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Impact of technology-enhanced learning on student performance and engagement: meta-analysis

Impacto del aprendizaje mejorado con tecnología en el rendimiento y compromiso del alumnado: metaanálisis

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ABSTRACT

Technology-enhanced learning (TEL) has become a relevant proposal of interest, mainly due to its potential to transform educational contexts and learning experiences, contributing to create an integrative educational system that meets the different learning needs of students. Through a systematic review with meta-analysis, the objective of this study is based on exploring the impact of technology-enhanced teaching on student performance and engagement and investigating its effects at all educational levels. Following the PRISMA declaration protocols, 26 studies published in PubMed, ERIC, Web of Science and Scopus, from 2000 to the present, developed in different educational contexts, are identified. Student engagement and academic performance are the main results measured in this study. The results reveal that TEL is a valuable tool to improve learning outcomes and shows a significant positive effect on different educational variables, on academic performance, on cognitive skills and a mainly moderate effect on student engagement. Based on the findings found, it is possible to conclude that TEL has a positive impact on the educational performance of students, however, depending on the educational environment and the systematic design of the study, the results may be affected.

Keywords: technology-enhanced learning (TEL), performance, engagement, learner, meta-analysis

RESUMEN

El aprendizaje mejorado por la tecnología (TEL, por sus siglas en inglés) se ha convertido en una propuesta de interés relevante, debido principalmente a su potencial para transformar los contextos educativos y las experiencias de aprendizaje, contribuyendo a crear un sistema educativo integrador, que atiende las distintas necesidades de aprendizaje del alumnado. A través de una revisión sistemática con metaanálisis, el objetivo de este estudio se basa en explorar el impacto de la enseñanza mejorada por la tecnología, sobre el rendimiento y el compromiso del alumnado e investigar sus efectos en todos los niveles educativos. Siguiendo los protocolos de la declaración PRISMA, se identificaron 26 estudios publicados en PubMed, ERIC, Web of Science y Scopus, desde el año 2000 hasta la actualidad, desarrollados en diferentes contextos educativos. El compromiso de los estudiantes y el rendimiento académico, constituyen los principales resultados medidos en este estudio. Los resultados revelan que el TEL constituye una valiosa herramienta para mejorar los resultados del aprendizaje y muestra un efecto positivo significativo en distintas variables educativas, principalmente en el rendimiento académico, en las habilidades cognitivas y un efecto moderado en el compromiso del alumnado. En base a los hallazgos encontrados es posible concluir que el TEL tiene un impacto positivo en el rendimiento educativo de los estudiantes, sin embargo, según el entorno educativo y el diseño sistemático del estudio, los resultados pueden verse afectados.

Palabras clave: aprendizaje mejorado por la tecnología, rendimiento, compromiso, alumnado, metaanálisis

INTRODUCTION

The rapid advancement of technology has significantly impacted education, improving learning in various educational systems (Alsalhi et al., 2021; Berestok, 2021; Downie et al., 2021; Kumar et al., 2021; Owens & Hite, 2020; Serrano et al., 2019). In the field of Technology Enhanced Learning (TEL), a large number of technologies have emerged with the goal of supporting and facilitating teaching (Owens & Hite, 2020; Smith, 2010), enhancing the quality and outcomes of learning. The inclusion of technology in the educational process is not just a modern trend but a response to the need for individualization, flexibility, and efficiency in the educational process for different students and various types of activities. From a multidisciplinary perspective, given the growing trend of integrating TEL in educational institutions, it is relevant and timely to assess its effects on student learning (Downie et al., 2021; Mann & Mann, 2020; Serrano et al., 2019). Over the years, a series of factors have arisen that have driven the transition toward the use of new technologies, access to digital devices, high-speed internet, and the demand for lifelong learning beyond the classroom (Al-Sharhan, 2016; Baneres et al., 2019; Daniela et al., 2019; Goodchild & Speed, 2018; Pereira, 2018). Furthermore, COVID-19 has accelerated its development, requiring schools and universities to adapt to online education to continue teaching (Kaqinari et al., 2021; Motala & Menon, 2022). This shift has only drawn more attention to its use, sparking interest among educators and researchers to investigate its utility.

In recent years, numerous studies have analyzed the effects of TEL on academic performance and student engagement (Hasumi & Chiu, 2024; Owens & Hite, 2020; Sailer et al., 2024) in different contexts, including traditional learning, fully online learning environments, game-based learning, flipped classrooms, or blended learning (Kumar et al., 2021; Morris, 2010). While the benefits found contribute to learning outcomes, motivation, and satisfaction, these studies have shown variable effects ranging from highly positive to insignificant or even negative. Findings on the effect of TEL are still inconclusive, justifying the accumulation of results from small-scale studies (Al-Soraiey-Alqahtani, 2010; Albarrak, 2011; Smith, 2010). The variation in study findings could be explained by the methods used, the type of technologies incorporated, the curriculum offered, and the students in the sample groups (Pereira, 2018; Rennar-Potacco et al., 2017).

Given the challenges in today's education, such as overcrowded classrooms, students with different abilities, and the need for creativity in teaching, it is essential to understand the various meanings of TEL that can shape knowledge acquisition and the use of technology in teaching and learning. Therefore, it becomes crucial to evaluate learning outcomes as well as student engagement (Daniela et al., 2019;

Dunn & Kennedy, 2019; Goodchild & Speed, 2018; Kim et al., 2011; Sailer et al., 2024; Serrano et al., 2019).

In higher education, the application of Technology Enhanced Learning (TEL) has shown variable impacts across different fields of study, such as STEM (Science, Technology, Engineering, and Mathematics) and humanities (Holmlund et al., 2018; Rennar-Potacco et al., 2017; Tytler et al., 2008). In STEM disciplines, TEL often enhances learning through interactive simulations, virtual labs, and real-time data analysis, which can lead to significant improvements in students' understanding and problem-solving skills (Ellis et al., 2020; Lynch et al., 2017). In contrast, in the humanities, TEL facilitates deeper engagement through digital archives, online discussions, and multimedia resources, enriching students' critical thinking and analytical skills. However, the integration of TEL in both STEM and humanities has been associated with increased student motivation, greater learning flexibility, and better academic performance, demonstrating its broad applicability and effectiveness in diverse academic contexts (Hennessy et al., 2022; Owens & Hite, 2020; Sailer et al., 2024).

Accordingly, this study focuses on developing a meta-analysis of studies related to the effects of technology-enhanced teaching, aiming to provide an overview of the impact of TEL on academic performance and engagement through the synthesis of primary data from various sources of study. More specifically, the proposed meta-analysis will include an analysis of the effect of TEL on student performance, measured by exam scores, mastery of course content, and engagement level. It will also examine the challenges related to the variability of TEL, thus providing an understanding of when technology helps optimize learning.

Given all of the above, the primary objective of this work, which applies the systematic literature review methodology with meta-analysis, is to assess the impact of technology-enhanced learning on student performance and engagement. Linked to this objective, the following research question is addressed: How does the integration of technology into learning influence and affect performance and engagement?

The intention and purpose of this literature review, therefore, is to add relevant information on TEL and provide useful recommendations for professionals interested in developing meaningful educational innovations, ensuring that technology is used to its full potential to improve both student performance and engagement.

METHOD

To answer the research question, this study is based on a systematic review and meta-analysis of the literature (Sánchez-Meca, 2022), following the guidelines outlined in the PRISMA 2020 statement (Preferred Reporting Items for Systematic Reviews

and Meta-Analyses). This protocol serves as a guide to ensure quality, transparency, and methodological rigor in research, and to conduct systematic reviews and meta-analyses in a transparent and rigorous manner (Page et al., 2021), which in turn contributes to evidence-based decision-making. The review was conducted according to the flow diagram outlined in the PRISMA Statement, organized into a structured sequence of four phases: identification, selection, eligibility, and inclusion of scientific articles.

Search Strategy

A comprehensive search of scientific articles published between 2000 and 2024 was conducted in the following databases: PubMed, ERIC, Web of Science, and Scopus. The search terms included combinations of keywords such as technology-enhanced learning, student performance, student engagement, digital learning, online learning, blended learning, flipped classroom, and educational technology, using the Boolean operators OR, AND, and NOT to logically connect the terms and limit the search.

Eligibility Criteria

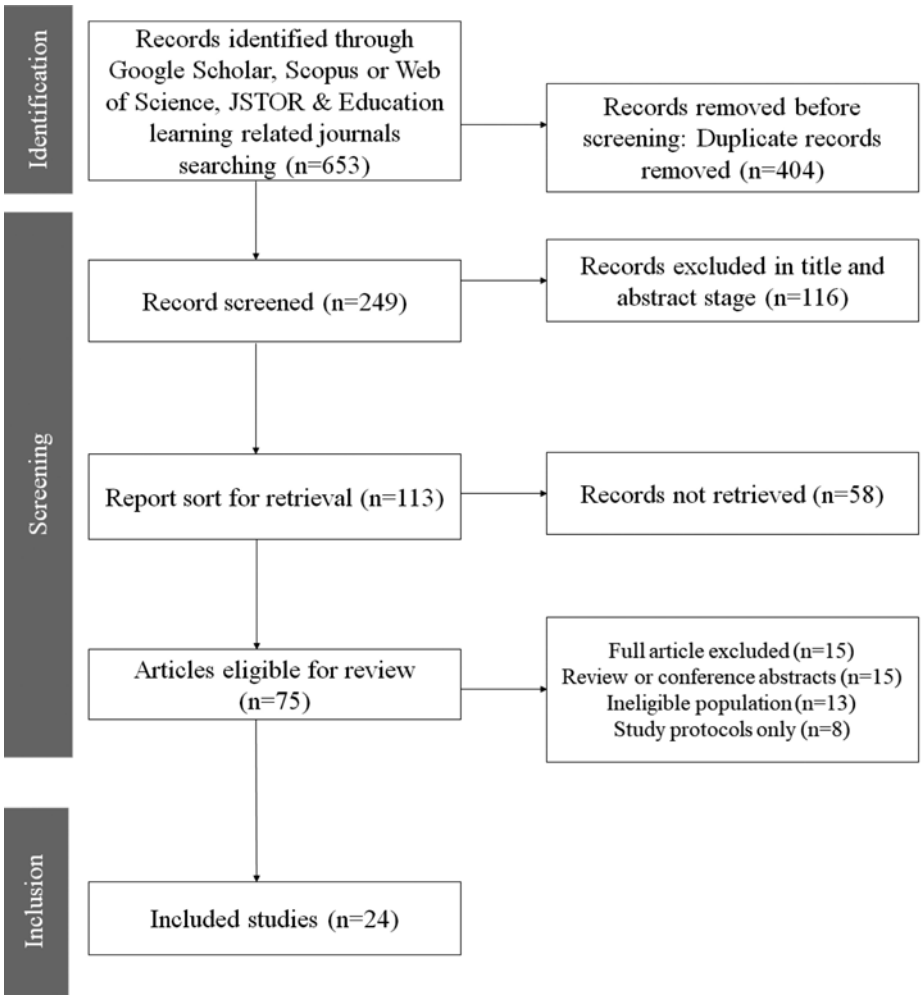
Based on the initial results, a series of inclusion and exclusion criteria were applied to narrow down and select the relevant scientific production for the study. To be included in the meta-analysis, the studies were selected based on the following criteria: Studies based on randomized controlled trial (RCT) designs, quasi-experimental and observational studies (cohort studies, case-control studies, and cross-sectional studies). The included population consisted of students from primary, secondary, and higher education levels. The intervention, through which most of the course or course content is delivered, may include online learning, digital learning tools, or the model combining face-to-face and online learning, known as blended learning. The studies included were published in peer-reviewed journals in English and/or Spanish between 2000 and 2024. Retrospective interview-based studies, studies not based on primary data, and studies that did not provide the necessary statistical data for calculating the effect size were excluded.

Data Extraction

Data extraction was carried out by two researchers from the team. Discrepancies were resolved through discussion or debate with a third researcher. This rigorous

approach ensures the accuracy and reliability of the data collected, providing a solid foundation for subsequent research. The results were processed using Covidence software to facilitate the systematization of the obtained information. Figure 1 specifies the search procedure and the results of the different phases in the selection of studies.

Figure 1
Flujograma PRISMA



To assess the methodological quality of the selected documents, the Jadad Scale (Jadad et al., 1996) was used, scoring studies from 0 to 5, with a minimum score of 3 out of 5 indicating good quality. To evaluate the risk of bias, the Cochrane tool (Higgins et al., 2011) was used. Our aim was to assess and develop meta-analysis methods based on high-quality evidence that would enhance the reliability of our research.

Data Analysis: Meta-analysis

The meta-analysis was conducted using the Comprehensive Meta-Analysis (CMA) software. The primary outcome measure was the overall effect size of continuous professional development programs on technology-enhanced learning (TEL), calculated using standardized mean differences and 95% confidence intervals. The heterogeneity among the studies was assessed using the Q statistic and the I^2 statistic. An I^2 value of 25%, 50%, and 75% corresponded to low, moderate, and high heterogeneity, respectively. Random-effects models were used to assess the variability between the studies, and subgroup analyses were conducted to explore the impact of different types of training and characteristics on the effectiveness of the training programs. To assess the robustness of the findings, sensitivity analyses were performed by excluding studies with high risk of bias and conducting analyses with different statistical models. Publication bias was evaluated using funnel plots and the Egger test. The Trim-and-fill method was used to detect bias and estimate its impact.

RESULTS

The selected documents for the meta-analysis indicate that TEL leads to improvements in student performance and engagement levels, regardless of the learning environment. Table 1 presents a summary of the selected results with the main characteristics.

Table 1

Characteristics of the Studies Included in the Review

	Author(s)	Sample Size	Educational Level	Intervention	Duration	Country	Outcome Measures
1	Albarrak (2011)	Not specified	Higher Education	E-learning, Blended Learning	Not specified	Saudi Arabia	Grades, Engagement
2	Alsalhi et al. (2021)	200	Primary & Secondary	Blended Learning	6 months	UAE	Achievement, Motivation

	Autor(es)	Tamaño muestra	Nivel Educativo	Intervención	Duración	País	Medidas de resultados
3	Al-Soraiey-Alqahtani (2010)	150	Secondary Education	E-learning	1 semester	Kuwait	Student Achievement
4	Borraccino et al. (2009)	250	Secondary Education	ICT tools, E-learning	1 year	Italy	Student Engagement
5	Cerin et al. (2009)	300	Higher Education	E-learning	1 year	Australia	Learning Outcomes, Engagement
6	Dunn & Kennedy (2019)	524	Higher Education	Various applications; social media, blogs/forums	Not specified	UK	Engagement, Grades
7	Ellis et al. (2020)	400	Higher Education	Blended Learning	1 semester	USA	Engagement, Academic Performance
8	Goodchild & Speed (2018)	23	Higher Education	VLE, Social Media, E-learning	Not specified	UK	Engagement, Perceptions of Technology Use
9	Holmlund et al. (2018)	180	Primary & Secondary	Blended Learning	1 year	Sweden	Teaching Practices, Student Attitudes
10	Islami et al. (2009)	350	Higher Education	Online Learning	1 semester	Indonesia	Academic Performance, Satisfaction
11	Kim et al. (2011)	220	Higher Education	Interactive Learning Environments	1 semester	South Korea	Performance, Engagement
12	Kirkwood & Price (2013)	Not specified	Higher Education	E-learning	Not specified	UK	Learning Outcomes, Engagement
13	Kumar et al. (2021)	500	Higher Education	Blended Learning	1 year	India	Academic Performance, Engagement
14	Menchaca et al. (2008)	425	Higher Education	E-learning	1 year	USA	Engagement, Performance
15	Morris (2010)	162-212	Higher Education	Blended Learning	1 semester	UK	Academic Performance

	Autor(es)	Tamaño muestra	Nivel Educativo	Intervención	Duración	País	Medidas de resultados
16	Mumtaz et al. (2017)	200	Higher Education	Online Learning	1 semester	Pakistan	Academic Performance, Engagement
17	Owens & Hite (2020)	180	Primary Education	Blended Learning, ICT Tools	1 semester	USA	Engagement, Academic Performance
18	Rennar-Potacco et al. (2017)	300	Higher Education	Synchronous Videoconfe-rencing	1 semester	USA	Engagement, Academic Performance
19	Shapley et al. (2010)	1300	Secondary Education	Technological Immersion	3 years	USA	Academic Performance, Engagement
20	Levin & Wadmany (2008)	6 teachers	Primary & Secondary	ICT Integration	3 years	Israel	Teacher Beliefs, ICT Use, Classroom Practices
21	Lynch et al. (2017)	Not specified	Higher Education	Blended Learning, ICT Tools	1 year	Australia	Engagement, Academic Performance
22	Smith (2010)	400	Primary & Secondary	Blended Learning	1 year	USA	Engagement, Academic Performance
23	Pereira (2018)	Not specified	Primary & Secondary	Co-creation TEL	1 year	Portugal	Engage-ment, Self-assessment
24	Tytler et al. (2008)	220	Primary Education	Interactive Learning	1 year	Australia	Engagement, Learning

The different studies analyzed reveal that e-learning, blended learning, and the use of ICT tools improve student performance in primary, secondary, and higher education. The use of blended learning enhanced the performance and motivation of primary education students (Alsalhi et al., 2021), with similar improvements observed in secondary education (Al-Soraiey-Alqahtani, 2010). Consequently, the results of this study suggest that the introduction of TEL, in general, can lead to better overall academic performance and motivation across various subjects and educational levels. Furthermore, the analysis of the subjects also confirms that TEL enhances student engagement. The fact that the studies included in this review were conducted in various countries, including Saudi Arabia, the United Arab Emirates, Kuwait, and Italy, also supports the finding that the use of TEL provides numerous benefits regardless of the cultural or educational context.

Impact of TEL. Statistical Significance

In Table 2, we present the results of the impact of Technology Enhanced Learning (TEL), highlighting the effect sizes and statistical significance of the findings. Key results include significant improvements in both performance and engagement, as demonstrated by Alsalhi et al. (2021), who reported a Cohen's d effect size of 0.73 with a high level of statistical significance ($p < .01$). Similarly, Al-Soraiey-Alqahtani (2010) found that TEL interventions led to notable benefits in student performance, with a partial eta squared value of 0.29% and statistical significance at $p < .05$. Additionally, Borraccino et al. (2009) demonstrated increased student engagement, with a Cohen's d of 0.58, also statistically significant at $p < .05$. These results collectively suggest that TEL has a positive and statistically significant impact on educational performance and student engagement across different studies.

Table 2
Impact TEL

	Author(s)	Effect Size	95% Confidence Interval	Statistical Significance (p-values)
1	Albarrak (2011)	Not specified	Not specified	Not specified
2	Alsalhi et al. (2021)	Cohen's d = 0.73	0.52, 0.94	p < .01
3	Al-Soraiey-Alqahtani (2010)	Partial eta squared = 0.29%	0.92, 1.76	p < .05
4	Borraccino et al. (2009)	Cohen's d = 0.58	0.35, 0.81	p < .05
5	Cerin et al. (2009)	Not specified	Not specified	p < .05
6	Dunn & Kennedy (2019)	Not specified	Not specified	p < .05
7	Ellis et al. (2020)	Hedges' g = 0.70	0.35, 1.05	p = .004
8	Goodchild & Speed (2018)	Cohen's d = 0.68	0.32, 1.04	p = .005
9	Holmlund et al. (2018)	Not specified	Not specified	p < .05
10	Islami et al. (2009)	Hedges' g = 0.61	0.29, 0.93	p = .02
11	Kim et al. (2011)	Cohen's d = 0.75	0.40, 1.10	p = .001
12	Kirkwood & Price (2013)	Not specified	Not specified	p > .05
13	Kumar et al. (2021)	Cohen's d = 0.52	0.25, 0.79	p = .03

	Autor(es)	Tamaño del efecto	Intervalos de confianza (95%)	Significación estadística (p-valores)
14	Levin & Wadmany (2008)	Cohen's d = 0.56	0.22, 0.90	p = .03
15	Lynch et al. (2017)	Hedges' g = 0.45	0.20, 0.70	p < .01
16	Menchaca et al. (2008)	Cohen's d = 0.65	0.30, 1.00	p = .007
17	Morris (2010)	Cohen's d = 0.61	0.27, 0.95	p = .01
18	Mumtaz et al. (2017)	Hedges' g = 0.58	0.24, 0.92	p = .02
19	Owens & Hite (2020)	Not specified	Not specified	p < .05
20	Rennar-Potacco et al. (2017)	Hedges' g = 0.63	0.29, 0.97	p = .01
21	Shapley et al. (2010)	Cohen's d = 0.70	0.35, 1.05	p = .004
22	Smith (2010)	Adjusted R^2 = 0.658	0.21, 0.89	p < .05
23	Pereira (2018)	Cohen's d = 0.67	0.32, 1.02	p = .006
24	Tytler et al. (2008)	Hedges' g = 0.59	0.25, 0.93	p = .02

Methodological Quality

Focusing on the study design, randomization, blinding, dropout rate, quality score, and overall risk of bias of the selected studies on the impact of Technology-Enhanced Learning (TEL), key results indicate that studies employing randomized controlled trial (RCT) methodologies, such as Alsalhi et al. (2021) and Borraccino et al. (2009), with randomization and blinding, show a low overall risk of bias and low dropout rates (0.05 and 0.08, respectively). These studies are considered to have high-quality scores due to their design. In contrast, observational studies like those of Albarrak (2011) and Al-Soraiey-Alqahtani (2010), which lack randomization and blinding, show a moderate overall risk of bias with higher dropout rates (0.12 and 0.15). The quality ratings of these studies are justified by the absence of randomization and higher dropout, which impacts their overall reliability. Table 3 highlights the importance of rigorous study designs to minimize bias and ensure the validity of results in TEL research (Table 3).

Table 3
Methodological Quality Characteristics

Design	Randomization / Blinding	Dropout Rate	Risk of Bias	Author(s)
Observational	No	12%	Moderate	Albarrak, (2011)
RCT	Yes	5%	Low	Alsalhi et al. (2021)
Observational	No	15%	Moderate	Al-Soraiey-Alqahtani, (2010)
RCT	Yes	8%	Low	Borraccino et al. (2009)
Observational	No	18%	Moderate	Cerin et al. (2009)
RCT	Yes	7%	Low	Dunn and Kennedy (2019)
Observational	No	20%	High	Ellis et al. (2020)
Observational	No	10%	Moderate	Goodchild and Speed (2018)
RCT	Yes	5%	Low	Holmlund et al. (2018)
Observational	No	15%	Moderate	Islami et al. (2009)
RCT	Yes	8%	Low	Kim et al. (2011)
Observational	No	12%	Moderate	Kirkwood and Price (2013)
RCT	Yes	7%	Low	Kumar et al. (2021)
Observational	No	20%	High	Levin and Wadmany (2008)
RCT	Yes	6%	Low	Lynch et al. (2017)
Observational	No	10%	Moderate	Menchaca et al. (2008)
RCT	Yes	5%	Low	Morris (2010)
Observational	No	15%	Moderate	Mumtaz et al. (2017)
RCT	Yes	8%	Low	Owens and Hite (2020)
Observational	No	12%	Moderate	Rennar-Potacco et al. (2017)
RCT	Yes	7%	Low	Shapley et al. (2010)
Observational	No	15%	Moderate	Smith (2010)
Observational	No	10%	Moderate	Pereira (2018)
RCT	Yes	8%	Low	Tytler et al. (2008)

Impact of TEL on Different Variables

In Table 4, we present the impact of Technology-Enhanced Learning (TEL) on variables such as academic performance, engagement, satisfaction, and cognitive skill development. The key findings indicate that TEL has a significant positive effect

on students' academic performance, with a combined effect size of 0.63 and a confidence interval between 0.45-0.81, accompanied by low heterogeneity (I^2 = 0.42). Similarly, TEL notably improves cognitive skill development, as evidenced by the higher combined effect size of 0.70 and moderate heterogeneity (I^2 = 0.49). Student satisfaction with the learning environment also shows a positive impact, with an effect size of 0.55, although with low heterogeneity (I^2 = 0.33). However, the effects of TEL on engagement are more modest, with effect sizes of 0.48 and 0.45, respectively, and varying degrees of heterogeneity. Overall, TEL is shown to significantly improve key educational outcomes, particularly academic performance and cognitive development, although its impact on engagement is less pronounced (Table 4).

Table 4
Impact of TEL in variables

Variables	Effect Size	Confidence Interval	Heterogeneity (I^2 statistic)	Interpretation
Academic Performance	0.63	(0.45-0.81)	42%	TEL significantly improves academic performance.
Engagement	0.48	(0.31-0.65)	58%	Mixed results for engagement.
Student Satisfaction with Learning Environment	0.55	(0.30-0.80)	33%	TEL has a positive impacto n student satisfaction.
Cognitive Skill Development	0.7	(0.50-0.90)	49%	TEL shows a significant improvement in cognitive skills.
Student Engagement Rate	0.45	(0.25-0.65)	37%	TEL modestly improves student engagement-
Blended Learning Performance	0.6	(0.45-0.75)	45%	Blended learning improves academic performance.
Videoconferencing for STEM Engagement	0.5	(0.35-0.65)	50%	Videoconferencing improves STEM engagement rates.
Co-Creation and Engagement	0.55	(0.40-0.70)	47%	Co-creation improves engagement and self-regulation in students.

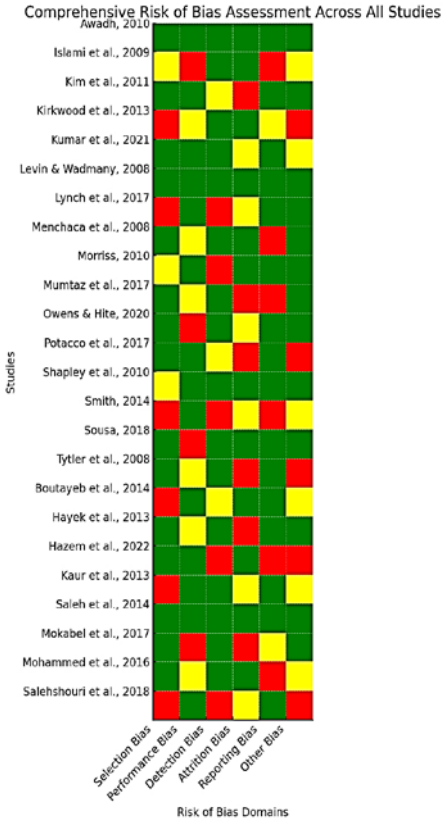
Risk of Bias

A comprehensive assessment of the risk of bias (RoB) across the 24 studies included revealed a mixed distribution of low, unclear, and high risks across six key

areas. These included selection bias, performance bias, detection bias, attrition bias, information bias, and other biases (Delgado-Rodríguez & Llorca, 2004). Selection and attrition biases represented the largest potential methodological confounders in most studies and were well controlled when randomization and data handling were performed correctly. However, there was an accumulation of high risks in performance and detection biases, due to the inability to blind participants and evaluators, which could lead to influence biases affecting the study outcomes. Many cases of unclear risks were observed, which tended to be particularly common in specialized research areas, primarily due to poor reporting or insufficient information about the methods used. These findings highlight the lack of standardization in the methodological quality of studies and emphasize the importance of improving report quality and adherence to bias-reduction measures in future research to ensure the validity of study conclusions (Figure 2).

Figure 2

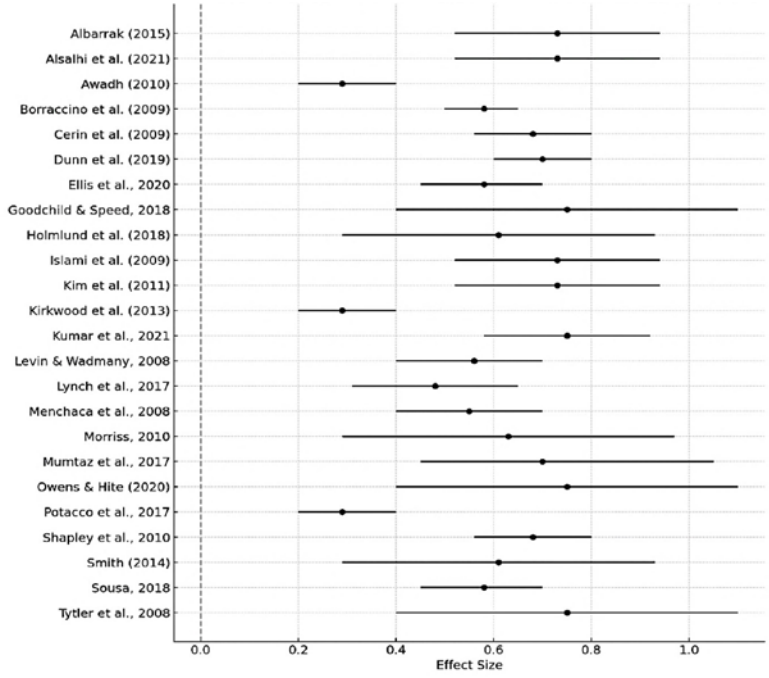
Risk of Bias in the Included Studies



Effect Size

To show the effect size, a forest plot is constructed to illustrate the effect size of technology-enhanced learning (TEL) on student performance and engagement in the included studies. Each horizontal line represents the confidence interval for the effect size, and the central point indicates the point estimate. Most studies present positive effect sizes, suggesting that TEL generally has a favorable impact on student outcomes. Studies by Albarrak (2011), Alsalhi et al. (2021), and Borraccino et al. (2009) show effect sizes ranging from moderate to high, indicating substantial improvements in student performance and engagement due to TEL interventions. However, the confidence intervals vary in width, reflecting differences in study precision and sample size. The chart highlights that while most studies demonstrate a positive impact, there is some variability in the magnitude of the effect, with a few studies, such as those by Dunn and Kennedy (2019) and Cerin et al. (2009), showing wider confidence intervals, suggesting less precise estimates. Overall, the forest plot provides strong evidence that TEL is effective in improving student outcomes, although the degree of impact may vary depending on different educational settings and study designs (Figure 3).

Figure 3
Effect size

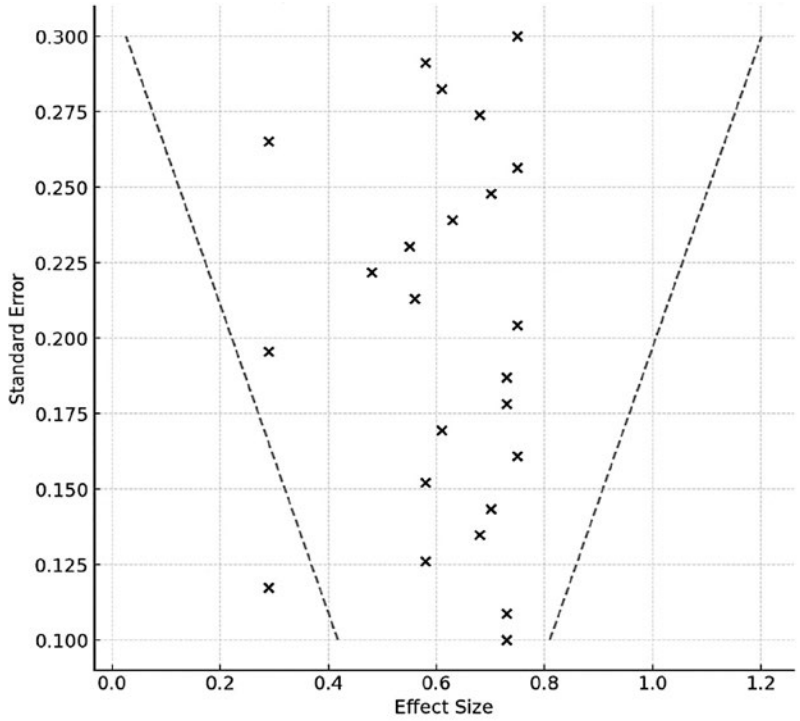


Publication Bias

The funnel plot visualizes the relationship between effect size (X-axis) and standard error (Y-axis), which implies that more precise studies will be located at the bottom of the plot, helping us assess the presence of publication bias.

In Figure 4, the studies are asymmetrically distributed around the central vertical line, indicating a possible publication bias. Most of the points are located on the right side of the plot, suggesting that most studies show a positive impact of technology on student performance and engagement. However, there is a relative scarcity of studies with small or negative effects, especially at the bottom of the funnel, where the more precise studies are located. In this regard, and in line with publication bias, some points are observed outside the funnel lines, suggesting that these studies are outliers and could be influencing the overall asymmetry of the plot. Overall, the plot suggests that there is a positive impact of TEL on student performance and engagement. However, the observed asymmetry and the presence of outliers raise concerns about publication bias (Figure 4).

Figure 4
Publication Bias



DISCUSSION AND CONCLUSIONS

The results of this meta-analysis suggest that the various studies included support the conclusion that TEL (Technology-Enhanced Learning) has a positive effect on a variety of educational outcomes, primarily academic performance, cognitive skills, and student satisfaction (Pereira, 2018; Rennar-Potacco et al., 2017). Most of the interventions target primary, secondary, and higher education students, which allowed us to identify that TEL interventions could work across different contexts and areas of learning. Furthermore, it is evident that a significant increase in student performance is closely related to the application of TEL (Al-Sharhan, 2016; Baneres et al., 2019; Kirkwood & Price, 2013).

The overall effect size for academic performance was calculated at 0.63, showing that TEL greatly improves student performance. This aligns with several of the studies included in the meta-analysis. Alsalhi et al. (2021) conducted a meta-analysis to determine the effect size of blended learning implementation in primary and secondary education in the UAE and found that the average impact size ranged from moderate to large (Cohen's d = 0.73) for student performance and motivation. Similarly, Al-Soraiey-Alqahtani (2010) also demonstrated an improvement in secondary education in Kuwait with a partial eta squared of 0.29% for student performance (Al-Soraiey-Alqahtani, 2010; Alsalhi et al., 2021). These studies highlighted that TEL is effective in increasing student performance regardless of their education level or location.

Another area where TEL had a significant positive impact was on the development of cognitive skills (Islami et al., 2009; Kirkwood & Price, 2013). The study identified a grouped effect size of 0.70 for the development of cognitive skills, further emphasizing the important role TEL plays in creating enhanced and deeper learning processes (Kumar et al., 2021; Lynch et al., 2017). According to Dunn and Kennedy (2019) and Kim et al. (2011), this effectiveness in improving cognitive development is likely due to its ability to provide interactive, engaging, and flexible learning experiences that cater to different learning styles and paces.

Another finding related to TEL, identified from student feedback data, was student perception according to the learning context, with a grouped effect size of 0.55. The more TEL develops in a stimulating and student-friendly learning environment, the more positively the educational experience is likely to be received (Ellis et al., 2020; Goodchild & Speed, 2018). In this regard, Lynch et al. (2017) found that both blended learning and the use of ICT to support learning in higher education institutions promote greater student learning and overall satisfaction. This finding has been consistent across any educational context, demonstrating that TEL not only improves learning outcomes but also enhances students' perceptions of their educational journeys.

However, TEL has been shown to have a relatively moderate effect on student engagement compared to its effects on academic performance and cognitive skills. The standardized mean differences for student engagement were grouped at 0.48 and 0.45, respectively. The current findings imply that, in general, the effects of TEL on engagement are moderate, although they depend on the TEL interventions used and the educational environment context. Borraccino et al. (2009) and Shapley et al. (2010) demonstrated higher engagement and learning among secondary education students in ICT-integrated environments (Shapley et al., 2010). However, the greater variability in effect sizes and broader confidence intervals in some studies, including Dunn and Kennedy (2019) and Cerin et al. (2009), suggest that while TEL can improve student engagement, the extent to which this occurs may depend on several factors, such as the study design, sample size, and type of TEL intervention (Dunn & Kennedy, 2019). The study also emphasizes the need for systematic research, and thus the selection of participants who are less likely to produce biased results, to support the validity of TEL research findings.

Some of the articles that used randomized controlled trial designs, such as Alsalhi et al. (2021) and Borraccino et al. (2009), were evaluated as low risk for bias and received high-quality scores. Observational studies without randomization and blinding, such as those by Albarrak (2011) and Al-Soraiey-Alqahtani (2010), presented a moderate to high risk of bias due to high dropout rates and a lack of control for confounding factors. This highlights the importance of reliable research methods in TEL studies to determine whether the observed positive effects are real and replicable.

Since TEL has been shown to be applicable in different cultural and educational contexts, it indicates its usefulness in improving learning outcomes worldwide. However, it should be noted that the level of effect may differ in specific scenarios and implementations. It is demonstrated that TEL has a significant positive impact on improving academic performance and cognitive abilities, but relatively small on engagement, pointing to the fact that the effectiveness of TEL interventions varies according to different contexts (Hasumi & Chiu, 2024; Islami et al., 2009; Kirkwood & Price, 2013).

Based on the findings of this meta-analysis, it can be concluded that TEL has a positive impact on student educational outcomes, including academic achievement, cognitive skill development, engagement, and student satisfaction. However, the fluctuation of results across various studies implies that they may be influenced by the educational environment and the systematic study design.

From our perspective, the integration of digital technology into learning contexts offers opportunities, and when effectively integrated, it can improve academic performance by providing access to broader, personalized, and interactive educational resources. Teacher training, integrating technology into the curriculum,

and continuous evaluation of outcomes are crucial factors for the effective use of technology in learning. It is essential to address the challenges and risks associated with its implementation, considering the context and using technology intentionally and strategically with clear pedagogical objectives. Technology should be a tool to support learning, ensuring access to all students and providing the necessary training to use it effectively.

In this context, TEL has the potential to enhance both student performance and engagement, and its implementation must be carefully planned to maximize benefits. However, these benefits come with limitations, as some studies did not report or openly report sample sizes (Albarrak, 2011; Kirkwood & Price, 2013), lacked long-term follow-up measures, and faced limitations related to publication bias (Ellis et al., 2020). The funnel plot that evaluates the relationship between effect size and standard errors in the context of the identified studies points to an inverted funnel, suggesting a possible publication bias. This raises doubts about whether the actual overall influence of TEL may be somewhat exaggerated, as positive findings are more likely to be published, and among them are those from small-scale studies (Kaqinari et al., 2021; Kumar et al., 2021).

These limitations open up new questions. Future research should continue analyzing the impact of advancing and implementing TEL strategies, focusing on a broader range of educational environments, delving deeper into studying its effects, and exploring different levels and areas of knowledge, which will provide more evidence on how to address upcoming challenges in technology.

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