null hypothesis that the true effect size was the same in all studies was rejected. The I-squared value was 89.3%, which is also considered a high level of heterogeneity (Higgins & Thompson, 2002).

Other students' learning and behavioural outcomes

Apart from students' achievement and satisfaction, other aspects investigated in the reviewed studies included students' problem-solving ability (Lin, 2019; Hsu & Lin, 2016), attention, confidence (Chang et al., 2018, competencies acquisition (Pattanaphanchai, 2019; Elmaleh & Shankararaman, 2019), learning motivation (Lin, 2019; Abdallah, 2020; McCord and Jeldes, 2019), and learning attitude (Lin, 2019; Taşpolat et al., 2021).

Students' problem-solving ability was reported in two studies (Lin, 2019; Hsu & Lin, 2016) comparing the effects of flipped classrooms and lecture-based methods in delivering programming courses. Both studies contributed similar effect sizes and favoured the flipped classroom in improving students' problem-solving ability in programming courses. Other statistical parameters were not computed given that only two studies were included in this analysis.

The application of flipped classrooms in delivering programming courses was found to increase students' attention and confidence compared to the traditional teaching method (Chang et al., 2018). In terms of competencies acquisition, students' knowledge and expertise increased significantly ($P < 0.05$) following the implementation of flipped classrooms with pre-and post-intervention scores (mean, SD) of 3.14 ± 0.72 and 3.57 ± 0.69 (Pattanaphanchai, 2019). Another study by Elmaleh and Shankararaman (2019) reported that competencies acquisition among students in the flipped classroom increased significantly by 27% compared to 20% in the lecture-based method. Likewise, students were more motivated and demonstrated significantly higher attitude scores towards flipped classrooms in teaching programming courses compared to the traditional method (Lin, 2019; Abdallah et al., 2020; McCord & Jeldes, 2019).

Students' level and subject areas

The analysis could not be broken down by student levels, as 24 studies were conducted among undergraduate students while the remaining three articles were unspecific. In terms of subject areas, 21 studies were conducted among only computer science students (Elmaleh & Shankararaman, 2019; Chang et al., 2018a; 2018b; Abdallah, 2020; Hsu & Lin, 2016; Jonsson, 2015; Loftsson & Matthiasdottir, 2021; Souza & Rodriguez, 2015; Cabi, 2018; Wang et al., 2019; AlJarrah et al., 2018; Durak, 2019; Patrick, 2016; Indi, 2016; Hayashi et al., 2015; Zhuo & Qi, 2015; Puarungroj, 2015; Mithun & Evans, 2018; Taşpolat et al., 2021; Amira et al., 2019; Ruiz de Miras et al., 2022), three studies among Engineering students (Nikolic et al., 2019; Lin, 2019; McCord & Jeldes, 2019), two studies among Computer and Engineering students (Karaca & Ocak, 2017; Alhazbi et al., 2016) and one study involved students from several disciplines (Pattanaphanchai, 2019).

The effect sizes by subject area comparing student performance in flipped classrooms and lecture-based methods are shown in Table 4. The flipped classroom was favoured with corresponding positive effect sizes than the traditional method. Given that most studies enrolled at least computer science students (k = 13), the subject area recorded the highest population of participants (N = 2106) with the moderate effect size at g = 0.59 and statistically significant (p < 0.001). Meanwhile, the engineering subject area (k = 2) involved a total of 1751 students, with a small effect size at g = 0.19, which was also statistically significant. The subject areas (computer and engineering) were subjected to a post-hoc test. The findings indicate that Engineering students benefit less from the use of flipped classrooms in delivering programming courses compared to Computer science students. Nevertheless, there is no statistical evidence to suggest that the Engineering discipline will benefit significantly from the traditional method.

Table 4
Effect sizes of flipped classroom students' achievement/performance based on subject areas and publication sources

	Effect Size and 95% CI								Heterogeneity		
	N	K	G	SE	Lower	Upper	Z	P	Q	Df (Q)	P
Subject area											
Computer science	2106	13	0.59	0.13	0.34	0.85	4.58	0.000	98.60	13	0.000
Engineering	1751	2	0.19	0.05	0.06	0.28	3.68	0.000	0.18	1	0.67
Publication sources											
Conference/proceeding	1110	8	0.67	0.19	0.29	1.06	3.40	0.001	88.32	7	0.000
Journal articles	2622	7	0.54	0.21	0.13	0.95	2.57	0.010	92.06	6	0.000

K = number of studies, SE = standard error, df = degree of freedom

Sources of Publication

Table 4 also illustrates the distribution of effect sizes according to publication sources, specifically for articles comparing students' achievement in flipped classrooms and traditional teaching methods. The studies were equally divided into conference (k = 8) and journal articles (k = 7) with a total of 1110 and 2622 programming students, respectively. Overall, the effect size was 0.67 for conference and 0.54 for journal articles and both were statistically significant. These effect sizes are considered moderate to high. Both publication sources favoured the use of flipped classroom models compared to lecture-based or traditional methods with high heterogeneity level above 90.0%.

Publication Bias

Publication bias was investigated for each of the result sections that were eligible for such analysis. The funnel plot generated from the first meta-analysis of studies comparing the effects of flipped classrooms and lecture-based methods on students' achievement or performance is shown in Figure 3. Meanwhile, Figures 4 and 5 depict the funnel plots for publication bias based on publication sources, conference and journal respectively. Upon visual inspection, all the funnel plots present an overall symmetrical distribution around the weighted mean effect sizes. Sterne and Egger (2001) described a funnel plot as a scatter plot of effect sizes computed from each study including a meta-analysis against a measure of study precision as quantified by the standard error. Specifically, the vertical and horizontal axis in the diagram represents the standard errors and the Hegdes' *g*, respectively. The presence of a symmetric funnel plot indicates that the meta-analysis lacks a publication bias (Duval and Tweedie, 2000).

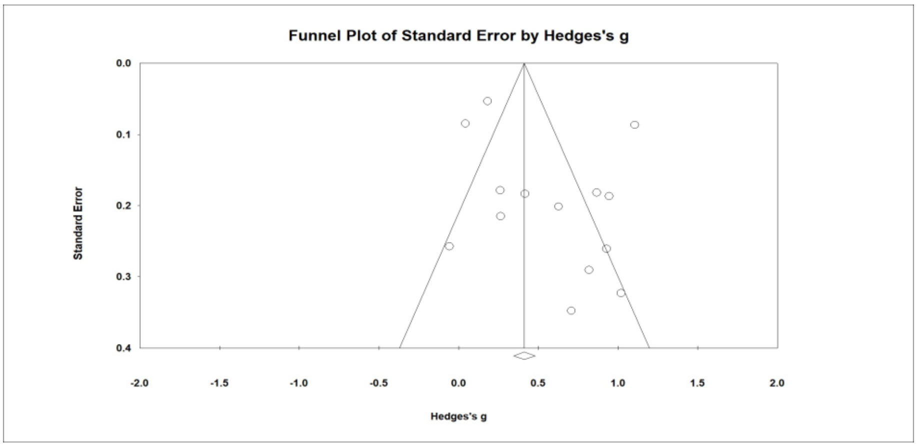

Figure 3
Funnel plot of standard error by hedges' g for the 14 articles comparing the effects between flipped classroom and traditional teaching method on students' performance in programming courses

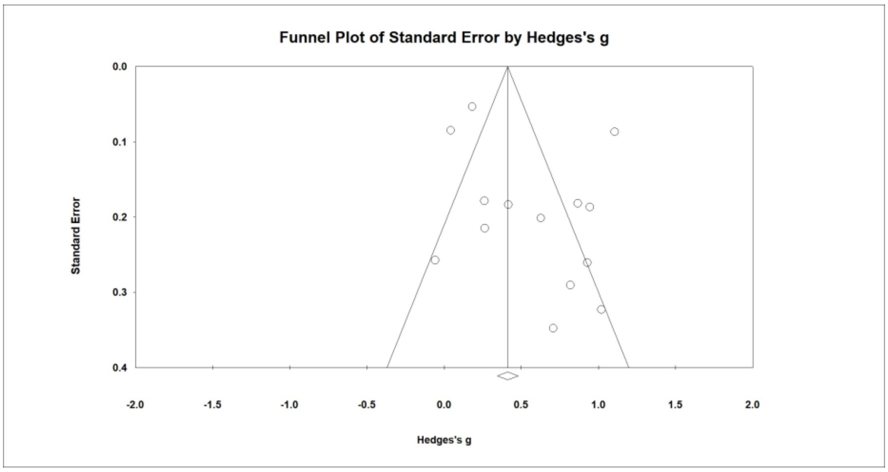

Figure 4
Funnel plot of standard error by hedges' g for the conference articles (n = 8) comparing the effects between flipped classroom and traditional teaching method on students' performance in programming courses

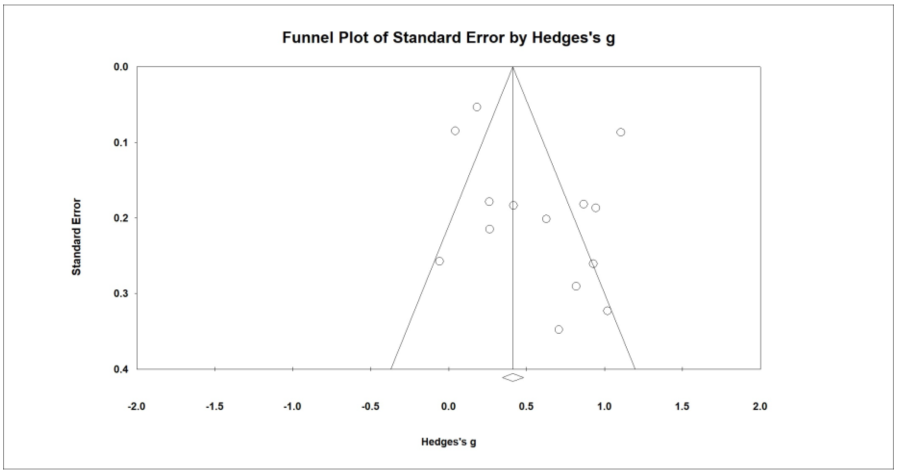

Figure 5
Funnel plot of standard error by hedges' g for the journal articles (n = 7) comparing the effects between flipped classroom and traditional teaching method on students' performance in programming courses

Table 5 shows the Classic fail-safe and Orwin's fail-safe *N* tests. Resultantly, the overall effect size detected in the current meta-analysis could only be nullified following the addition of another 535 studies of programming students' learning or performance outcomes. Thus, the absence of publication bias is further confirmed based on the funnel plots and fail-safe *N* tests results. However, these tests were not conducted for students' satisfaction given that at least three studies are required for publication bias analysis. Likewise, publication bias could not be performed for studies regarding the effects of flipped classrooms on students' problem-solving abilities.

Table 5
Classic fail-safe and Orwin's fail-safe *N* tests to assess publication bias in studies reporting the effects of flipped classroom on students' performance/achievement in programming courses

Classic fail-safe N	Achievement/performance
Z-value for observed studies	12.27
P-value for observed studies	0.00
Alpha	0.05
Tails	2.0
Z for Alpha	1.95
Number of observed studies	14.0
Number of missing studies that would bring p-value to > alpha	535
Orwin's fail-safe N	
Hedge's g in observed studies	0.41
Criterion for a trivial std diff in means	0.00
Mean hedge's g in missing studies	0.00

DISCUSSION

This study entailed a systematic assessment and meta-analysis of the effects of flipped classrooms on learning on students' performance/achievement, learning satisfaction, and problem-solving abilities in programming education. In order to discuss the effects objectively, the main findings are elucidated in the following

The first research question addressed in this study is to compare the effects of flipped classrooms and traditional teaching methods on students' performance or achievement in programming courses. Accordingly, 14 studies reporting students' performance in the selected articles considered flipped classrooms as the experimental group and traditional lecture-based learning as the control group. Most of the studies were quasi-experimental and only one was a randomised control trial. The computed effect size based on the fixed and random effects was 0.41 and 0.56, respectively. These values were trivial to small and moderate effect size (Cohen, 1992) and statistically significant ($P < 0.05$). These effects represent the hinge point (> 0.4) of the average effects of educational interventions that should be the aim of teachers and researchers (Hattie, 2012). Nevertheless, these interpretative rules of effect sizes need to be elucidated in terms of the underlying dependent variable assessed in this study, which is students' performance. For instance, an effect size of 0.41 indicates that the average score of a student in the flipped classroom is 0.41 standard deviations above the average student in the traditional teaching method. In other words, 59% of the students in the flipped classroom will score above the mean of the students in the traditional classroom. These interpretations revealed that the effect on students' performance seems small but very meaningful in the context of programming education.

The effect sizes found in this study are consistent with other meta-analyses conducted among higher education students (Spanjers et al., 2015; Chen et al., 2018; van Alten et al., 2019). For instance, an insight into comparable meta-analyses to gauge the relative size of effects was provided by Schneider and Preckel (2017). The researchers ranked a total of 105 variables according to the strength of their association with higher education students' achievement and found that an effect size of 0.36 is comparable to other interventions on the instruction variable technology such as blended learning (0.33, 52nd position) and intelligent tutoring systems (0.35, 47th position). Overall, the present outcomes align with prior flipped classroom meta-analysis reporting small average effect sizes that ranged from 0.19 to 0.47 on students' learning outcomes (Spanjers et al., 2015; Chen et al., 2018; Hew & Lo, 2018; Lo et al., 2017; van Alten et al., 2019). Given that this study is the first attempt to perform a meta-analysis on flipped classrooms in programming education, these findings could impact future research positively.

Another important aspect in this meta-analysis was students' satisfaction with the use of flipped classrooms and traditional teaching methods in teaching programming courses. Resultantly, a high effect size was detected following the meta-analysis of the relevant articles. All three studies favoured students' satisfaction with flipped classrooms compared to lecture-based methods, and the effect sizes were statistically significant. Nevertheless, this result should be interpreted with caution as it does not completely mean that students were dissatisfied with traditional classrooms. The number of studies included in this analysis is relatively small to make such a strong conclusion. The present findings are inconsistent with the previous meta-analyses (Spaniers et al., 2015; van Alten et al., 2019), where blended learning had a non-significant trivial effect size on students' satisfaction. However, these studies included articles from various disciplines while the present study focused on programming courses. Given the large heterogeneity between the studies included in this analysis, the impact of flipped classrooms on programming students' satisfaction requires further investigation. For instance, Loftsson and Matthiasdottir (2021) reported that 47% and 33% were satisfied and dissatisfied with flipped classrooms, respectively. Additionally, 60% of surveyed students were satisfied with the teaching method but 50% of them felt that the course lacked traditional lecturing. Therefore, the design and educational context of the flipped classroom needs to be carefully planned before implementation for programming courses.

Students' problem-solving ability was reported in two studies (Lin, 2019; Hsu & Lin, 2016) comparing the effects of flipped classrooms and traditional methods in delivering programming courses. Both studies contributed similar effect sizes and favoured the flipped classroom. Other aspects that were reported in the reviewed studies included students' attention, confidence (Chang et al., 2018), competencies acquisition (Pattanaphanchai, 2019; Elmaleh & Shankararaman, 2019), learning motivation (Lin, 2019; Abdallah, 2020), and learning attitude (Lin, 2019). These studies were not sufficient to perform a meta-analysis, however, most of the findings also favoured the application of flipped classrooms.

The third research question addressed in this study is the possible moderator effects of students' level, subject areas, and publication sources on the effectiveness of flipped classrooms for programming courses. In all the meta-analyses, the significant heterogeneity in effect sizes between studies was mainly attributed to random sampling given the variation in sample sizes. Moreover, no study reported that students in the flipped classroom performed worse than the lecture-based method in terms of performance, learning outcome, satisfaction, and problem-solving ability.

Moderating effects were sparingly found in this study. The main moderating effect detected in this study was the students' discipline as the flipped classroom was more effective for computer science students compared to those in engineering. This is in line with the FTC meta-analysis by Cheng et al. (2018), who found that subject areas significantly moderated their results. Nonetheless, the meta-analysis for students' satisfaction had low power for proper moderator analysis. Thus, there is no strong evidence to ascertain that moderator effects were absent.

Various subject areas or disciplines have been investigated in previous meta-analyses comparing the flipped classroom to the traditional teaching method (Holdhusen, 2015; Karabulut-Ilgu et al., 2018; van Alten et al., 2020). The present analysis involved only two major disciplines: Computer science and Engineering, which is expected as these subject areas entailed the introduction of undergraduates to various programming courses. Resultantly, computer subjects benefitted more (higher effect size) from the implementation of flipped classrooms in delivering programming courses than engineering subjects. This outcome aligns with a previous meta-analysis in which the subject of Engineering underperformed compared to other disciplines following the introduction of flipped classrooms (Cheng et al., 2019). However, this result needs to be interpreted with caution as there is no evidence to suggest that flipped classrooms will impact Engineering subjects negatively, and only two studies in this review focused on Engineering students. Moreover, the Engineering field has been among the top advocates of the flipped classroom model (Holdhusen, 2015). A previous meta-analysis found a low number of studies reporting the use of flipped classroom models in engineering subjects (Karabulut-Ilgu et al., 2018). Given that the present meta-analysis focused on programming education, it is not surprising as only three relevant engineering studies were identified in this study. Most of the articles identified in the initial literature search lacked mean scores, SD, and sample sizes required for performing a meta-analysis.

All the reviewed studies were conducted among undergraduate students. Hence, student levels were not subjected to further analysis in this study. This result is unsurprising as it aligns with a previous meta-analysis in which undergraduates accounted for the highest percentage of students enrolled in studies comparing flipped classrooms and traditional teaching methods (van Alten et al., 2020). Graduate students were not included in any of the 28 reviewed articles, which might be due to the relatively low implementation of lectures in graduate programming education compared to undergraduate students. Moreover, graduate programming students usually analyse research works when outside the class while the little time on lectures is mainly under the traditional lecturing method.

Most of the publications that met the inclusion criteria were articles from conferences and proceedings. Additionally, these articles demonstrated small to moderate effect sizes favouring flipped classrooms over traditional methods in delivering programming courses. Similar results were also detected in the journal articles comparing flipped classrooms and the traditional method. Meanwhile, no significant difference was observed between the effect sizes of publication sources (conferences/proceedings vs journal articles). In general, no strong evidence of publication bias was observed in the empirical studies on flipped classroom models included in the present meta-analysis. Apart from the assessment of the funnel plot of studies included in the analysis, the Classic fail-safe N test and Orwin's fail-safe N test were also computed to determine if any publication bias existed. Nevertheless, all the methods consistently showed that evidence of publication bias was lacking in the meta-analysis.

LIMITATIONS

This meta-analysis focused on the effectiveness of flipped classroom model on various student learning and behavioural outcomes in programming education. However, only a few studies reported students' behavioural outcomes, such as satisfaction and motivation, hence, effect sizes were mainly estimated from a relatively high number of studies reporting learning outcomes (academic performance, achievement, problem-solving abilities and so on). Hence, findings from this study might inform policymakers in the educational sector more about cognitive learning outcomes when deciding to implement flipped classrooms for delivering programming courses.

Most of the studies did not mention the student level, study duration and frequencies of the flipped classroom implementation. Thus, the potential moderating role of these variables was not analysed in this study. Attempts were made to assess the moderating role of the subject area but the number of studies, especially for the engineering discipline, was very small. Given that flipped classroom has continued to receive extensive interest among researchers, more evidence will be available across various programming subjects in the future for a more robust analysis. Pedagogical characteristics and study quality were also not coded in this meta-analysis. Most of the analysed studies lack sufficient detail on flipped classroom implementations. Meanwhile, the majority of studies were quasi-experimental as only a single RCT was conducted among programming students.

Additionally, the articles included in this meta-analysis were mainly from conferences/proceedings and journals. Given that the former publication sources are not frequently subjected to rigorous review, more peer-reviewed journal articles are needed to gain highly robust data to improve the present knowledge on flipped classroom effectiveness in programming education.

CONCLUSION

This meta-analysis reviewed previous studies investigating the effectiveness of flipped classrooms in programming education. Furthermore, the analysis focused on comparative studies between the flipped classroom and traditional teaching methods in delivering programming courses. Upon computing the overall effect, the flipped classroom was favoured over traditional teaching methods in terms of students' learning outcomes, mainly achievement/performance and problem-solving ability, with a small to moderate effect size. Similarly, the flipped classroom was favoured ahead of the traditional method in terms of students' satisfaction with methods of delivering programming courses. Factors such as student type and type of publication had no moderating effects on the results, however, the subject area seems to moderate the effectiveness of flipped classrooms. This study is the first attempt to perform a meta-analysis of flipped classroom implementation in programming education. Hence, these findings may be helpful to researchers, educations and practitioners either when designing or deciding to introduce flipped classroom pedagogy in delivering programming courses. More research articles are needed to elucidate the impact of flipped classroom models on various dimensions of programming students' learning outcomes, including performances, attitudes, satisfaction, self-efficacy and so on.

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