The Impact of Flipped Classroom on College Students' Academic Performance: A Meta-Analysis Based on 20 Experimental Studies

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Abstract: *The flipped classroom is one the most popular teaching models in recent years. Domestic and international scholars have carried out many experimental and quasi-experimental studies to explore the impact of flipped classroom on students' academic performance, but the results are mixed. To further explore the impact of flipped classroom on college students' academic performance, this paper adopted the meta-analysis method to quantitatively analyze 20 domestic and international experimental studies of flipped classroom. We found that: i) The flipped classroom positively affected college students' academic performance, and the overall combined effect size was 0.66; ii) Effect sizes vary somewhat by subject types. For example, effect sizes for science, liberal arts, and engineering were 0.75, 0.72, and 0.34, respectively; iii) The flipped classroom had the same effect on the learning effect of different knowledge types, but practical knowledge learning was better than theoretical knowledge; and iv) The flipped classroom had produced significant impact on different class sizes, particularly medium class size.*

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Conflict of Interests: *None.*

Background

I N traditional teaching, teachers mainly teach. Teachers are the center of teaching and classroom. Students passively accept the knowledge imparted by teachers, and do not truly master the learning. The flipped classroom can enable teachers to change the traditional instillation teaching and become instructors and helpers.

Flipped classrooms, also known as "inverted classrooms," started in the United States at the end of the 20th century and made substantial progress at the beginning of the 21st century. In 2000, American scholars Lage, Platt, and Treglia (2000) published an article titled "Inverting the classroom: A gateway to creating an inclusive learning environment." They proposed to use flipped classroom in the introductory economics course at the University of Miami to activate differentiated teaching and adapt to the different learning styles of different students. In the same year, "The 'Classroom Flip': Using web course management tools to become the guide by the side" in which he proposed the flipped classroom teaching model for the first time (Baker，2000). Beginning in the fall of 2000, at the University of Wisconsin-Madison, teachers began to use e-Teach streaming video to teach computer science courses. Students watch instructional videos on the Internet, while the classroom is mainly based on answering questions and solving puzzles instead of the traditional classroom teaching method. In 2007, Jonathan Bergmann and Aaron Sams, two chemistry teachers at Woodland Park High School in Colorado, USA, used screen recording software to make PowerPoint presentations and lectures in order to help students who were unable to keep up with their academic progress due to absent classes. They put them on the school's public platform so that students could study at home. This form of teaching was also widely welcomed among students who were not absent. Later, many teachers began to apply this new teaching model to their classrooms (He, 2014). Because of the beginning of two middle school teachers, the flipped classroom entered the middle and elementary school classrooms. In 2011, Salman Khan founded the Khan Academy to provide teaching videos, online exercises, online assessments, and other contents, which also provides a basis for the application of flipped classrooms. This has aroused great attention from global educators on flipped classrooms.

Different scholars explain the concept of flipped classroom from different angles. For instance, Strayer's definition of flipped classroom takes the transformation of the traditional classroom teaching process as the starting point to define the new model, new process. That is to say, students can preview their knowledge by watching teaching videos or other electronic materials before class. Students can learn through cooperative and independent learning methods during the class, allowing students to fully interact and collaborate and consolidate knowledge (Strayer, 2012). Hamdan et al. (2013) believed that flipped classroom is a teaching method that transfers the direct teaching behavior space to the private teaching space. The teacher's role is the instructor and a teaching model that uses a dynamic and interactive learning place, group discussion as a teaching space. Bishop and Verleger (2013) summarize the flipped classroom as a pedagogical technology that includes interactive group learning activities and computer-

based personalized teaching outside the classroom. Research on flipped classroom in China started relatively late. Before the flipped classroom was introduced to China, some Chinese schools and scholars had already explored the Chinese-style "flipped classroom." One of the first schools that experimented flipped classroom teaching was Chongqing Jukui Middle School. In 2012, Zhang Yujiang, an information technology teacher in this middle school, after drawing lessons from the American flipped classroom teaching reform model, combined with the actual situation of the school, proposed the "four steps before class" and "five links in class" basic flipped classroom model (Zhang & Li, 2012). Besides, more typical was the "problem-oriented autonomous learning model" of the political discipline of Jiangsu Mudu High School in the 1980s, the "Learn first and then teach, practice in class" in Jiangsu Yangsi Middle School, the "3-3-6" model of Shandong Dulangkou Middle School, and the "Self-study: Demonstration Mode" of Xinjiang, Yuncheng, Shanxi Province (Wang et al., 2013).

Chinese scholar Professor Zhong Xiaoliu of Tsinghua University and others believe that flipped classrooms are in an information environment where course teachers provide learning resources in teaching videos. Students complete the learning of learning resources before class, and teachers and students complete homework Q&A, collaborative exploration, and interactive communication activities together in class (Zhong et al., 2013). Zhu Hongjie of Nanjing Normal University believes that teachers create flipped classroom, students study at home or outside class and then return to the classroom for face-to-face sharing and exchange of learning results and experiences between teachers and students, students and students, in order to achieve teaching goal (Zhu & Zhu, 2013). Shandong Changle No. 1 Middle School is based on Bloom's mastering learning theory, and based on the original teaching reform results, built an online teaching system based on a digital learning platform, classroom wireless APs and students' personal tablet computers, forming a "two stages, four steps and ten links" flipped classroom model (Dong & Guo, 2014). In August 2013, now led by the MOOC Center of East China Normal University, 20 well-known domestic universities have established the C20 MOOC Alliance. Subsequently, the junior high and elementary school MOOC alliance was established, which significantly promoted the practice of flipped classrooms in China (Zhang, 2015).

The flipped classroom reverses the teaching process of the traditional classroom. The roles of teachers and students have changed: teachers have changed from the lecturers to the instructors, and the status of students in learning has changed from passive to active. Students use learning resources to study in advance before class and solve problems under guidance during class (Li et al., 2018).

The flipped classroom is a brand-new, deep-level blended learning model. It is a high degree of integration of traditional classroom teaching and online learning in form, means, and content and a mixture of different teaching concepts, learning concepts, and teaching modes. The flipped classroom uses online learning methods to allow students to choose learning resources and self-paced according to their specific learning situation. If knowledge transfer is completed before class, teacher can then use classroom time and classroom learning activities to help and guide students complete

knowledge's internalization The breakthrough change in the form of flipped classroom, in a sense, can genuinely realize the dominance of teachers' teaching and the exertion of the subjectivity of students' learning; promote the improvement of students' learning effects and the improvement of teachers' teaching efficiency, and significantly save the time of knowledge acquisition (He, 2014).

Although scholars at home and abroad have many flipped classroom definitions, they all believe that flipped classroom is a new type of classroom teaching mode that subverts the traditional teaching model. The flipped classroom aims at student development, highlights students' primary role, improves students' hands-on ability, broadens students' horizons, enhances students' learning enthusiasm and initiative, and changes students' learning attitudes and ways of thinking, and improves students' problem-solving skills ability.

Is the Flipped Classroom More Effective for Students?

Whether in academic research or teaching practice, flipped classroom has become a hot issue in the education circles at home and abroad. The impact of flipped classroom on students' learning has aroused many scholars' attention. However, the research results are somewhat mixed, making it difficult to explain the flipped classroom's theoretical research. The current research has the following three conclusions: i) Compared with traditional classroom teaching, flipped classroom teaching can significantly improve students' academic performance (some references). ii) The effect of traditional classroom teaching is significantly better than that of flipped classroom (some references). iii) There is no significant difference between the flipped classroom and the traditional classroom on students' academic performance (some references).

Flipped Classroom is Superior to the Traditional Classroom.

Many scholars believed that compared to traditional classrooms, flipped classrooms have a positive impact on student learning. Thai and others from the Department of Educational Research at Ghent University in Belgium used the "invertebrate science" course in the second year of undergraduate studies to conduct experimental research. The results showed that the test scores of students who adopt the flipped classroom teaching method were significantly higher than those of the classroom teaching group (Thai et al., 2017). Casasola of the University of California, USA, took 547 undergraduate students majoring in chemistry as the research objects. Through quasi-experimental design research, they found that the student's performance in flipped classroom teaching was significantly higher than traditional classroom teaching (Casasola et al., 2017). Chinese scholar Lei Xing et al. (2015) conducted experimental research on two "College Physics" courses. It was found that the grades of the class using flipped classroom teaching improved significantly than the class using traditional teaching.

Traditional Classroom is Better Than Flipped Classroom.

Although some studies have shown that flipped classroom teaching is significantly better than traditional classroom teaching (van Alten et al., 2019; Jang & Kim, 2020; Lo et al., 2019), some scholars have also questioned that traditional classrooms are superior to flipped classrooms in teaching some knowledge points. Foreign scholar Pi and Do selected students who participated in the two classes of "English Grammar and Writing for College Students" as experimental subjects and analyzed the experimental data using an independent sample t-test. The study found that the students' post-test results in the flipped classroom teaching group were lower than the pre-test results, while the students in the traditional classroom teaching group improved and reached a statistically significant level. It shows that the traditional classroom's overall teaching effectiveness in the "University English Grammar and Writing" course is better than the flipped classroom (Pi & Do, 2017). Chinese scholar Wentao He selected two parallel classes in the Vocational and Technology College traditional classroom's overall teaching effect experimental research objects. In the course of "C language programming," the flipped classroom teaching experiment was carried out to test the academic performance of the students in the modules of "C language knowledge concept," "analysis program," "debugging program," and "programming" module. The research results showed t, "t in the "C language knowledge concept" module, students in the traditional classroom group had higher learning love performance than the flipped classroom group. It showed that in terms of emphasizing conceptual knowledge, the effect of flipped classroom was not as good as that of the traditional classroom (He, 2014). Also supporting this view was the research of scholar Xiulin Ma and others. She applied the flipped classroom model to "College Information Technology" courses to test students' skills in "Computer Knowledge," "Win Application," "Word Processing," and "Network Application." It was found that in the "Computer General Knowledge" module, the traditional teaching model was better than the flipped classroom model (Ma et al., 2013).

No Difference between a Flipped Classroom and a Traditional Classroom.

Some scholars hold a neutral attitude and believe that flipped classroom teaching and traditional classroom teaching have no significant difference in students' academic performance. American scholar Clark used quasi-experimental methods to compare the effects of flipped classroom teaching and traditional classroom teaching on middle school students' mathematics performance. The study results found no significant difference in students' academic performance under the two classroom teaching modes (Clark, 2015). The American scholar Gloudeman explored the flipped classroom's impact on medical students' academic performance through comparative experiments. The study found that there was no significant difference in test scores between the experi-

mental group (flipped classroom) and the control group (traditional classroom) (Gloudeman et al., 2018). Scholar Ojennus selected two parallel classes in the "College Biochemistry" class to explore the impact of the two teaching methods on students' learning using experiments. Research results show that the two teaching methods have the same effect on students' academic performance (Ojennus, 2016). Smallhorn applied the flipped classroom teaching to the "University Biology" course and selected the knowledge points of genetics, evolution, and biodiversity to explain. Experimental results show that flipped classrooms can improve students' motivation to learn, but there is no significant academic performance difference than in the traditional classroom (Smallhorn, 2017). Chinese scholar, Huadong Yin's research on the flipped classroom teaching found no significant difference between flipped classroom teaching and traditional classroom teaching on students' academic performance (Yin, 2016).

Through the research mentioned above conclusions of domestic and foreign scholars, it can be found that as to whether the flipped classroom can significantly improve students' academic performance, no unified conclusion has been reached so far. Based on this, this study attempts to explore the following questions through scientific analysis methods:

(i) Compared with the traditional higher education, is the flipped classroom more effective in improving students' academic performance?

(ii) Does the flipped classroom affect students' academic performance in different college level? If yes, how big is it?

(iii) If the flipped classroom has a positive effect on student performance, what are the conditions for effective use of flipped classroom teaching?

This article collected specific samples based on consulting a large amount of literature and exploring this with scientific and rigorous research methods to answer the above questions.

Research Methodology and Procedures

Traditional literature analysis methods are mainly based on qualitative analysis or description. Traditional studies are challenging to give a quantitative and reliable conclusion, and some did not consider the impact of the quality of the research and the size of the sample on the conclusion. As the number of studies continues to increase, the probability of reaching a biased conclusion also increases. The use of meta-analysis applies specific design and statistical methods to the overall and systematic qualitative and quantitative analysis of previous research, which improves traditional research (Xia, 2005). We have collected studies on flipped classrooms at home and abroad and aimed to use meta-analysis to evaluate the impact of flipped classrooms on students' academic performance and explore flipped classroom teaching effectiveness.

Methods

Meta-analysis is a concept first proposed by educational psychologist Gene Glass. It is a research method that integrates research results and uses statistical methods to analyze multiple related independent research results (Glass, 1976). However, traditional descriptive literature reviews are mostly reviews without comments, and quantitative and comprehensive analysis of these research conclusions cannot be made (Cui & Ning, 2010).

Meta-analysis makes up for the inconsistency of conclusions on the same research topic: the insufficiency of the research object, research environment, and other factors, as well as the researcher's reasons. It uses systematic methods to synthesize seemingly inconsistent or conflicting results from different studies quantitatively. Effect size is the key to meta-analysis. It standardizes research results for direct comparison (Lipsey & Wilson, 2001). In this study, Standardized Mean Difference (SMD) is used as the effect size to indicate the impact of flipped classroom on academic performance.

Procedures

• **Selection Criteria**

Meta-analysis needs to determine the literature inclusion criteria according to the research purpose, research content, and statistical requirements (Borenstein et al., 2009). Combined with the US based "What Works Clearinghouse" (WWC) experimental standards, this study developed the following selection criteria:

(i)   The studies must examine the impact of flipped classroom on student performance, and flipped teaching is used as the primary research independent variable.

(ii) The studies must be experimental research or quasi-experimental design with pre-test and post-test data. Studies with pretest difference of more than 50% of standard deviation are excluded.

(iii) The studies must include sufficient statistics such as sample sizes, means, and standard deviation to calculate the effect size.

(iv) Participants of the studies must be college students at higher education institutions. The sample size is more than 25 people, and the two groups' sample sizes are similar to ensure the experiment's accuracy.

• **Literature Retrieval and Screening**

Based on Google Scholar and China National Knowledge Infrastructure (CNKI) databases, with flipped classroom and student performance as keywords, the time is set from 2000 to 2020, a total of 136,890 articles were searched. First, screen the titles of the literature, and then (i) exclude duplicate titles; (ii) exclude inconsistent titles without flipped classroom research; (iii) read the abstract after downloading the literature, and exclude no empirical research in the abstract; (iv) read the literature in batches, and exclude articles without experimental research; (v) read the full text of relevant research, and exclude articles without pre-test data in the experiment; (vi) re-search the selected
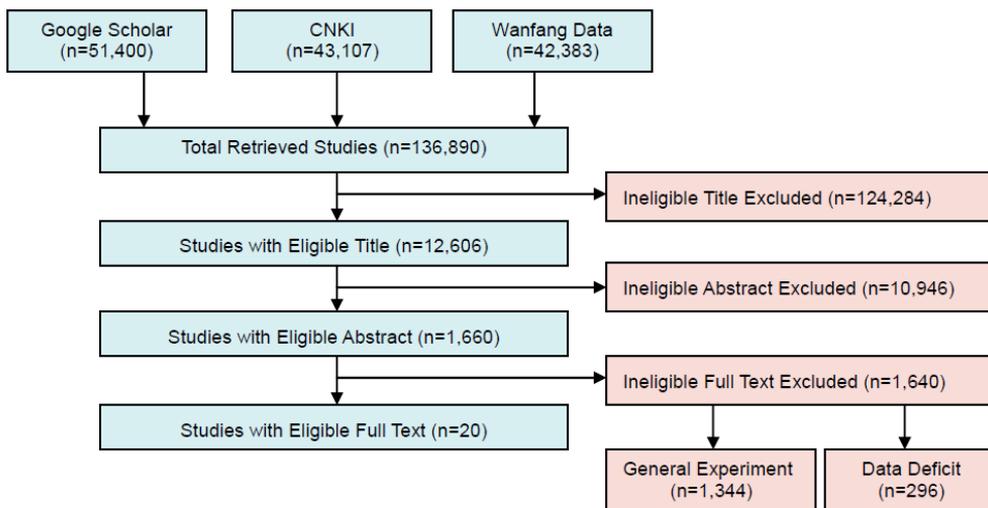
Figure 1. Flow Chart of Literature Retrieval and Screening.

Table 1. The Overall Impact of Flipped Classrooms on Student Learning.

		Effect size and 95% confidence interval				Heterogeneity			
Model	# of Studies	Effect Size	SMD	Lower Limit	Upper Limit	Q-Value	Df (Q)	p	I^2
Fixed	20	28	0.62	0.54	0.695	108.377	27	0.000	75.087
Random	20	28	0.66	0.502	0.82				

literature, discuss with the group, and finally screen out the standard documents that meet the requirements.

According to the selection criteria, a total of 20 studies finally met the requirements. Twenty-eight sets of data can be used for analysis (some research samples contain multiple sets of data). The literature retrieval and screening process are shown in **Figure 1**, and the literature screening information is shown in **Table 1**.

• **Eigenvalue Coding**

After the literature search and screening are completed, in order to facilitate later analysis and statistics, a three-person blind coding form is adopted to code the eigenvalues of

the documents included. The coding objects are the authors of the literature, the year of publication, the number of samples, the experimental subject, the type of knowledge, and the experimental method. According to the three disciplines of liberal arts, science, and engineering, the knowledge type is theoretical and practical. The theoretical type mainly teaches declarative knowledge such as concepts, rules, facts, and principles, and the student's mastery of the knowledge is tested through test papers. The suitable type is to teach procedural knowledge such as skills, experience, and operating procedures. The emphasis is on the ability of students to apply the knowledge they have learned to practice. The test is generally a computer operation or an operation display (Li et al., 2018). See **Supplemental Table 1** for the meta-analysis literature information used for statistical analysis.

- **Data Analysis**

This article uses CMA3.0 (Comprehensive Meta-Analysis 3.0) software as a data analysis tool. The specific analysis used for the publication bias, heterogeneity test, and effect size.

Results and Analysis

A total of 20 studies and 28 sets of data met the inclusion criteria. Liberal arts accounted for 64%, and science and engineering were 36%. The knowledge type accounted for 57% of the theoretical type, and the knowledge type accounted for 43% of the practical type. Small-sized classes accounted for 32%, medium-sized classes accounted for 29%, and large-sized classes were 39% in terms of sample size. The specific analysis results were as follows:

Heterogeneity Test

Heterogeneity testing is another core work of meta-analysis. According to the statistical principle of meta-analysis, only good homogeneous data can be combined for effect size. However, due to differences in the research sample size, evaluation criteria, and research methods obtained by meta-analysis, it is necessary to test the results of multiple studies for heterogeneity to select an appropriate effect model based on the heterogeneity results analysis. When the research's heterogeneity is significant, the random effect model is used for analysis; when the research's heterogeneity is small, the fixed-effect model is used (Li et al., 2018).

Commonly used methods of heterogeneity testing include the Q test and I2 test. The inspection level of Q inspection is usually set to 0.10. If the heterogeneity test results $p > 0.10$, it can be judged that multiple studies are homogeneous, and then the fixed effects model can be selected. If the heterogeneity test result of multiple studies is $p \leq 0.10$, it can be judged that multiple studies are not homogeneous, and the random-effects model is used (Borenstein et al., 2009).

The I^2 statistic is a supplement to the heterogeneity results of the Q test. It can give clearer results. When $I^2 = 0\%$, it indicates that there is no heterogeneity between studies. When $I^2 < 25\%$, there is slight heterogeneity. When $25\% \leq I^2 < 50\%$, there is moderate heterogeneity. When $I^2 > 50\%$, it is considered to be highly heterogeneous (Higgins et al., 2003).

Table 1 shows the combined effect size of the 20 included studies. The test results of sample heterogeneity showed that Q = 108.377, p = 0.000 (p $\leq$ 0.01), I^2 = 75.087% ($I^2 > 50\%$), indicating that there is a large heterogeneity between samples. Therefore, we used a random-effects model for data analysis.

The Effect of Flipped Classroom on Student's Academic Performance

To examine the overall impact of flipped classroom on students' academic performance, the selected literature was assembled into 28 sets of research data, and the random-effects model was used to analyze the flipped classroom teaching (see **Table 1**).

According to **Table 1**, the combined effect size SMD of the included study was 0.66. According to Cohen's statistical theory of effect size, the study produced a moderate effect. It can be seen that the flipped classroom is conducive to improving students' academic performance and has a positive impact on students' academic performance.

The Impact of Flipped Classroom on Different Subject Types

Different disciplines have their characteristics. Liberal Arts are also called humanities and social sciences. The learning content is mainly written narrative, requiring a wide range of knowledge, with emotion as the guidance, using events to evaluate characters and meaning to evaluate events, with solid perceptual awareness. Most of the science learning content is partially vectorized research, based on data, logical judgments, and solving problems with rigorous reasoning methods, which belong to natural sciences. The engineering department emphasizes application, pays more attention to practical application and experience (experiment) and applies science and technology principles to solve problems. So, does the flipped classroom have an impact on all subject types? What is the impact on different disciplines? Statistical analysis of the impact of flipped classroom on different disciplines is shown in **Table 2**.

According to **Table 2**, we can see that the combined effect size test of the three subjects of liberal arts, science, and engineering was p = 0.000 (p < 0.05), reaching a statistically significant level, which indicates that the flipped classroom has a positive impact on students of different types of subjects. From the perspective of the between-group effect test, the difference between the three subjects of liberal arts, science, and engineering showed p = 0.008 (p < 0.05), indicating that the flipped classroom has different effects on the learning of different subject types. From the perspective of specific

Table 2. The Impact of Flipped Classrooms on Different Subject Types.

Subject	# of Studies	Effect Size	95% Confidence Interval		Intergroup Effect Size	
			Lower Limit	Upper Limit	QBET	p
Engineering	6	0.34	0.153	0.533		
Liberal Arts	4	0.72	0.085	1.356	9.583	0.008
Science	18	0.75	0.571	0.925		
Combined Effect Size Test	Z = 8.733, p = 0.000					

Table 3. The Impact of Flipped Classrooms on Different Types of Knowledge.

Knowledge Type	# of Studies	Effect Size	95% Confidence Interval		Intergroup Effect Size	
			Lower Limit	Upper Limit	QBET	p
Theory	16	0.63	0.437	0.823		
Practice	12	0.70	0.431	0.977	0.189	0.664
Combined Effect Size Test	Z = 8.137, p = 0.000					

Table 4. The Effect of Flipped Classroom on the Performance of College Students of Different Class Sizes.

Class Size	# of Studies	Effect Size	95% Confidence Interval		Intergroup Effect Size	
			Lower Limit	Upper Limit	QBET	p
Large	11	0.66	0.373	0.945		
Medium	9	0.52	0.342	0.696	3.286	0.193
Small	8	0.81	0.546	1.065		
Combined Effect Size Test	Z = 9.344, p = 0.000					

discipline types, engineering had a combined effect size of 0.34, liberal arts had a combined effect size of 0.72, and science had a combined effect size of 0.75, and its combined effect size was ranked as follows: science > liberal arts > engineering. It suggests that the flipped classroom is more helpful to science students.

The Impact of Flipped Classroom on Different Types of Knowledge

Do different types of knowledge have different effects on students' academic performance? Is the application of flipped classrooms in practical classrooms better than in theoretical classrooms? We divided the knowledge types into theoretical and practical types, and the analysis is shown in **Table 3**.

It can be seen from **Table 3** that the combined effect size of theoretical knowledge and practical operation learning scores were both positive, and the combined effect size test p = 0.000 (p < 0.05), which was significant. It can be seen that the flipped classroom had a moderately positive effect on the academic performance of different types of knowledge. From the inter-group affect test results, p = 0.664 > 0.05, which did not reach the significant level. Therefore, no significant difference existed in the impact of flipped classroom on academic knowledge and practical performance. In terms of specific effects, the combined effect of academic knowledge (SMD = 0.63) and practical knowledge (SMD = 0.70) were very close. Studies have shown that flipped classrooms have good application prospects for theoretical knowledge teaching and practical knowledge teaching, improving and enhancing academic performance.

The Impact of Flipped Classrooms on Classes of Different Sizes

To examine the impact of flipped classrooms on the performance of students of different class sizes, we divided the sample size of students into three categories: small-scale, medium-scale, and large-scale class size according to the class size of public schools in China. The analysis is shown in **Table 4**.

From **Table 4**, the combined effect size of students' academic performance in small, medium, and large-sized classes were all positive, and the combined effect size test Z = 9.344, p = 0.000 (p < 0.05), reaching a significant level. This result shows that flipped classroom teaching has a moderately positive effect on student learning regardless of the class size. From the perspective of the effect size between groups, QBET = 3.286, p = 0.193 > 0.05, and it can be seen that the flipped classroom has no significant difference in the effect of large, medium, and small-sized students academic performance. In terms of specific effects, the combined effect size of small-sized classes (SMD = 0.52), the combined effect size of large-sized classes (SMD = 0.66), and the combined effect size of medium-sized classes (SMD = 0.81). This shows that compared
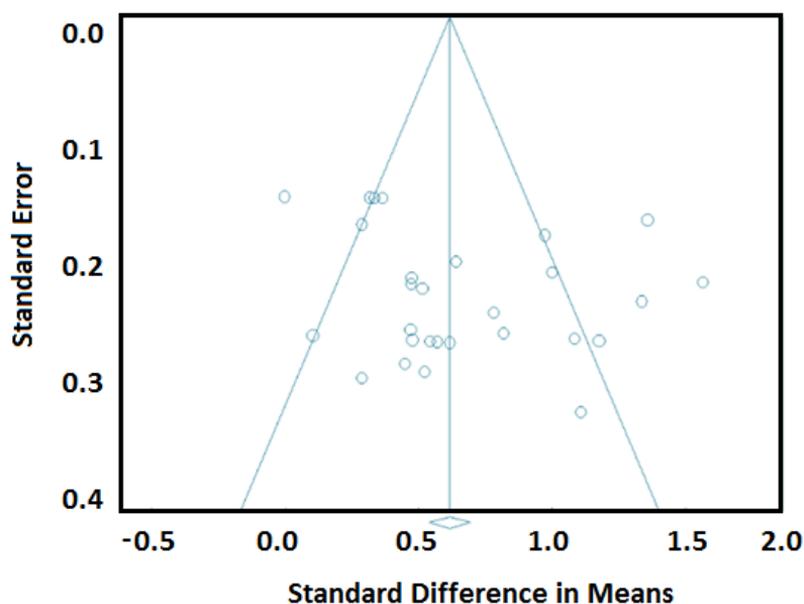
Figure 2. Funnel Plot of the Publication Bias Test.

to the impact of small-scale flipped classrooms and large-scale flipped classrooms, medium-scale flipped classrooms' impact is more obvious.

Publication Bias Test

Bias, also known as a systematic error, refers to the deviation between research results or inferred values and actual values. If the published research literature cannot systematically represent the totality of research completed in the field, it is considered that publication bias has occurred. If there is publication bias, the meta-analysis results may be at risk of amplifying the actual effects of interventions (Rothstein, 2005).

Publication bias is an essential factor affecting the reliability of research results. Therefore, testing it is an indispensable part of the meta-analysis. Due to the small sample size in this study, to ensure the flipped classroom research results' scientific characteristics, the funnel plot combined with the Egger test method was used to perform publication bias on the included research samples. The result is shown in **Figure 2**.

From **Figure 2**, the sample effect size of the included study is symmetrically distributed on both sides of the average effect size, indicating that the publication bias of the study included in this study was unlikely. To avoid the subjectivity of the funnel plot, the study combined the Egger method to test further. If the result shows t < 1.96, p > 0.05, there is no significant publication bias between the studies (Begg & Mazumdar,

1994). The result showed that t = 1.54, p1 = 0.07, p2 = 0.14. Both the research data and the funnel plot indicated that the flipped classroom studies we included were less likely to have publication bias, and the combined effect size obtained was relatively robust and reliable.

Discussion and Conclusions

Compared with the traditional classroom teaching model, flipped classroom impact on student performance is significant regardless of class size. It shows that flipped teaching has a significant positive correlation with student performance, which is more conducive to students' development, and the medium-sized effect is the best. However, flipped teaching is also affected by many factors. It reflects the following aspects explicitly:

The Flipped Classroom is Significantly Related to Student Academic Performance

Our study showed that flipped classroom is positively correlated with students' academic performance, with a combined effect size of 0.66, which moderately positively affects students' academic performance. This result is consistent with the research results of Gao (2017), Li (2018), Cheng (2019), and Zhou (2020). Our study examined the relationship between flipped classroom and college students' academic performance. According to the research results, it can be inferred that the impact mechanism between the two may be: Compared with traditional classrooms, flipped classrooms can increase students' interest in learning, stimulate students' interest in learning, and turn students' learning from passive to active so that learning is indeed implemented in students. Luo (2015) pointed out that flipped classroom application has generally increased students' interest in learning. Under this teaching format, students learn to retrieve information, learn independently, and think actively. Liu et al. (2017) mentioned that more than 70% of students believed that flipped classrooms could help them master the essential and challenging points of knowledge, cultivated their learning interest, enhanced their classroom participation, and cultivated their learning autonomy.

The Moderating Effect of Subject Type, Knowledge Type, and Class Size

The moderating effect test results show that flipped classroom positively affect students' academic performance, but effect sizes vary by subject types, knowledge types, and class sizes.

Flipped classroom have significant differences between liberal arts, sciences, and engineering in terms of subject types. The combined effect sizes for engineering, liberal arts, and sciences were 0.34, 0.72, and 0.75, respectively. It indicating that the flipped classroom is more helps to science students.

Flipped classrooms have no significant differences in applying different types of knowledge in terms of knowledge types, but flipped classrooms are more suitable for practical courses from the perspective of effect size. Ma's (2013) research indicated that the flipped classroom is not effective in teaching systematic knowledge, but for content convenient for task-driven and project-based teaching methods (for example, word processing modules and spreadsheet modules) had more superior performance.

In terms of class size, our study showed that compared to large-scale classes and small-scale classes, medium-scale flipped classrooms had a larger effect size, with a practical value of 0.81. However, because this study's object is college students, which have specific particularity, Fu (2016) pointed out that contemporary college students' study input is at the middle or below level. Liu (2020) believed that under the influence of long-term traditional "spoon-feeding" teaching, college students have low self-learning ability and inactive learning behaviors, which have a particular impact on the application of flipped classrooms in different class sizes.

In sum, after using meta-analysis to analyze 20 experimental studies on the impact of flipped classroom teaching on students' academic performance, we can conclude:

(i) Compared with traditional classrooms, flipped classrooms have a moderately positive impact on students' academic performance (SMD = 0.66).
(ii) In terms of different subject types, flipped classroom is more suitable for science students (SMD = 0.75).
(iii) In the performance of different knowledge types, flipped classroom application in practical operation class is better than the application in theoretical class (SMD practice = 0.70; SMD theory = 0.63).
(iv) Compared with large-scale classes and small-class teaching, medium-scale flipped classrooms are more conducive to improving students' academic performance (SMD = 0.81).

The findings are obtained through data analysis based on collecting certain sample documents, which have certain reliability, but there are also shortcomings. Since meta-analysis is an exploratory analysis tool, its conclusions are inferential results rather than factorial results and are affected by moderating variables' moderating effects.

Implications

Studies have found that flipped classrooms can effectively improve classroom teaching, and flipped classrooms positively impact students' learning attitudes and learning strategies. However, research also shows that flipped classroom have certain limitations, and flipped classroom teaching should be designed scientifically and rationally according to students' characteristics at different stages, different subjects, and different knowledge points. It can be improved from the following aspects in specific research and application.

Find Classroom Flipping Models Suitable for Different Subjects

It can be seen from the learning effect of flipped classroom that it is not suitable for reasoning, conceptual and systematic courses, such as language, history, and other liberal arts courses. However, flipped classrooms have apparent advantages for abstract and logically clear science teaching such as mathematics, physics, and chemistry. The possible explanation is: liberal arts courses need to create an ideal situation to promote students' emotional exchanges and ideological collisions to cultivate their humanistic feelings. In this case, teachers can practice and study the flipping model for liberal arts courses through effective grouping, role assignment, process guidance, results in the display, exchange experience, and process evaluation methods to improve their teaching effects.

Appropriate Flipping According to the Characteristics of Knowledge Content

Although flipped classroom has a moderately positive effect on improving student learning, not all knowledge in all courses is suitable for flipping. Different types of knowledge points should be different when designing flips. One should design more background knowledge of advanced organizers before class and internalize and explain the critical and challenging classroom points for theoretical knowledge. The practical knowledge can be arranged operational knowledge before the class, and the class focuses on learning more profound skills. Design targeted inquiry activities that can give full play to students' initiative and creativity to flipped classroom teaching, and knowledge types are properly integrated (Li et al., 2018).

Cultivate Students' Ability to Learn Independently

Affected by traditional educational thoughts, Chinese students have been in a passive position for a long time in their studies. They do not make a study plan and have no sense of inquiry. Data surveys show that most students still rely on teacher requirements as the mainline after entering the university and cannot learn independently (Liu et al., 2017). The flipped classroom has higher requirements for students to learn independently. The flipped classroom breaks the traditional teaching model of "teacher-centered," gives full play to the students' initiative, and allows students to arrange the time and progress of learning by themselves. This requires college students to conduct self-learning management, enhance self-efficacy, enhance learning motivation, and improve self-consciousness. Teachers can provide appropriate assistance to monitor and understand students' pre-class knowledge learning to provide more targeted classroom guidance. Flipped classroom is an advanced hybrid learning model of online learning supported by modern information technology and traditional classroom. Its connotation

will continue to extend with science and technology advancement and deepening people's teaching practice.

While the flipped classroom brings advantages to students, it also places higher demands on teachers. Teachers must build a relatively complete learning support system and construct a virtual learning environment suitable for independent learning and obtain students' learning resources. In this process, in addition to the guarantee of learning resources, specific guiding methods must be used to stimulate students' inner learning motivation.

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Appendix Table 1. Characteristics of the Included Studies.

ID	Author(s)	Sample Size	Subject	Subject Type	Knowledge Type	Research Design	Effect sizes
1	Chen, Y. (2020)	T=52 C=53	English	Liberal Arts	Theory	Exp.	1.01
2	Cheng, X.F. (2019)	T=57 C=56	English	Liberal Arts	Practice	Exp.	1.85
3	Qiu, H. (2014)	T=31 C=67	English	Liberal Arts	Theory	Exp.	0.57
4	Gao, W.Y. (2017)	T=39 C=36	English	Liberal Arts	Theory	Exp.	0.93
5	He, W.T. (2014a)	T=30 C=30	C Language Program Design	Science	Theory	Exp.	-0.16
6	He, W.T. (2014b)	T=30 C=30	C Language Program Design	Engineering	Practice	Exp.	0.48
7	He. W.T. (2014c)	T=30 C=30	C Language Program Design	Engineering	Practice	Exp.	0.42
8	He. W.T. (2014d)	T=30 C=30	C Language Program Design	Engineering	Practice	Exp.	0.61
9	Li, D. (2019)	T=37 C=31	English	Liberal Arts	Theory	Exp.	1.67
10	Li, X.X. (2017)	T=34 C=32	English	Liberal Arts	Theory	Exp.	0.99
11	Liu, J.W. (2015)	T=55 C=52	English	Liberal Arts	Practice	Exp.	0.56
12	Liu, J.J. (2016a)	T=46 C=46	English	Liberal Arts	Theory	Exp.	0.51
13	Liu, J.J. (2016b)	T=46 C=46	English	Liberal Arts	Practice	Exp.	9.22
14	Song, P. (2019a)	T=74 C=69	English	Liberal Arts	Practice	Exp.	0.95
15	Song, P. (2019b)	T=74 C=69	English	Liberal Arts	Theory	Exp.	0.25
16	Wei, T. (2019)	T=31 C=29	English	Liberal Arts	Theory	Exp.	0.49
17	Xia, Z. (2015)	T=46 C=42	English	Liberal Arts	Theory	Exp.	0.42
18	Xing, L. (2015)	T=87 C=95	Physics	Science	Theory	Exp.	5.92
19	Xu, H.J. (2017)	T=27 C=25	English	Liberal Arts	Theory	Exp.	0.19
20	Yin, H.D. (2016)	T=39 C=30	English	Liberal Arts	Practice	Exp.	5.50
21	Zhong, H. (2019)	T=32 C=32	English	Liberal Arts	Practice	Exp.	0.46
22	Ma, X.L. (2013a)	T=89 C=100	Information Technology	Science	Theory	Exp.	-0.25
23	Ma, X.L. (2013b)	T=89 C=100	Information Technology	Engineering	Practice	Exp.	0.28
24	Ma, X.L. (2013c)	T=89 C=100	Information Technology	Engineering	Practice	Exp.	0.27
25	Ma, X.L. (2013d)	T=89 C=100	Information Technology	Engineering	Practice	Exp.	-0.01
26	Thai (2017)	T=23 C=22	Biology	Science	Theory	Exp.	1.43
27	Pi (2017)	T=24 C=26	English	Liberal Arts	Theory	Exp.	-0.81
28	AlJaser (2017)	T=34 C=18	English	Liberal Arts	Theory	Exp.	-0.20