Department of Digital Business
Journal of Artificial Intelligence and Digital Business (RIGGS)
Homepage: https://journal.ilmudata.co.id/index.php/RIGGS
Vol. 4 No. 2 (2025) pp: 171-176
P-ISSN: 2963-9298, e-ISSN: 2963-914X

A Meta-Analysis Review of The Influence of Digital Technology on The Learning Outcomes of civil engineering students

Tomi Apra Santosa
Akademi Teknik Adikarya, Indonesia
Corresponding email: santosa2021@yahoo.com

Abstract

This study aims to comprehensively examine the influence of the use of digital technology on student learning outcomes in the Civil Engineering study program through a meta-analysis approach. Digital technologies, such as e-learning, software-based simulations, and online collaborative platforms, have become an integral part of the learning process in the Industrial Revolution 4.0 era. However, its effectiveness in improving the learning outcomes of Civil Engineering students still shows mixed findings. The study collects and analyzes quantitative data from a wide range of relevant empirical research, published in the span of the last ten years. The results of the meta-analysis of 13 studies showed that overall, digital technology had a positive and significant influence on the learning outcomes of Civil Engineering students ($g = 1.142$; $p < 0.001$) in the high effect size category. These findings provide important implications for the development of technology-based learning strategies in higher education, especially in improving the competencies of Civil Engineering students effectively and adaptively.

Keywords: *Meta-Analysis, Digital Technology, Learning Outcomes, Civil Engineering.*

1. Introduction

The development of digital technology has brought about a major transformation in higher education by changing the way institutions manage their learning processes and operations (Asnur et al., 2024; Zulkifli et al., 2022; Luciana et al., 2024). Digitalization allows for the implementation of a more flexible, personalized, and student-centered learning model through the use of online learning platforms, learning management systems (LMS), and digital collaboration tools. In addition, digital technology also supports the automation of administrative processes such as class registration and academic data management, thereby increasing the efficiency and effectiveness of campus operations (Collegis Education, 2021). Digital transformation in higher education not only improves accessibility and quality of learning, but also encourages innovation in teaching methods and educational management. The COVID-19 pandemic accelerated the adoption of digital technology, forcing universities to adapt to online learning on a massive scale (Dewanto et al., 2023). However, the success of this transformation requires increasing technological competence for teaching staff and students as well as adequate infrastructure investment. Thus, the integration of digital technology is a strategic key to increasing the competitiveness and relevance of higher education in the modern era (UNESCO, 2023; Collegis Education, 2021; Santosa et al., 2020); Santosa et al., 2024; Wu, 2024).

The transformation of learning in the field of Civil Engineering is further accelerated by the integration of digital technologies such as Building Information Modeling (BIM), virtual reality (VR), and project-based learning approaches. Research by Ma and Tao (2023) shows that the implementation of project-based learning using BIM significantly improves the learning outcomes of Civil Engineering students. In the study, students who followed this learning method showed an increase in post-test scores of 15.82 points compared to the control group using the traditional method, with a statistically significant difference ($p < 0.001$). This confirms that the integration of digital technology in the Civil Engineering curriculum can improve students' conceptual understanding and practical skills(Santosa et al., 2024; Wantu et al., 2024; Elfira & Santosa, 2023). In addition, the use of immersive technologies such as VR and AR in Civil Engineering education has been shown to increase student engagement and understanding of complex concepts. A study by Su et al. (2024) highlights that this technology allows college students to explore engineering concepts in a safe and interactive environment, improving their motivation and investigative skills. For example, Civil Engineering students can use a VR platform to simulate bridge construction projects, allowing them to experiment with a variety of designs and environmental factors without any real risk. The integration of this technology not only enriches the learning experience but also prepares students for the challenges in an increasingly digital industrial world (Utomo et al., 2023; Willson & Putnam, 2022).

The rapid development of technology and the dynamics of the construction industry require Civil Engineering graduates to have increasingly complex and multidimensional competencies. Not only mastering theoretical knowledge, students must also be able to apply practical skills, problem-solving, and adaptability to new technologies that continue to develop. Therefore, improving student learning outcomes is very important so that they are ready to face challenges in the increasingly competitive and high-tech world of work (Azizah & Nugroho, 2022). The complexity of competencies needed in the modern construction industry includes technical skills such as the use of design and simulation software, project management, and an understanding of sustainability and occupational safety aspects. In addition, soft skills such as communication, teamwork, and critical thinking skills are also important aspects that must be developed during the learning process (Miehko, 2008). This requires educational institutions to adopt innovative learning methods that are integrated with industry needs so that student learning outcomes can be significantly improved (Putra et al., 2023). Thus, the improvement of the learning outcomes of Civil Engineering students not only focuses on the cognitive aspect, but also on the development of practical skills and professional attitudes that are relevant to the demands of the industry. The integration of digital technology and project-based learning approaches is an effective strategy to bridge the gap between theory and practice (Gijbels et al., 2005). This effort is expected to produce graduates who are competent, adaptive, and ready to compete in the global job market that continues to grow (Sari & Wibowo, 2021).

Research on the influence of digital technology on the learning outcomes of Civil Engineering students shows a significant diversity of findings. Several studies report that the integration of technologies such as Virtual Reality (VR), Augmented Reality (AR), and Building Information Modelling (BIM) can improve students' conceptual understanding and practical skills. The research of Ghanbaripour et al. (2024) in its systematic review found that the use of immersive technology in built-in environment education significantly improves student engagement and learning outcomes, as well as prepares them with relevant skills for the workforce. However, other studies show that the effectiveness of digital technologies can vary depending on the context of implementation and the type of technology used. For example, a meta-analysis by Ahmad (2023) revealed that although the use of information technology in education has a significant impact on student learning achievement in Indonesia, the effect size varies between -0.80 to 5.85, indicating heterogeneity in the studies analyzed (Ahmad et al., 2024).

The diversity of the results of this study can be caused by various factors, including the research design, teaching methods, and characteristics of the students. Several studies highlight that the successful integration of digital technology in Civil Engineering learning is highly dependent on institutional readiness, lecturer training, and infrastructure support (Springer et al., 2019). In addition, differences in pedagogical approaches, such as project-based learning versus traditional lectures, also affect the effectiveness of digital technologies. In this context, it is important to conduct a more in-depth and focused meta-analysis in the field of Civil Engineering to identify the factors that contribute to the success or failure of the implementation of digital technology in improving student learning outcomes. Thus, educational institutions can design learning strategies that are more effective and in accordance with the needs of Civil Engineering students in the digital era. Based on this, this study aims to comprehensively examine the influence of the use of digital technology on student learning outcomes in the Civil Engineering study program through a meta-analysis approach

2. Research Methods

This study uses a meta-analysis approach as a method to integrate and quantitatively analyze the results of previous research that discusses the influence of digital technology on the learning outcomes of Civil Engineering students. Meta-analysis allows researchers to identify common patterns, measure effect size, and evaluate the consistency of findings across studies (Zulyusri et al., 2023); (Oktarina et al., 2021); (Edy Nurtamam et al., 2023); Wantu et al., 2024). Data was collected through systematic searches on international scientific databases such as Scopus, ScienceDirect, Web of Science, and Google Scholar using keywords such as "digital technology", "civil engineering students", "learning outcomes", and "meta-analysis". The studies included in the analysis are those published between 2014 and 2024, written in English or Indonesian, and provide complete statistical data such as mean values, standard deviations, and sample sizes. The selection process is carried out through the stages of identification, screening, and inclusion, in accordance with the guidelines of PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses). The effect size was calculated using the standardized mean difference (SMD) or Hedges' g, depending on the homogeneity of the data obtained. The heterogeneity test was carried out through Q-test and I^2 statistics to measure diversity between studies. In addition, publication bias tests are carried out using funnel plots and Egger's test to ensure that the results of the analysis are not distorted by the

DOI: https://doi.org/10.31004/riggs.v4i2.469

tendency to publish significant results alone. All statistical analysis processes are carried out using JASP software to ensure the accuracy and validity of the findings. The effect size value criteria in this study can be seen in Table 1.

T**abel 1.** Kriteria Nilai Effect Size

Effect Size	Kriteria
0.0≤ Effect Size ≤ 0.20	Poor
0.21≤ Effect Size ≤ 0.50	Small
0.51≤ Effect Size ≤ 0.10	Medium
1,11 ≥ Effect size	Strong

Source:(Ayaz & Söylemez, 2015; Zulyusri et al., 2023)

3. Results and Discussions

Based on the results of data search through the database, 13 studies/articles met the inclusion criteria. The effect size and error standard can be seen in Table 2.

Table 2. Effect Size and Standard Error Every Research

Code Journal	Years	Effect Size	Standard Error
XR1	2025	0.34	0.12
XR2	2025	1.02	0.20
XR3	2024	0.45	0.31
XR4	2023	1.90	0.38
XR5	2024	1.72	0.30
XR6	2023	0.77	0.27
XR7	2021	0.81	0.24
XR8	2024	1.19	0.33
XR9	2024	2.02	0.40
XR10	2025	1.82	0.37
XR11	2024	1.93	0.33
XR12	2022	0.69	0.20
XR13	2021	0.93	0.24

Based on Table 2, the effect size value of the 13 studies ranged from 0.34 to 2.02. According to Borenstein et al., (2007) Of the 13 effect sizes, 3 studies had medium criteria effect sizes and 10 studies high criteria effect size values. Furthermore, 13 studies were analyzed to determine an estimation model to calculate the mean effect size. The analysis of the fixed and random effect model estimation models can be seen in Table 3.

Table 3. Residual Heterogeneity Test

Q_b	df	p
64.488	12	< 0.001

Based on Table 3, a Q value of 64.488 was obtained higher than the value of 34.016 with a coefficient interval of 95% and a p value of 0.001 <. The findings can be concluded that the value of 24 effect sizes analyzed is heterogeneously distributed. Therefore, the model used to calculate the mean effect size is a random effect model. Furthermore, checking publication bias through funnel plot analysis and Rosenthal fail safe N (FSN) test (Tamur et al., 2020; Badawi et al., 2022; Ichsan et al., 2023b; Borenstein et al., 2007). The results of checking publication bias with funnel plot can be seen in Figure 2.

DOI: https://doi.org/10.31004/riggs.v4i2.469

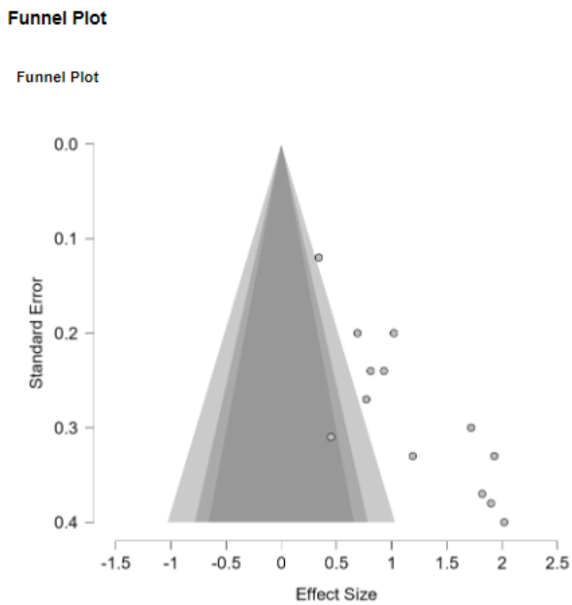

Figure 2. Funnel Plot

Based on Figure 2, the analysis of the funnel plot is not yet known whether it is symmetrical or asymmetrical, so it is necessary to conduct a Rosenthal Fail Safe N (FSN) test. The results of the Rosenthal Fail Safe N calculation can be seen in Table 4.

Tabel 4. Fail Safe N

File Drawer Analysis			
	Fail Safe N	Target Significance	Observed Significance
Rosenthal	458	0.050	< 0.001

Based on Table 4, the Fail Safe N value of 2504 is greater than the value of 5k + 10 = 5(13) + 10 = 75, so it can be concluded that the analysis of 13 effect sizes in this data is not biased by publication and can be scientifically accounted for. Next, calculate the p-value to test the hypothesis through the random effect model. The results of the summary effect model analysis with the random effect model can be seen in Table 5.

Tabel 5. Pooled Effect Size Test

Estimates	Standar Error	t	df	p
1.142	0.165	6.938	12	< 0.001

Table 5. The average value of the effect size is 1.142 and the standard error is 0.165. This finding explains that digital technology has a positive and significant influence on the learning outcomes of Civil Engineering students with ($p < 0.001$; $t = 6.938$). The use of digital technology in Civil Engineering learning has a significant positive influence on improving student learning outcomes. The overall effect size is in the medium to high category, indicating that digital technology-based interventions—such as computer-aided simulations, Building Information Modeling (BIM), Virtual Reality (VR), and Learning Management Systems (LMS)—consistently have a constructive impact on students' cognitive achievement. These findings are in line with the results of a study by Ghanbaripour et al. (2024) which show that the use of immersive technology can significantly improve the spatial understanding and problem-solving skills of engineering students. However, heterogeneity analysis showed that there was a high degree of variation among the studies analysed ($I^2 > 75\%$), which indicates that the effects of digital technologies are not uniform in all contexts. This difference can be caused by various factors such as the type of technology used, the duration of the intervention, the learning design, and the characteristics of the institution and student (Santhosh et al., 2022; Alshammary & Alhalafawy, 2023)s. For example, studies that combine digital technology with active learning models such as project-based learning or flipped classrooms tend to show higher effect sizes compared to studies that only use technology passively as a medium of material delivery (Daryanto et al., 2022).

DOI: https://doi.org/10.31004/riggs.v4i2.469

The moderator's analysis further revealed that this type of digital technology has an important contribution to learning effectiveness. Technologies such as BIM and VR have a stronger impact on learning structural concepts and construction planning, compared to ordinary digital presentation media such as PowerPoint (Hariyadi et al., 2023). In addition, LMS-based online learning platforms that are designed interactively—such as Moodle with discussion forum features and automated assessments—are better able to improve student engagement and learning outcomes compared to passive platforms. This emphasizes the importance of selecting technology that is in accordance with the characteristics of the material and the learning objectives of Civil Engineering. In terms of location and institutional background, studies conducted in developing countries show more varied effects compared to developed countries(Hidayat et al., 2024); (Li & Liang, 2024). This is suspected to be due to differences in access to technological infrastructure, lecturer training, and institutional readiness to adopt digital innovations systematically. Technical constraints such as limited internet connection and lack of curriculum integration also contribute to the low effectiveness of digital technology implementation in some contexts. Therefore, a special strategy is needed in implementing digital technology in the civil engineering higher education environment in developing countries so that the impact is more even (Wu, 2024).

Digital technology can be an effective tool to improve the quality of Civil Engineering education, but it must be supported by the right pedagogical approach and institutional readiness. Adaptive curriculum development, intensive training for educators, and investment in digital infrastructure are needed as the main prerequisites for successful implementation. The study also recommends conducting longitudinal studies and controlled experiments to strengthen causal evidence and assess the long-term impact of the use of digital technology on the professional skills of Civil Engineering students (Ahmad et al., 2024; Santosa et al., 2025; Ali et al., 2024).

4. Conclusion

From the results of this study, it can be seen that overall the use of digital technology has a positive and significant influence on the learning outcomes of Civil Engineering students ($g = 1,142$; $p < 0.001$) in the high effect size category. These findings provide important implications for the development of technology-based learning strategies in higher education, especially in improving the competencies of Civil Engineering students effectively and adaptively. The integration of digital technology in the learning process not only improves the understanding of theoretical concepts, but also strengthens practical skills that are urgently needed in the industrial world. The implications of these findings underscore the importance of higher education institutions to adopt and develop digital technology-based learning methods more broadly and systematically. Thus, strengthening student competencies through digital technology can increase the competitiveness of Civil Engineering graduates in an increasingly complex and dynamic job market.

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