Effectiveness of Blended Learning in Biomedical Engineering: A Meta-Analysis

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The goal of this meta-analysis is to assess the effectiveness of blended learning in biomedical engineering. To that end, the PubMed and Medline databases were combed for relevant research through January 2022, and the eligible papers were picked using a rigorous PRISMA-based selection approach. Blended learning was compared to traditional teaching approaches in all of the research considered. As a consequence of the present search, eighteen research articles with a total of 3097 participants adopting blended learning for biomedical engineering education were dis-covered. Two studies were included from each of the following countries including Australia, Brazil, Germany, Spain and USA. While, one study from China, Denmark, France, KSA, Malaysia, Serbia, Turkey and United Kingdom was included. The results of a meta-analysis employing random effects models revealed a significant difference between all blended learning and conventional learning methods [MD and its 95% CI were 2.36 (0.94, 3.78)]. The findings advised that biomedical engineering education stakeholders use an innovative teaching strategy based on digital pedagogies.

Keywords: blended learning, biomedical engineering, meta-analysis, digital pedagogies

INTRODUCTION

The growing number of students enrolled in Biomedical Engineering courses necessitates the rationalization of teaching procedures, which includes the use of e-learning, distant learning, and self-assessment technologies. In the recent decade, the rapid growth of e-learning systems has opened up new frontiers for re-solving these difficulties. Students can train separately without direct personal supervision using modern e-learning tools. Physiological processes as well as the operation of biomedical devices such as a pacemaker are depicted in interactive animations. Due to the nature of Biomedical Engineering, presence activities such as laboratory exercises or specialized seminars are required. Blended learning mixes online learning with in-person activities to create a long-term platform for effective mentorship of Biomedical Engineering students (Kožuško et al., 2012; Marrhich et al., 2021). Biomedical Engineering students would be able to efficiently generate and share supportive educational materials and learning re-sources in an online learning environment that is both efficient and interesting for students. Technologies that enable online education by introducing or in-creasing the possibilities of synchronous and asynchronous contributions may also assist students in learning in a face-to-face classroom: tasks that can be completed before, during, or after class (Hrastinski, 2008; Murray et al., 2014). Blended learning, on the other hand, claims to improve classroom learning while simultaneously reinventing the learning environment to give students greater autonomy (Smith & Hill, 2019). Students should be allowed to study more independently of time and place, as well as choose their own subject and pace of learning. The major concern is whether online tools can substitute for some classroom time while maintaining educational quality and performance (Owston & York, 2018). This is especially important in light of the COVID-19 outbreak. Many universities are considering using an online learning environment to replace part or all of their classroom training, both now and in the future (Peters et al., 2022; Saichaie, 2020). Appropriate use of technology can help us learn more by helping us to more effectively carry out our current activities or invent new ones (Tsekhmister, 2021). The use of a blended learning approach to teach biomedical engineering allows students to combine a variety of online asynchronous learning modalities with face-to-face learning and teaching, potentially promoting active, student-centered learning and the development of important problem-solving skills. As a result, educational institutions all over the world are under increasing pressure to use current Information and Communication Technologies to teach students and assist them in gaining the knowledge and skills they will need in the twenty-first century. The purpose of this research was to see how successful blended learning is in bio-medical engineering.

METHODOLOGY

We searched PubMed and Medline databases in January 2022 for this meta-analysis, which included the most recent literature on randomized controlled trials and cohort studies for the effectiveness of blended learning in biomedical engineering. The search criteria employed were biomedical engineering, higher education, randomized control trials, cohorts, and practical experiences. During the first search, we also searched through the reference tracking of bibliographies and manual searches to see if there were any additional studies that were relevant. Titles and abstracts were separately reviewed for inclusion by the authors.

The studies were identified using the PRISMA method, and they were only considered qualified if they satisfied the inclusion criteria (Fig. 1). After removing material that was obviously unconnected, the authors separately examined the study abstracts and full texts, deciding which publications to include based on the inclusion and exclusion criteria (Table 1). Any issues or conflicts were dis-cussed and resolved by all writers.

FIGURE 1
THE PRISMA FLOW CHART OF THE LITERATURE SELECTION FOR THE META-ANALYSIS

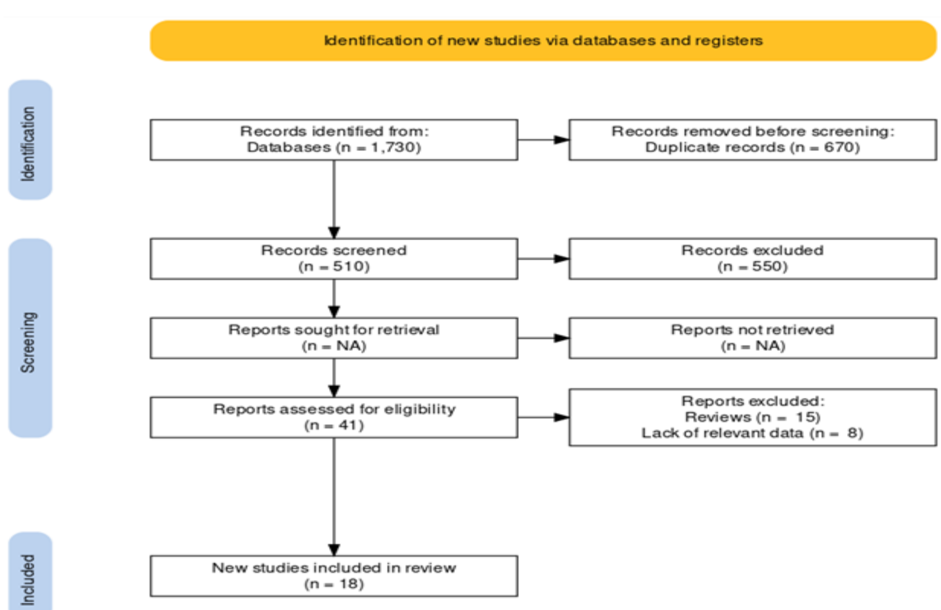


TABLE 1
CRITERIA FOR THE INCLUSION AND EXCLUSION OF STUDIES IN THE META-ANALYSIS

Inclusion	Exclusion
Original article	Reviews
Randomized control trials	Meta-analysis
Cohort studies	Systemic reviews
Innervation measures	Books/documents
Biomedical Engineering	Studies not related to biomedical engineering

Data Analysis

Review Manager 5.4 was used to examine the retrieved data with a 95% confidence interval. The heterogeneity among the studies was determined using the random model. Forest plots were created in order to determine the total cumulative impact. Because we predicted heterogeneity among the papers included in the meta-analysis, we used a random effects model.

FINDINGS / RESULTS

The PRISMA flowchart in Fig. 1 depicts a simplified research selection procedure. Table 2 shows the findings of the current search, which reveal eighteen researches with a total of 3097 participants using blended learning method.

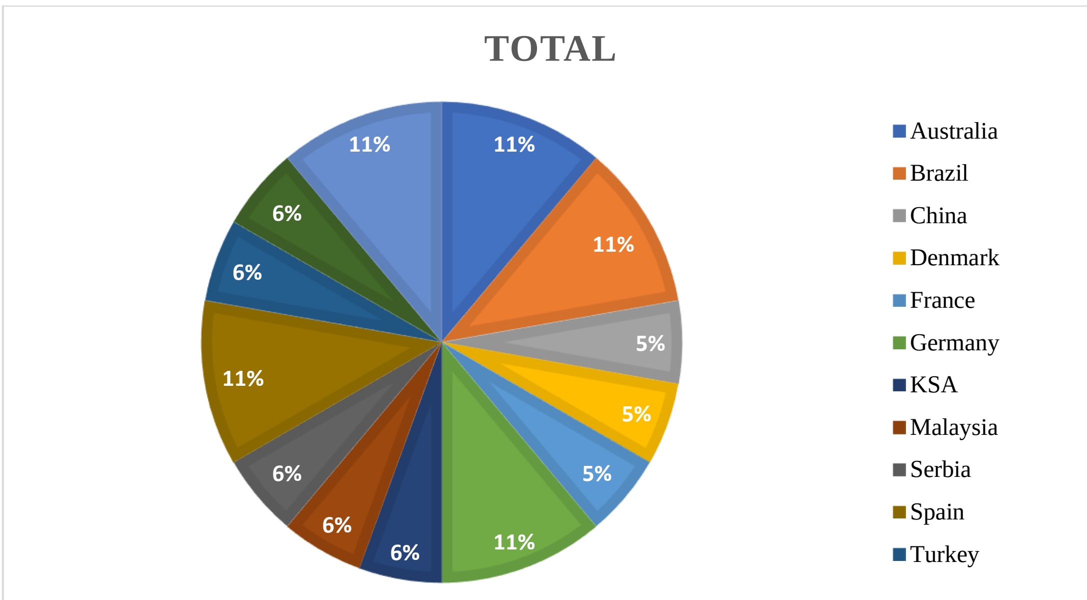
TABLE 2
CHARACTERISTICS OF INCLUDED STUDIES PRESENTING STUDY DESIGN AND COUNTRY

Authors	Country	Study design
(Ulrich et al., 2021)	Denmark	360° video used as e-learning
(Elzainy et al., 2020)	KSA	e-learning and online assessment
(Bartlett & Smith, 2020)	USA	Blended learning approach with mobile app
(Lozano-Lozano et al., 2020)	Spain	Blended learning approach with Ecofisio interactive website/app
(Jarrett-Thelwell et al., 2019)	USA	Traditional and integrative approach to teaching
(Shimizu et al., 2019)	Japan	Blended problem-based learning
(Marchalot et al., 2017)	France	Blended learning course and flipped classroom
(McCutcheon et al., 2018)	United Kingdom	Online learning versus blended learning
(Kho et al., 2018)	Malaysia	Blended learning
(Rocha et al., 2017)	Brazil	Educational video game (quiz type)
(da Costa Vieira et al., 2017)	Brazil	Blended learning approach with e-learning classroom
(Noll et al., 2017)	Germany	Augmented reality and blended learning
(Zhan et al., 2017)	China	Blended learning and pure e-learning
(Milic et al., 2016)	Serbia	Blended learning model

(Fernández-Lao et al., 2016)	Spain	Blended learning approach with interactive/app (Ecofisio)
(Küçük et al., 2016)	Turkey	Mobile augmented reality
(Nicklen et al., 2016)	Australia	Remote-online challenge based learning
(Lehmann et al., 2015)	Germany	Blended learning with web-based virtual patients
(Ilic et al., 2015)	Australia	Blended learning education

A total of 18 studies were selected for this meta-analysis those reported in various regions of the world as presented in Fig. 2. Two studies were included from each of the following countries including Australia, Brazil, Germany, Spain and USA. While one study from China, Denmark, France, KSA, Malaysia, Serbia, Turkey and United Kingdom was included.

FIGURE 2
COUNTRY WISE DISTRIBUTION OF SELECTED STUDIES PRESENTING BLENDED LEARNING IN BIOMEDICAL ENGINEERING



The blended learning was compared to traditional learning approaches in all of the research considered. When compared to conventional learning, we aggregated seven research with a total of 2010 individuals who used online blended learning. The meta-analysis using random effects models showed significant difference in online blended learning and traditional learning [MD and its 95% CI were 3.13 (0.81, 5.45)] as showed in Fig. 3. This result showed statistically significant (P=0.008) difference between blended learning and traditional learning in Biomedical Engineering. A significant heterogeneity was observed among studies (I2=99%).

The test of asymmetry funnel plot indicated publication bias among studies as presented in Fig. 4 and suggested that blended learning was more effective than traditional learning.

Further, for studies using digital blended studies (n=8) a total of 748 participants were included. The meta-analysis using random effects models showed non-significant difference in digital blended learning and traditional learning [MD and its 95% CI were 0.44 (-0.58, 1.46)] as showed in Fig. 5. These results showed no statistically significant (P=0.39) difference between digital blended learning and traditional teaching in higher education.

FIGURE 3
FOREST PLOT PRESENTING EFFECT OF ONLINE BLENDED LEARNING WHEN COMPARED TO TRADITIONAL METHODS

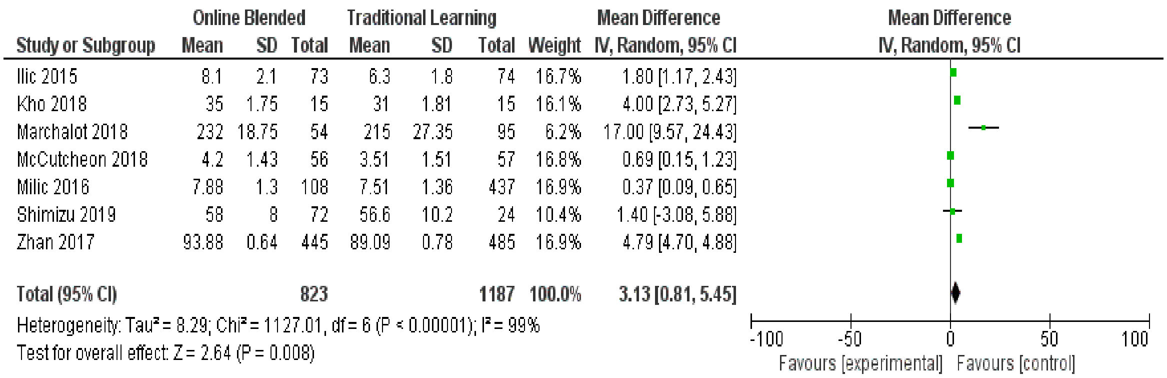


FIGURE 4
FUNNEL PLOT OF ONLINE BLENDED LEARNING VERSUS TRADITIONAL LEARNING

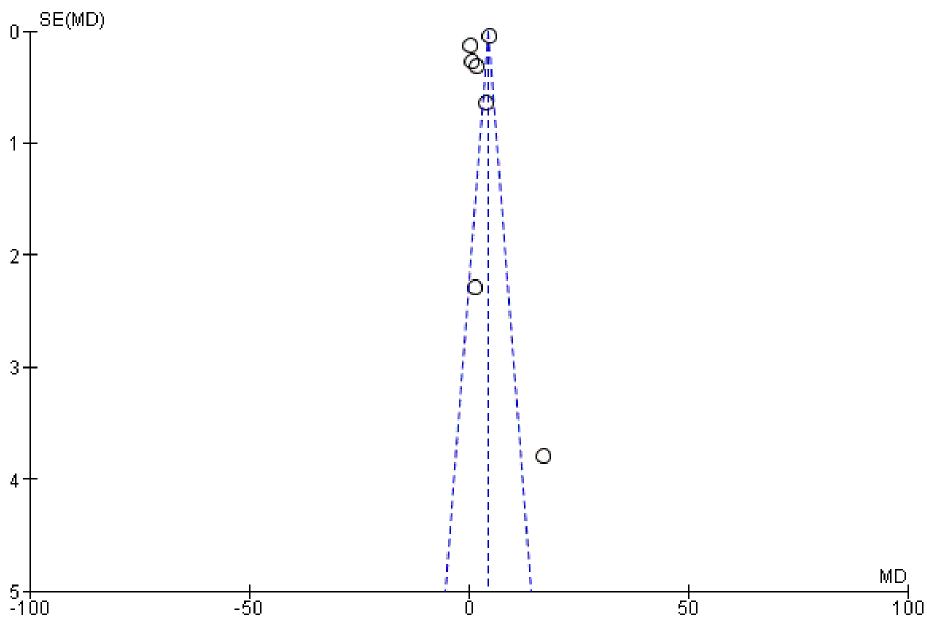
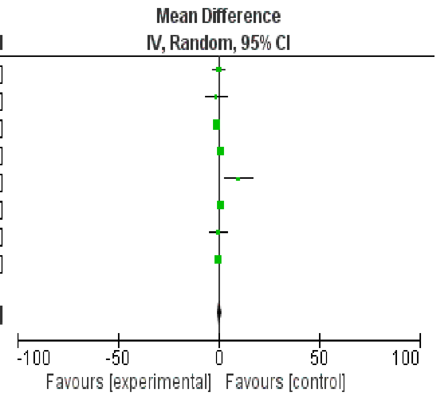


FIGURE 5
FOREST PLOT PRESENTING EFFECT OF DIGITAL BLENDED LEARNING WHEN COMPARED TO TRADITIONAL METHODS

	Digital Blended			Traditional Learning				Mean Difference
Study or Subgroup	Mean	SD	Total	Mean	SD	Total	Weight	IV, Random, 95% CI
Bartlett and Smith 2020	11.33	3.07	6	11.14	2.47	7	7.5%	0.19 [-2.87, 3.25]
da Costa Vieira 2017	73.02	9.51	32	74.06	11.63	35	3.4%	-1.04 [-6.11, 4.03]
Fernandez-Lao 2016	7.21	1	25	8.09	0.921	24	22.0%	-0.88 [-1.42, -0.34]
Jarrett-Thewell 2019	91.3	4.8	178	90	6.04	184	18.2%	1.30 [0.18, 2.42]
Kucuk 2016	78.14	16.19	34	68.34	12.83	36	2.0%	9.80 [2.93, 16.67]
Lozano-Lozano 2020	7.3	1.5	50	6.3	1.5	55	21.8%	1.00 [0.43, 1.57]
Nicklen 2016	77.05	6.96	19	77.1	5.75	19	5.0%	-0.05 [-4.11, 4.01]
Noll 2017	6.67	1.62	22	6.63	1.3	22	20.0%	0.04 [-0.83, 0.91]
Total (95% CI)			**366**			**382**	**100.0%**	**0.44 [-0.58, 1.46]**

Heterogeneity: $Tau^2 = 1.16$; $Chi^2 = 34.39$, $df = 7$ ($P < 0.0001$); $I^2 = 80\%$
Test for overall effect: $Z = 0.85$ ($P = 0.39$)

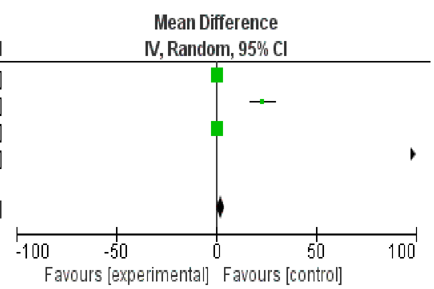


Similarly, we also pooled four studies including a total of 339 participants that used virtual reality blended method in their learning when compared to tradition-al learning. The meta-analysis using random effects models showed non-significant difference in virtual reality blended learning and traditional learning [MD and its 95% CI were 2.29 (0.39, 4.19)] as showed in Fig. 6. This result showed statistically non-significant (P=0.02) difference between virtual reality blended learning and traditional teaching.

FIGURE 6
FOREST PLOT PRESENTING EFFECT OF VIRTUAL REALITY BLENDED LEARNING WHEN COMPARED TO TRADITIONAL METHODS

	Virtual Reality Blended			Traditional Learning				Mean Difference
Study or Subgroup	Mean	SD	Total	Mean	SD	Total	Weight	IV, Random, 95% CI
Elzainy 2020	4.73	0.008	78	4.39	0.1	78	46.2%	0.34 [0.32, 0.36]
Lehman 2015	92.2	4.7	27	68.8	16.3	30	8.0%	23.40 [17.30, 29.50]
Rocha 2017	9.07	0.6	32	8.58	0.64	39	45.7%	0.49 [0.20, 0.78]
Ulrich 2021	6,728	1,173	28	2,469	1,534	27	0.0%	4259.00 [3535.42, 4982.58]
Total (95% CI)			**165**			**174**	**100.0%**	**2.29 [0.39, 4.19]**

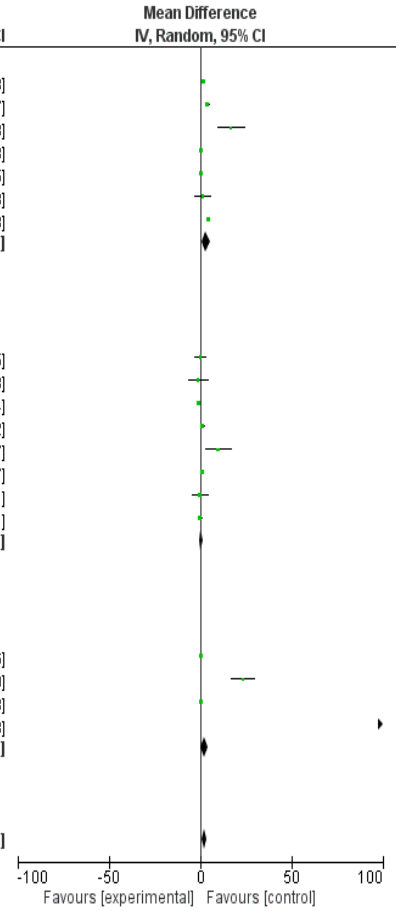
Heterogeneity: $Tau^2 = 2.03$; $Chi^2 = 189.06$, $df = 3$ ($P < 0.00001$); $I^2 = 98\%$
Test for overall effect: $Z = 2.36$ ($P = 0.02$)



The overall effect of blended learning for selected studies (n=18) in Biomedical Engineering was also determined. The meta-analysis using random effects models showed significant difference among all digital pedagogies and tradition-al learning [MD and its 95% CI were 2.36 (0.94, 3.78)] as showed in Fig. 7. This result showed statistically significant (P=0.05) difference between blended learn-ing and traditional learning.

FIGURE 7

Study or Subgroup	Blended Mean	Blended SD	Blended Total	Traditional Mean	Traditional SD	Traditional Total	Weight	Mean Difference IV, Random, 95% CI
1.4.1 Online blended Vs Traditional learning								
Ilic 2015	8.1	2.1	73	6.3	1.8	74	6.8%	1.80 [1.17, 2.43]
Kho 2018	35	1.75	15	31	1.81	15	6.5%	4.00 [2.73, 5.27]
Marchalot 2018	232	18.75	54	215	27.35	95	2.4%	17.00 [9.57, 24.43]
McCutcheon 2018	4.2	1.43	56	3.51	1.51	57	6.8%	0.69 [0.15, 1.23]
Milic 2016	7.88	1.3	108	7.51	1.36	437	6.9%	0.37 [0.09, 0.65]
Shimizu 2019	58	8	72	56.6	10.2	24	4.1%	1.40 [-3.08, 5.88]
Zhan 2017	93.88	0.64	445	89.09	0.78	485	6.9%	4.79 [4.70, 4.88]
Subtotal (95% CI)			**823**			**1187**	**40.3%**	**3.13 [0.81, 5.45]**
Heterogeneity: Tau² = 8.29; Chi² = 1127.01, df = 6 (P < 0.00001); I² = 99%								
Test for overall effect: Z = 2.64 (P = 0.008)								
1.4.2 Digital blended Vs Traditional learning								
Bartlett and Smith 2020	11.33	3.07	6	11.14	2.47	7	5.2%	0.19 [-2.87, 3.25]
da Costa Vieira 2017	73.02	9.51	32	74.06	11.63	35	3.7%	-1.04 [-6.11, 4.03]
Fernandez-Lao 2016	7.21	1	25	8.09	0.921	24	6.8%	-0.88 [-1.42, -0.34]
Jarrett-Thewell 2019	91.3	4.8	178	90	6.04	184	6.6%	1.30 [0.18, 2.42]
Kucuk 2016	78.14	16.19	34	68.34	12.83	36	2.6%	9.80 [2.93, 16.67]
Lozano-Lozano 2020	7.3	1.5	50	6.3	1.5	55	6.8%	1.00 [0.43, 1.57]
Nicklen 2016	77.05	6.96	19	77.1	5.75	19	4.4%	-0.05 [-4.11, 4.01]
Noll 2017	6.67	1.62	22	6.63	1.3	22	6.7%	0.04 [-0.83, 0.91]
Subtotal (95% CI)			**366**			**382**	**42.9%**	**0.44 [-0.58, 1.46]**
Heterogeneity: Tau² = 1.16; Chi² = 34.39, df = 7 (P < 0.0001); I² = 80%								
Test for overall effect: Z = 0.85 (P = 0.39)								
1.4.3 Virtual reality blended Vs Traditional learning								
Elzainy 2020	4.73	0.008	78	4.39	0.1	78	6.9%	0.34 [0.32, 0.36]
Lehman 2015	92.2	4.7	27	68.8	16.3	30	3.0%	23.40 [17.30, 29.50]
Rocha 2017	9.07	0.6	32	8.58	0.64	39	6.9%	0.49 [0.20, 0.78]
Ulrich 2021	6,728	1,173	28	2,469	1,534	27	0.0%	4259.00 [3535.42, 4982.58]
Subtotal (95% CI)			**165**			**174**	**16.8%**	**2.29 [0.39, 4.19]**
Heterogeneity: Tau² = 2.03; Chi² = 189.06, df = 3 (P < 0.00001); I² = 98%								
Test for overall effect: Z = 2.36 (P = 0.02)								
Total (95% CI)			**1354**			**1743**	**100.0%**	**2.36 [0.94, 3.78]**
Heterogeneity: Tau² = 7.65; Chi² = 8886.62, df = 18 (P < 0.00001); I² = 100%								
Test for overall effect: Z = 3.25 (P = 0.001)								
Test for subgroup differences: Chi² = 6.03, df = 2 (P = 0.05), I² = 66.8%								



DISCUSSION

The advantages of e-learning and blended learning differ depending on the audience. All university students prefer flexibility. Students value the ability to learn with well-known instructors at their leisure, when and when they wish. Presence activities are required for training using technical devices. If they are supported by an e-learning tutorial, they can be implemented more efficiently. The e-learning system, particularly the self-assessment components for classifying pupils and selecting an appropriate level of difficulty, needs to be improved. It enables for the efficient identification of student collaborators who are especially well-suited to research initiatives. A greater use of e-learning and blended learning at all levels of the educational process is a necessary condition for success in top universities. Digital learning offers various benefits, including enabling students to engage in self-directed learning (Huynh, 2017) and keeping curriculum up to date (Ruiz et al., 2006). The goal of this study was to see the effectiveness of blended learning in Biomedical Engineering. The meta-analysis using random effects models showed significant difference in online blended learning and traditional learning [MD and its 95% CI were 3.13 (0.81, 5.45)]. This result showed statistically significant (P=0.008) difference between blended learning and traditional learning in Bio-medical Engineering. A significant heterogeneity was observed among studies (I2=99%). In one meta-analysis, self-produced films outperformed traditional classroom education on a practical skill in a cervical spine scenario by a statistically significant margin (Maloney et al., 2013; Maloney et al., 2013). This conclusion needs to be validated in a bigger meta-analysis due to the small number of participants. When compared to practical classroom instruction alone, combining practical classroom teaching with students' self-produced videos practicing practical skills may encourage greater skill development (Li, 2022). The capacity to relate transferred information to practical consequences and student achievement is one reason for this impact. This corresponds to mobile learning, which focuses on students' newly acquired information and abilities (Merrill, 2022; Jamaris et al., 2021). Using self-produced films as a complement to practical classroom instruction also allows teachers, tutors, and supervisors to provide feedback on students' clinical performance. Furthermore, self-produced films allow for peer-to-peer learning by sharing and discussing the outcomes of the videos, as well as the opportunity for self-reflection as part of the process of building professional clinical abilities. In terms of efficacy, the meta-analysis found a statistically significant improvement in learning outcomes for blended learning [MD and its 95% CI were 2.36 (0.94, 3.78)]. These findings are consistent with a comprehensive evaluation of 12 research that found considerable increase in nursing students' self-directed learning skills (Liu et al., 2018). A study of 24 research in health professions education, on the other hand, found no convincing evidence that the flipped classroom im-proved academic outcomes (Evans et al., 2019). The flipped classroom model's or blended learning options have the ability to encourage and engage students in pre-class learning activities, develop self-regulatory abilities, and increase the flexibility and transparency of the learning process (Låg & Sæle, 2019). In addition, in-class activities need engaged students and provide a greater chance for students to integrate new subject to past knowledge in order to solve issues, which can lead to higher-order thinking. Another option is to get immediate feedback from peers and professors (Merrill, 2022). As a result of these pedagogical options, we may infer that the flipped class-room approach has the potential to improve students' learning results (Låg & Sæle, 2019). Further, for studies using digital blended studies (n=8) a total of 748 participants were included. The meta-analysis using random effects models showed non-significant difference in digital blended learning and traditional learning [MD and its 95% CI were 0.44 (-0.58, 1.46)]. These results showed no statistically significant (P=0.39) difference between digital blended learning and traditional teaching in higher education. The impact of utilizing a mobile app/computer pro-gram on practical abilities was shown to be statistically insignificant (Arroyo-Morales et al., 2012; Cantarero-Villanueva et al., 2012). These findings are contradicted by a comprehensive evaluation of 29 research that found mobile learning to be as successful as, if not more effective than, conventional learning (Dunleavy et al., 2019). Students may see how to do practical skills and learn theoretical information through interactive websites/apps since they are adaptable, accessible, and transparent. In general, studies demonstrate that incorporating mobile learning technologies into higher education courses improves student engagement, attentiveness, and learning (Merayo et al., 2018; Ernawati & Ikhsan, 2021). Some risk-biased research might be to blame for the discrepancy in our findings. Similarly, the current meta-analysis, which used random effects models, found no statistically significant difference between virtual reality/simulation and traditional learning [MD and its 95% CI were 1.67 (-0.20, 3.54)].

The blended learning designs were most likely planned didactic learning designs with digital learning technologies and a constructive alignment strategy. Other studies have found greater student involvement, engagement, communication, critical conversations, and student–teacher relationship as a result of these findings (Damşa et al., 2015; Mącznik et al., 2015; Tsekhmister, 2022). It might be advised that medical education stakeholders embrace a new teaching technique based on digital pedagogies. This integration of digital tools generates an effective learning environment and encourages self-learning, which enhances the pedagogical performance of students and teachers.

CONCLUSION

In terms of knowledge and practical skills development, the findings showed that blended learning are either equally or more successful than traditional classroom teaching in higher education. The online blended learning had substantial effects on student learning, according to the meta-analyses. However, bigger controlled experiments are needed to corroborate these findings.

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