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Article

Meta-analysis reveals the effectiveness evaluation of blended learning models across different academic disciplines

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Abstract: With the rapid development of modern electronic information technology, blended learning has gradually gained attention and acceptance among universities and individuals. Most studies indicate that, due to the combination of teacher guidance and active student participation in blended learning models, their effectiveness often surpasses that of traditional, single-learning methods. However, different disciplines possess unique characteristics, and there is currently a paucity of research exploring the effectiveness of blended learning across various academic fields. This study aims to evaluate the effectiveness of blended learning models in different academic disciplines using meta-analysis methods, through a comprehensive quantitative synthesis of 18 relevant experimental and quasi-experimental studies. The results reveal that blended learning demonstrates a moderately high level of effectiveness in the humanities (g = 0.795, P < 0.01) and an exceptionally high level of effectiveness in science and engineering disciplines (g = 1.017, P < 0.01). Lastly, this study offers suggestions on effectively implementing blended learning, considering three aspects: discipline characteristics, learning resources, and evaluation criteria.

Keywords: blended learning; learning outcomes; meta-analysis

1. Introduction

The development of modern electronic information technology has posed unprecedented challenges to education, and traditional teaching methods are no longer sufficient to fully meet the demands of contemporary students for personalized and diversified learning experiences. As a learning approach that combines the advantages of online and offline learning, blended learning is increasingly recognized as a key strategy in the digital transformation of education. To evaluate the effectiveness of blended learning models, numerous scholars have conducted extensive teaching experiments and research. However, the conclusions of these studies vary, and the effect size calculation indicators used are inconsistent, making direct comparison of results challenging. Meta-analysis, by quantitatively integrating finding from multiple independent studies and summarizing the findings of existing research, can provide a scientific summary of previous research conclusions and guide subsequent theoretical research and practical exploration. Therefore, this study aims to use meta-analysis to integrate the different research results on the effectiveness of blended learning in a specific subject to answer the following questions: (1) Is the blended learning approach more effective than traditional learning methods? (2) How does blended learning perform in terms of learning outcomes across different disciplines?

2. Research overview

2.1. Blended learning definition

By the end of the 1990s, the rise of electronic information technology significantly influenced traditional learning models, offering greater flexibility in terms of time and space through online teaching, which was gradually embraced by the public. However, it soon became evident that online learning faced several prominent challenges, such as lack of supervision, difficulties in guiding students effectively, challenges in maintaining self-motivation, and suboptimal learning outcomes. In response to these issues, the concept of blended learning was introduced and gradually attracted widespread attention. Although blended learning has received extensive attention in the field of education, scholars do not completely agree on its exact definition, and they offered different interpretations based on their respective perspectives. Overall, blended learning is the optimal combination of traditional learning and online learning [1], as it is an educational method that effectively merges traditional face-to-face teaching with digital online teaching [2]. It is an innovative learning model aimed at enhancing students' learning outcomes by integrating online educational resources with offline teaching activities.

2.2. The effects of blended learning

Whether new learning methods outperform traditional approaches is a question of general interest to scholars. In the study by Al-Qahtani, A. A. Y. and Higgins, S. E., they compared the effectiveness of face-to-face, online, and blended strategies for the same course through a quasi-experimental study. The results revealed that the academic performance of the blended group (n = 55) was significantly higher than that of the online group (n = 43) and the face-to-face group (n = 50), but there was no significant difference between the online and face-to-face groups [3]. Andri Setiyawan and his partners found that the academic performance of students in the experimental group (n = 30) significantly improved through a pretest-posttest non-equivalent control group experiment with 60 mechanical engineering students, while the academic performance of the control group students (n = 30) did not show significant improvement [4]. In Zhang Wei and Chang Zhu's article, they explored the effectiveness of blended, online, and face-to-face strategies in English subjects through a questionnaire survey. The study results indicated that the effectiveness of the blended learning model was higher than that of traditional learning models [5]. Warman, L. A. D. discussed the impact of Google Classroom on the English proficiency of college students in blended learning. An experiment with 68 Indonesian students found that the experimental group learning English through Google Classroom scored significantly higher than the control group learning English through traditional methods. However, a few studies suggest that blended learning does not bring substantial changes to learning [6]. Neal H. Olitsky. and Sarah B. Cosgrove examined the impact of blended courses on student learning outcomes in an introductory economics course. The results of this study indicated that blended learning had no significant impact on students' academic performance [7].

In addition, research on the effectiveness of blended learning has been quite extensive, with many scholars employing meta-analysis methods. Means and his colleagues found that, on average, students in online learning performed better than those in face-to-face instruction [8]. The results of Bernard and his colleagues also indicated that, in terms of academic achievement, blended learning conditions outperformed classroom-based learning by about one-third of a standard deviation [9].

In summary, most studies indicate that blended learning can optimize learning outcomes, while a few studies suggest that blended learning has no significant impact on students' academic performance, which may be attributed to differences in learning outcomes across different disciplines. Additionally, previous meta-analyses have focused more on comparing the effectiveness of blended learning with other learning methods, with less attention given to its performance in different academic disciplines. Therefore, this study aims to explore the effectiveness of blended learning based on existing research, while also considering its performance in various academic disciplines.

3. Research design

3.1. Research methods

Meta-analysis, a research method introduced by educational psychologist Gene V. Glass, integrates data from multiple experimental or quasi-experimental studies using statistical techniques to assess the overall effect of a specific topic. Compared to traditional literature reviews, meta-analysis provides a more systematic and scientific approach to interpreting differences in research results, resolving inconsistencies across studies, and forming comprehensive conclusions. The process of meta-analysis typically includes five steps: defining research objectives, extensively collecting relevant literature and materials, establishing criteria for inclusion and exclusion, summarizing basic information about the studies, and conducting quantitative analysis. In this study, we usedCMA3.0 software to extract data such as sample size, means, and standard deviations to analyze the results of studies on blended learning across different academic disciplines. The standardized mean difference (SMD) was employed as an evaluation metricto assess the effectiveness of blended learning models in various subject areas.

3.2. Comprehensively search and screen relevant research literature

In conducting literature searches, this study selected databases such as Google Scholar and Web of Science. For literature retrieval, we used the keywords "blended learning" (including "effects" and "influence"). The study limited the literature search time range to 2013 to 2023, resulting in a total of 1360 relevant documents. However, not all documents met our inclusion criteria. We established the following screening criteria: (1) First, duplicate documents were excluded if the same document was published in different journals or different forms; only one was selected; (2) the study must be an experimental or quasi-experimental study, excluding review articles and theoretical discussion articles; (3) the study must focus on the impact of blended learning on a specific subject; (4) the article needs to report specific impact indicators to evaluate the effectiveness of blended learning in different subject areas; (5) only documents that provide sufficient data to calculate the experimental effect size were included; documents that cannot calculate the effect size will be excluded. After three rounds of meticulous screening, we ultimately identified 18 English-language documents that align with the research objectives. For a detailed description of the screening process, please refer to **Figure 1**.

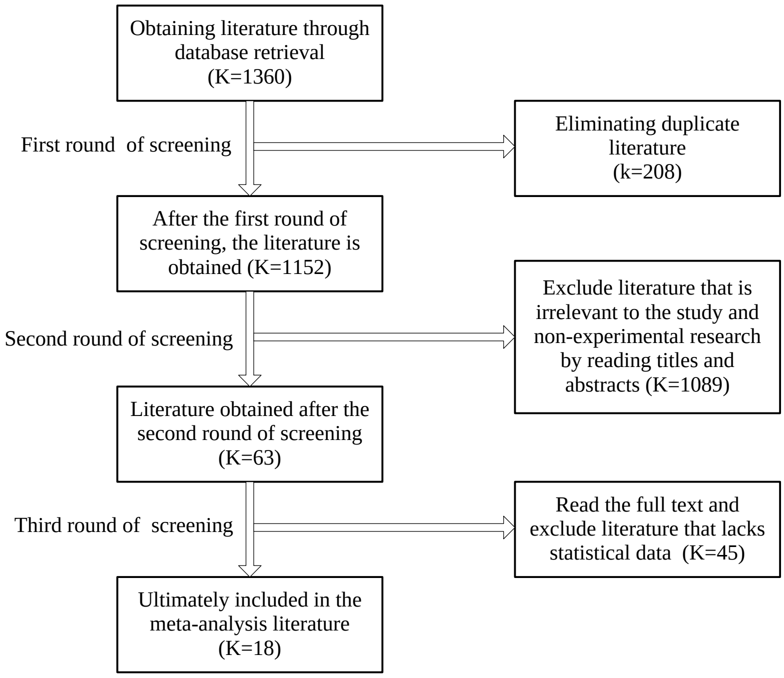

Figure 1. Literature search and screening process.

3.3. Literature coding

To facilitate data organization and to explore the application effects of blended learning models across different academic disciplines, we performed a coding process for the 18 original documents included in the meta-analysis. We recorded four key pieces of information: the author of the document, the year of publication, the sample size (Experimental Group EG/Control Group CG), and the discipline of the study. Using the discipline classification and code table released by the Development Planning Bureau of the Chinese Academy of Sciences in 2011, we categorized the experimental disciplines into linguistics, biology, preventive medicine and public health, power and electrical engineering, and mathematics. Due to the limited sample size, this study grouped linguistics under the Humanities and Social Sciences category and biology, preventive medicine and public health, power and electrical engineering, and mathematics into the Science and Engineering category for research purposes. Due to the limitations of literature retrieval and the disciplinary constraints of previous research on blended learning, this study, although not covering all disciplines, still offers valuable insights for the disciplines not included, given the unique characteristics of the humanities and social sciences as well as the natural and engineering sciences. **Table 1** presents the coded information.

Table 1. Literature coding.

No.	Author	Year of Publication	Sample size (EG/CG)	Subjects
1	Setiyawan [4]	2019	30/30	Science and Engineering
2	Humaira [10]	2019	38/38	Humanities and Social Sciences
3	Isda [11]	2021	25/25	Humanities and Social Sciences
4	Djiwandono [12]	2018	24/24	Humanities and Social Sciences
5	Grønlien [13]	2021	172/216	Science and Engineering
6	Katasila [14]	2022	8/8	Humanities and Social Sciences
7	Ebadi [15]	2018	20/20	Humanities and Social Sciences
8	Al Bataineh [16]	2019	15/13	Humanities and Social Sciences
9	Haryati [17]	2018	20/20	Humanities and Social Sciences
10	Huda [18]	2020	25/25	Humanities and Social Sciences
11	Mezaal [19]	2021	33/33	Humanities and Social Sciences
12	Warman [6]	2021	34/34	Humanities and Social Sciences
13	Astarilla [20]	2017	20/20	Humanities and Social Sciences
14	Ihbar [21]	2019	25/25	Humanities and Social Sciences
15	Wahyuni [22]	2018	32/36	Humanities and Social Sciences
16	Laili [23]	2018	45/45	Humanities and Social Sciences
17	Kiviniemi [24]	2014	28/38	Science and Engineering
18	Lin [25]	2016	27/27	Science and Engineering

3.4. Data analysis

This study uses experimental or quasi-experimental literature as samples, with corresponding effect sizes calculated using difference-type effect sizes, to measure the difference between the means of two groups and thereby assess the experimental effect or the degree of correlation between variables. By applying the standardized mean difference (SMD) formula, we extracted statistical data such as sample size, mean, and standard deviation from 18 studies to calculate the individual effect size for each study, and then further calculated the pooled effect size. The SMD commonly used in most studies include Cohen's d, Glass's Δ, and Hedges'g. In studies with large sample sizes, the effect sizes obtained from the three calculation methods are roughly the same; however, for studies with small sample sizes, Cohen's d may overestimate the effect size. To reduce estimation bias and provide a more accurate assessment of the effect size, this study decided to use Hedges'g (referred to as the g value) as the indicator for estimating the effect size. The calculation formula for Hedges'g value is as follows:

$$g = \frac{M_1 - M_2}{s} \tag{1}$$

In Equation (1), M_1 represents the mean of the experimental group, M_2 represents the mean of the control group, and *s* indicates the pooled standard deviation.

The calculation of the pooled standard deviation*s* is shown in Equation (2).

$$s = \sqrt{\frac{(n_1 - 1)s_1^2 + (n_2 - 1)s_2^2}{n_1 + n_2 - 2}} \quad (2)$$

In Equation (2), n_1 represents the sample size of the experimental group, n_2 represents the sample size of the control group, s_1 represents the standard deviation of the experimental group and s_2 represents the standard deviation of the control group.

This study utilizes Comprehensive Meta-Analysis 3.0 (CMA 3.0) for data analysis. By inputting the sample size (*n*), post-test mean (*M*), and standard deviation (SD) of both experimental and control groups into the CMA 3.0 software, the Hedges' g value can be calculated.

4. Results

4.1. Heterogeneity and overall effect test

In the process of meta-analysis, combining effect sizes from multiple studies is a crucial step. Before merging the effect sizes, it is necessary to determine whether to use a random-effects model or a fixed-effects model. The fixed-effects model is based on the assumption that all studies come from the same overall sample; the random-effects model is based on the assumption that various studies come from different population samples. Given that the experiments and quasi-experiments included in this study selected different samples, the random-effects model better reflects the differences between the samples in this study. Therefore, this study employs the random-effects model to merge effect sizes and conduct subsequent analyses.

After merging effect sizes, a heterogeneity analysis must be conducted. The purpose of Heterogeneity analysis is to identify the factors that lead to different study results, which may stem from variations in research methods, design, and research context affecting the effect sizes. By analyzing heterogeneity, researchers can quantify the differences between the effect sizes of included studies. Only when heterogeneity is present is it necessary to perform moderator analysis or subgroup analysis to explore the potential reasons for heterogeneity.

Currently, when conducting meta-analyses, the primary indicators used to assess heterogeneity include the *Q*-statistic and the I^2 statistic. According to Higgins, an I^2 value below 25% indicates low heterogeneity, 25% to 50% indicates moderate heterogeneity, and above 75% indicates high heterogeneity. The heterogeneity test results of this study show Q = 126.473 and I^2 = 85.768%, both reaching a statistically significant level (P < 0.001). Based on this result, it can be concluded that there is a high level of heterogeneity in this study, suggesting that moderator or subgroup analysis should be conducted. Furthermore, this result further confirms that the use of the random-effects model is appropriate.

Among the 18 studies included, one document provided two sets of experimental control results, resulting in a total of 19 sets of experimental control outcomes. These 19 sets of experimental control outcomes include sample size, mean, and standard deviation, with the effect sizes for each group ranging from

−0.888 to 3.329. The pooled effect size g, calculated using CMA 3.0, is 0.840 ($p < 0.001$), with a 95% confidence interval of 0.525 to 1.154. According to Cohen's criteria, effect sizes of 0.2, 0.5, and 0.8 are considered small, medium, and large effects, respectively. Therefore, this finding suggests that blended learning has a significant positive effect on improving learning outcomes, contributing to higher-quality learning achievements (see **Table 2**).

Table 2. The impact of blended learning on learning outcomes.

Model	Number Studies	Hedges's g	Effect size and 95% confidence interval		Heterogeneity			
			Lower limit	Upper limit	Q	Df	P	I^2
Fixed	19	0.618	0.507	0.729	126.473	18	0.000	85.768
Random	19	0.840	0.525	1.154				

4.2. Publication bias test and sensitivity analysis

4.2.1. Publication bias test and revise

The accuracy and credibility of a meta-analysis largely depend on the analysis of potential biases in the research process. Among these biases, publication bias is considered the most influential, making it essential to examine the extent to which it affects the meta-analysis. Publication bias refers to the tendency for statistically significant studies to be more likely accepted and published by academic journals, while studies with non-significant results are less likely to be published. A funnel plot is commonly used to make a preliminary judgment about publication bias, with a symmetric funnel plot usually indicating a smaller publication bias. A symmetric funnel plot generally suggests a smaller degree of publication bias. However, the symmetry of the funnel plot often involves personal subjective judgment. To reduce this subjectivity, more objective quantitative analysis methods can be employed, such as Egger's test. Egger's test is a linear regression method that can provide statistical evidence for publication bias testing to compensate for the subjectivity of the funnel plot. Therefore, the combined use of funnel plots and Egger's test can more accurately assess the degree of publication bias, which is crucial for ensuring the credibility and practical significance of the conclusions drawn from the meta-analysis.

By observing the funnel plot in **Figure 2**, it can be seen that its symmetry is not ideal. At the same time, according to the results of Egger's test regression equation, the estimated value of the intercept is 3.490, and its 95% confidence interval is between 0.584 and 6.395. The t-value for the intercept is 2.534 ($p < 0.001$), which means that there may be a risk of publication bias in this study. In an ideal situation, a meta-analysis should include all studies that strictly meet the inclusion criteria. However, in practice, due to various limitations, such as unpublished academic papers, it is difficult for us to collect all literature in the relevant field fully. This limitation may make it difficult for us to completely avoid the issue of publication bias. To address this issue, statisticians have provided effective methods to assess the potential impact of publication bias on the judgment of meta-analysis results, such as sensitivity analysis.

Figure 2. Funnel plot of standard error by Hedges's *g*.

4.2.2. Sensitivity analysis

To ensure the credibility of the corrected effect size, it is essential to assess the potential impact of publication bias on the meta-analysis results through sensitivity analysis. The classic fail-safe N is one of the commonly used methods in sensitivity analysis, and the fail-safe N can help researchers measure the severity of publication bias. It is important to note that the fail-safe N method is designed to determine whether publication bias significantly affects the research results, not to identify publication bias.

According to Rosenthal's theory, the fail-safe N should be less than $5n + 10$ (where n represents the number of studies included in the meta-analysis) for the unpublished literature to have an impact on the conclusions of the meta-analysis. In this study, the fail-safe N calculated using CMA 3.0 software is 733 ($\alpha = 0.05$, $p < 0.001$), which is significantly higher than $5n + 10$. This indicates that an additional 733 sets of effect size data would need to be included to potentially change the conclusions of this study, suggesting that the results are not influenced by publication bias.

4.3. Subgroup analysis

From the analysis results of **Table 3**, it can be seen that the effect of blended learning on the learning outcomes in humanities and social sciences is at a medium to high level ($g = 0.795$, $P < 0.01$), and the effect on the learning outcomes in science and engineering is at a high level ($g = 1.017$, $P < 0.01$). The between-group effect ($Q = 0.292$, $P > 0.05$) does not reach a statistically significant level, which means that the impact of blended learning on different disciplines is not significantly different.

Table 3. The impact of blended learning on different disciplines.

Subjects	Number Studies	Hedges's *g*	Effect size and 95% confidence interval		Test of null (2-Tail)		Heterogeneity
			Lower limit	Upper limit	*Z*-value	*P*-value	
Humanities and Social Sciences	15	0.795	0.419	1.172	4.141	0.000	$Q = 0.292$ $P = 0.589$
Science and Engineering	4	1.017	0.305	1.729	2.801	0.005	

5. Conclusions and recommendations

5.1. Conclusions

By conducting a meta-analysis of 18 articles (19 sets of experimental control results) to explore the effects of blended learning across different academic fields, two main conclusions were drawn.

5.1.1. Compared to traditional learning methods, blended learning has a positive effect on learning outcomes across various disciplines

The overall effectiveness test results answered the first question of this study, which is whether the effect of blended learning surpasses that of traditional learning. According to the meta-analysis results, the combined effect size of blended learning on learning outcomes is 0.840, with a high level of statistical significance. This not only confirms the positive role of blended learning in enhancing learning effectiveness but also aligns with existing research. As an innovative educational concept, blended learning is gradually gaining attention and recognition from both educators and students due to its unique charm. Blended learning skillfully integrates the advantages of traditional face-to-face classroom teaching with online learning, which can greatly stimulate students' curiosity and help them learn more effectively. By providing flexible learning time and space, blended learning enables students to access a broader range of learning resources. Moreover, when students encounter difficulties, they can engage in idea exchange through online learning communities and other platforms set up by schools, increasing their learning initiative. Overall, blended learning can not only provide students with a more flexible learning approach but also enhance their engagement and motivation in the learning.

5.1.2. The impact of blended learning on different subjects

The subgroup analysis results answered the second question of this study, which is that the learning effect of blended learning is at a medium to high level for humanities and social sciences and at a higher level for science and engineering. The primary difference arises from the different learning logics of each discipline. The field of humanities and social sciences is broad, with a core focus on shaping values, which requires creating suitable contexts to promote the exchange and collision of ideas. In contrast, science and engineering have well-defined knowledge structures and rigorous logical systems, focusing more on skill mastery and practical application. Taking English, the majority subject in this study's sample, as an example, compared to other subjects, applicability, humanistic nature, diversity, and memorability are the most distinctive characteristics of English. In humanities, the majority, traditional face-to-face classrooms have largely met these learning needs, so the potential for improvement through new learning methods is relatively limited. In the learning process of science and engineering, students need to reinforce theoretical knowledge through supporting experiments, emphasizing hands-on ability and practical operation. The blended learning model can provide a more flexible practical opportunity and experimental environment for science and engineering learning, such as virtual laboratories and simulation software. Compared to traditional classroom learning, online platforms provide students with a more flexible, convenient, and safe practical environment, better enhancing their practical skills and innovative thinking abilities. Therefore, blended learning is slightly more effective for science and engineering than for humanities and social sciences.

5.2. Recommendations

5.2.1. Assessing subject characteristics to implement blended learning flexibly

As demonstrated by the results of this study, due to the different learning logics across various disciplines, the effectiveness of implementing blended learning also varies. Therefore, in promoting blended learning, schools need to flexibly adjust teaching strategies based on subject characteristics and student needs. For instance, in the humanities and social sciences, there may be a greater emphasis on fostering discussion and developing critical thinking skills. In contrast, in the realm of science and engineering, there may be a stronger focus on training in experimental operations and problem-solving skills. In both cases, the key is to leverage the strengths of blended learning to complement the traditional classroom experience, ensuring that the educational approach is not only flexible but also aligned with the goals of each subject area. By doing so, schools can maximize the benefits of blended learning for all students, regardless of their field of study.

5.2.2. Enrich learning resources to provide a supportive environment for blended learning

Abundant learning resources and robust online learning systems provide strong environmental support for blended learning. By enriching online resources across various disciplines, students can more easily access learning materials beyond the limitations of textbook content. Additionally, during the implementation of blended learning, it is essential to strengthen training for teaching participants, especially in underdeveloped areas. Blended learning should not exacerbate regional disparities but should instead serve as a tool for achieving more balanced educational resources. In the context of blended learning, it is also important to ensure that all teaching participants, including teachers and support staff, are well-equipped to navigate the digital landscape. This means providing them with the necessary technological training and pedagogical support to effectively integrate online components into their teaching practices. Particularly in underdeveloped areas, where access to educational resources may be limited, blended learning can be transformative. By investing in the infrastructure and training needed to support blended learning, these regions can overcome traditional barriers to education, such as a lack of qualified teachers or physical textbooks. This approach can help to level the playing field and ensure that students, regardless of their geographic location, have access to high-quality education, regardless of their geographical location.

5.2.3. Introduce formative assessment to form an evaluation system adapted to blended learning

In traditional teaching evaluations, the outcomes are teacher-centric and based on end-of-term grades. It is evident that traditional teaching evaluations do not align well with the new dynamics of blended learning, hence the need for reforms and innovations in teaching assessments. In the context of blended learning, teaching evaluations should focus more on the continuous performance of students throughout the learning process, rather than focusing solely on exam scores at a single point in time. By observing the students' learning situation throughout the entire process, a more comprehensive understanding of their learning conditions can be achieved. This more holistic evaluation can better support the all-round development of students and provide teachers with more feedback information to guide the improvement of teaching practices. To further this goal, the introduction of process-oriented evaluations is essential for creating an assessment system that is well-suited to blended learning. Shifting from a focus on summative assessment to formative assessment allows for a more dynamic and continuous evaluation of student learning. It involves regular feedback and assessment tasks that are integrated into the learning process itself, such as quizzes, projects, and reflective journals, which can provide valuable insights into a student's understanding and progress at various stages.

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