The Effect of Integrated STEM Learning Models Based on Digital Technology on Improving Students' Digital Literacy

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Abstract: This study aims to analyze the influence of digital technology-based integrated STEM learning models on improving students' digital literacy through a meta-analysis approach. Digital literacy is an essential competency in the era of the Industrial Revolution 4.0, and STEM learning that integrates digital technology is believed to be able to facilitate the strengthening of these skills. This study examined 20 scientific articles published in the period 2015–2024 and met the inclusion and methodological quality criteria. The analysis was carried out using JASP. The results of the meta-analysis showed that the digital-based STEM learning model had a significant influence on improving students' digital literacy, with an average effect size value of 0.78 which was included in the large category. Subanalysis based on education level indicates that the strongest influence occurs at the secondary education level. These findings imply that the development of STEM-based learning curricula and strategies that are integrated with digital technology needs to be continuously encouraged to strengthen students' readiness to face the challenges of the digital world.

Keywords: 21st century learning; Digital literacy; Digital technology; Meta-analysis; STEM

Introduction

21st century education faces complex challenges that demand fundamental transformations in the learning system (Asnur et al., 2024; Luciana et al., 2024; Zulkifli et al., 2022). Rapid technological advances have changed the way humans access, process, and distribute information. Therefore, the education system must be able to develop essential skills such as critical thinking, problem-solving, creativity, collaboration, and adaptability to digital change (Elfira & Santosa, 2023; Utomo et al., 2023; Zulyusri et al., 2023). In this context, mastery of digital literacy is very important because it allows learners to think reflectively, access information effectively, and use technology wisely in daily life and future work environments (Laila & Asrizal, 2021; Ardianti et al., 2020).

Digital literacy not only includes technical skills in using digital devices, but also includes a critical understanding of digital information, cybersecurity, digital ethics, and digital media-based communication (Le et al., 2022; Laila & Asrizal, 2021; Lestari et al., 2021). In the midst of a massive and often misleading flow of information, learners must be equipped with

the skills to evaluate the credibility of sources, manage data, and use technology productively (Gholami & Salahshour, 2025). Without mastery of digital literacy, students will have difficulty adapting in an era marked by the dominance of information and technology (Dewanto et al., 2024; Soeswoyo et al., 2021). Therefore, digital literacy is an important foundation in supporting lifelong learning and job readiness in the era of the Industrial Revolution 4.0 and Society 5.0.

Digital literacy has a strategic role in supporting the learning process because it allows students to become active, independent, and adaptive learners to information technology developments (Kiryakova-Dineva & Yaneva, 2025; El Messaoudi, 2024). In a digital learning environment, students are required to be able to access, evaluate, and process information from various sources critically and responsibly (Joseph et al., 2024). This ability is essential in developing discovery-based and inquiry-based learning, where students do not only passively receive information, but are directly involved in the process of seeking and constructing knowledge (Sydorenko et al., 2024). Digital literacy also expands learning spaces beyond the boundaries of conventional classrooms, enables global interaction, and facilitates collaboration across cultures and disciplines.

In addition to supporting learning, digital literacy is also the foundation for the development of students' creativity and problem-solving skills (Rahmi et al., 2024; Ilić et al., 2024). Digital technology provides a variety of tools and platforms that students can use to express ideas, create digital products, and solve challenges innovatively. For example, the use of design applications, scientific simulations, and programming software allows students to think creatively and experimentally (Redhana et al., 2024; Net et al., 2024). With the mastery of digital literacy, students are not only able to use technology as a tool, but also as a medium for critical thinking and collaborative complex problem-solving. This makes digital literacy a key competency in preparing a generation that is able to actively contribute to a knowledge- and technology-based society.

The integration of digital technology in the learning process is an urgent need in facing the dynamics of the 21st century education world (Lachner et al., 2024; Coker et al., 2024). Digital technology not only functions as a medium to help learning, but also as a catalyst for changing the learning paradigm from teacher-centered to student-centered. The use of digital devices, such as Learning Management Systems (LMS), interactive learning applications, and cloud-based collaborative platforms, has been shown to increase student engagement, expand access to learning resources, and enable learning personalization (Bulut et

al., 2023; Amin et al., 2023). This integration also accelerates the transition to a competency-based learning model, where students are required to not only master the material, but also be able to apply it in real-world contexts through technology.

Furthermore, the integration of digital technology in learning is a strategic means to develop students' digital skills, including the ability to search, evaluate, manage, and create digital information. In this context, digital skills are no longer just an add-on, but an essential component in the modern curriculum (Angraini et al., 2023). This integration process also forms students who are digitally literate, adaptive to technological developments, and ready to compete in a work environment based on information and technology (Castañeda & Villar-Onrubia, 2023; Miliou & Angeli, 2023). Without systematic integration of technology, educational institutions will experience a gap between educational output and the demands of the industrial world and the digital society. Therefore, this urgency requires educational institutions, teachers, and policy makers to redesign pedagogical approaches by adopting digital technology in a sustainable and reflective manner (Siiman et al., 2014; Widiyatmoko et al., 2025).

STEM (Science, Technology, Engineering, and Mathematics)-based learning approaches play a critical role in equipping learners with essential 21st-century skills, such as critical thinking, creativity, collaboration, and innovative problem-solving skills. In a global era characterized by the complexity of real problems and the acceleration of technological development, conventional learning that is separate between disciplines is no longer considered adequate (Ismail, 2025). The STEM model encourages cross-disciplinary integration through contextual and problem-based approaches, where students learn not only to understand theoretical concepts, but also to apply them in designing solutions to real-life problems. Thus, STEM learning forms students who are adaptive, technologically skilled, and ready to face the challenges of the Industrial Revolution 4.0 and Society 5.0 era (Lestari & Rahmawati, 2020; Indriani et al., 2024).

Furthermore, STEM-based learning provides opportunities for students to develop 21st-century skills through technology-based exploration, experimentation, and collaborative projects. This approach fosters curiosity and love for science and technology, while strengthening digital literacy and numeracy (Suswandari, 2023). In practice, STEM learning emphasizes the process of scientific thinking and engineering design as pedagogical strategies that allow students to produce real and innovative products (Santosa et al., 2020; Santosa & Sepriyani, 2020; Santosa & Sudirman, 2023). This is very relevant in the context

of modern education which not only aims to transfer knowledge, but also produce a generation of problem solvers and creators who are globally competitive.

Research by Sahin & Öztürk (2019) examined the influence of integrating STEM with interactive digital media on high school students' 21st century skills, including digital literacy, and found that students engaged in digital project-based STEM learning showed significant improvements in the ability to use technology to solve problems and communicate ideas (Muzana et al., 2021). Similarly, research by Saleh et al. (2025) shows that the use of digital technology in STEM learning is able to encourage students to be more active in data exploration, information-based decision-making, and the development of digital products that reflect cross-disciplinary understanding. Another study by Özdemir et al. (2021) also confirms that STEM learning models integrated with digital platforms such as virtual simulation, coding, and robotics make a positive contribution to improving the digital literacy of primary and secondary school students.

Various previous studies have examined the effectiveness of digital technology-based STEM learning models in improving students' digital literacy, but the results still show significant variations. Several studies have found that the integration of STEM and digital technology can consistently improve students' ability to access, evaluate, and create digital content critically and creatively. However, other studies report that such effectiveness depends on a number of contextual factors, such as the readiness of the technological infrastructure, the competence of teachers in integrating STEM approaches, and the background and initial abilities of the students. This condition creates inconsistencies in the general conclusions regarding the extent to which this approach is effective in improving students' digital literacy (Lestari et al., 2021).

In addition, differences in methodological design in previous studies also affected the variation in results. Differences in the type of STEM model used (e.g. integrative vs. multidisciplinary), duration of intervention, respondents' level of education (elementary, junior high, or high school), and measured digital literacy indicators led to disparities in empirical findings. Some studies are also limited in sample scale or do not use robust experimental designs, making the results difficult to generalize. Therefore, a systematic and objective synthesis is needed through meta-analysis methods to identify common patterns and measure the strength of the influence of digital technology-based STEM learning approaches on students' digital literacy in a more comprehensive and evidence-based manner.

Method

Research Design

This study uses a quantitative approach with a meta-analysis method to synthesize and statistically analyze the results of previous research related to the influence of digital technology-based STEM learning models on improving students' digital literacy. Meta-analysis was chosen because it was able to provide a more accurate estimate of effect size through the combination of results from various empirical studies. This study refers to a systematic procedure developed by Glass (1976) and adjusted to the guidelines of Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA).

Literature Searching

The literature collection in this study was carried out systematically by referring to the PRISMA protocol (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) to ensure validity and transparency in the selection of studies. The literature search process is carried out through a number of reputable electronic databases, such as Scopus, Web of Science, ERIC, ScienceDirect, Google Scholar, and DOAJ. The search uses a combination of keywords relevant to the research topic, including: "STEM learning", "digital technology", "digital literacy", "integrated STEM", and "students' digital competence", with Boolean operators such as AND and OR to expand the scope of the search. The publication time range is limited between 2015 to 2024, to guarantee the novelty and relevance of the results of the analyzed research. In addition, only articles available in full-text form and written in English or Indonesian were considered in this study. From the results of the data search, 20 relevant studies were obtained.

Inclusion Criteria

In conducting the study selection, inclusion criteria are used, namely empirical research that tests the influence of digital technology-based STEM learning models on students' digital literacy, studies that use experimental or quasi-experimental quantitative design (e.g. pretest-posttest control group design), studies published in the 2015–2024 time frame, articles available in English or Indonesian and articles published in accredited journals or scientific proceedings which can be accessed in full-text.

Data Analysis

Data analysis was carried out using JASP software. Effect measures were calculated using the Standardized Mean Difference (SMD), specifically Cohen's d, to measure the strength of the intervention's influence.

Cohen's interpretation of d's value refers to the categories: small (0.2), medium (0.5), and large (0.8). In addition, a heterogeneity test was conducted using Q and I² statistics to determine the extent of variation between studies due to differences in study characteristics, not random errors. Subgroup analysis is also carried out based on the level of education and the type of digital technology used. Potential publication bias is analyzed using a plot funnel and Egger's regression test. . The classification of the effect size value is g = 0.2 (small effect), g = 0.5 (medium effect), g = 0.8 (large effect), g = 1.2 (very large effect) (Sawilowsky, 2009).

Result and Discussion

Based on the results of data search through the database, 20 studies/articles met the inclusion criteria. The effect size and error standard can be seen in Table 1.

Table 1. Effect size dan standard error

Journal Code	Education Level	Standard Error	Effect size(g)
AL 1	Elementary	0.35	0.91
AL 2	Secondary School	0.27	1.02
AL 3	Secondary School	0.22	0.73
AL 4	University	0.19	0.35
AL 5	University	0.33	1.03
AL 6	Secondary School	0.18	0.56
AL 7	University	0.37	1.56
AL 8	University	0.20	0.66
AL 9	Secondary School	0.15	0.44
AL 10	University	0.30	0.75
AL 11	Secondary School	0.26	1.80
AL 12	University	0.22	1.20
AL 13	Secondary School	0.19	0.49
AL 14	Elementary	0.29	0.88
AL 15	Secondary School	0.33	1.82
AL 16	University	0.40	2.45
AL 17	Secondary School	0.27	0.95
AL 18	Secondary School	0.21	0.67
AL 19	Secondary School	0.27	0.58
AL 20	University	0.16	0.33

Based on Table 1, the effect size value of the 20 studies ranged from 0.33 to 2.45. According to Borenstein et al. (2007) of the 20 effect sizes, 10 studies ad medium criteria effect sizes and 10 studies had high criteria effect size values. Based on the results of the data test based on JASP outputs, the following results were obtained:

Heterogeneity Test

Furthermore, analyze the heterogeneity test of the ten analyzed studies which can be seen in Table 2.

Table 2. Residual Heterogeneity test

Qc	df	P
75.863	19	< 0.001

Based on Table 2, the results of the heterogeneity test analysis showed that 20 researchers had a heterogeneous distribution (QC = 75.863; P < 0.001). With this, random effect size is effective to estimate the average effect size of the 10 studies analyzed. The results of the digital-based STEM learning model had a significant influence on improving students' digital literacy.

Hypothesis Test

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 3.

Table 3. Pooled effect size test

Estimate	Standard error	t	df	P
0.904	0.119	7.617	19	< 0.001

Table 3, the results of the analysis of the average value of effect size with the random effect model showed that there was a positive the digital-based STEM learning model had a significant influence on improving students' digital literacy (t = 7.617; p < 0.001).

Publication Bias

Checking publication bias through funnel plot analysis and Rosenthal fail safe N (FSN) test (Tamur et al., 2020; Hukom, 2023; Ichsan et al., 2023; Borenstein et al., 2007). The results of checking publication bias with funnel plot can be seen in Figure 1.
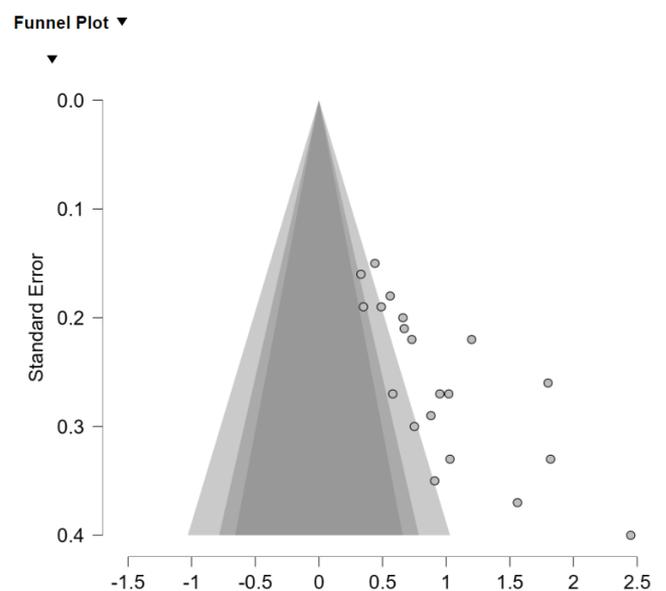

Figure 1. Funnel plot

Based on Figure 1, the analysis of the funnel plot is not yet known whether it is symmetrical or asymmetrical, so it is necessary to conduct a Egger's test. The results of the Egger's test calculation can be seen in Table 4.

Based on Table 4, the Z value is 2.419 and the p-value is 0.178 more than the sig value. 0.05 means that

there is no publication bias in this study. Next, the forest plot analysis can be seen in Figure 2.

Table 4. Egger's test

	z	p
Sei	2.419	0.178

Forest Plot ▼

0.16	0.33
0.27	0.58
0.21	0.67
0.27	0.95
0.4	2.45
0.33	1.82
0.29	0.88
0.19	0.49
0.22	1.2
0.26	1.8
0.3	0.75
0.15	0.44
0.2	0.66
0.37	1.56
0.18	0.56
0.33	1.03
0.19	0.35
0.22	0.73
0.27	1.02
0.35	0.91

0.33 [0.02, 0.64]
0.58 [0.05, 1.11]
0.67 [0.26, 1.08]
0.95 [0.42, 1.48]
2.45 [1.67, 3.23]
1.82 [1.17, 2.47]
0.88 [0.31, 1.45]
0.49 [0.12, 0.86]
1.20 [0.77, 1.63]
1.80 [1.29, 2.31]
0.75 [0.16, 1.34]
0.44 [0.15, 0.73]
0.66 [0.27, 1.05]
1.56 [0.83, 2.29]
0.56 [0.21, 0.91]
1.03 [0.38, 1.68]
0.35 [-0.02, 0.72]
0.73 [0.30, 1.16]
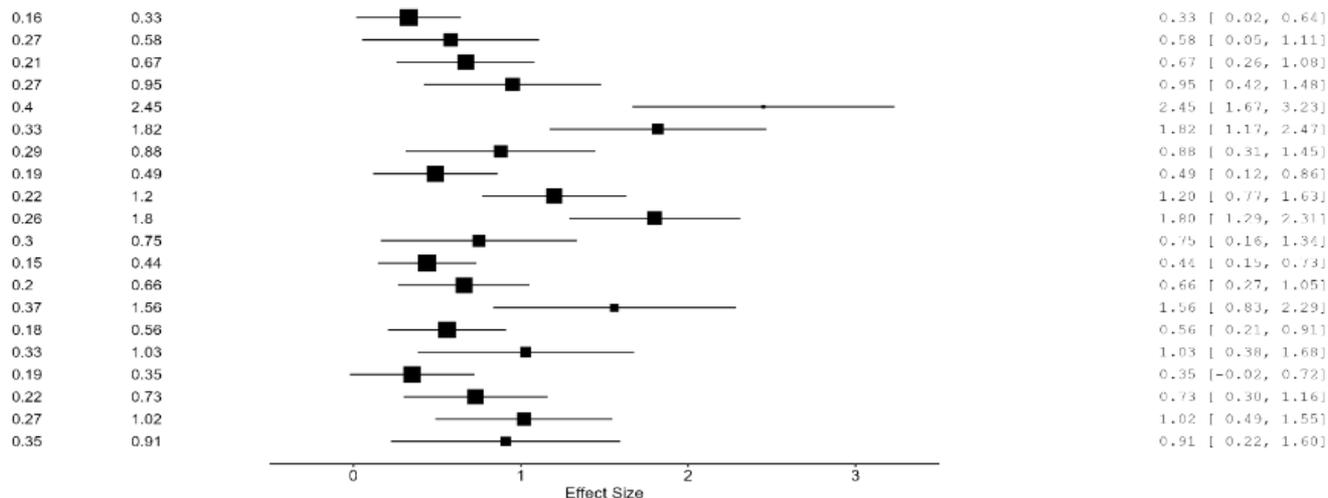1.02 [0.49, 1.55]
0.91 [0.22, 1.60]

Effect Size

Figure 2. Forest plot

Based on the forest plot analysis, it can be observed that the analyzed articles have values that vary between 0.33 to 2.45 with a summary effect size value of 0.692. This finding explains that the digital-based STEM learning model had a significant influence on improving students' digital literacy in the high category. These findings confirm that learning approaches that combine science, technology, engineering, and mathematics in an integrative and digital-based manner are able to improve students' skills in using technology to access, evaluate, and create information critically and productively. This is in line with the results of research by Chai et al. (2020) which show that the integration of technology in STEM learning not only improves conceptual knowledge, but also strengthens students' digital skills in facing the challenges of the 21st century (Dewi & Kamaludin, 2022; Helmi et al., 2023).

These findings also corroborate that digital technology serves as a catalyst in STEM-based learning (Lachner et al., 2024). The use of simulation software, collaborative learning platforms, and programming apps allows students to explore STEM concepts in a more in-depth and meaningful way (Siiman et al., 2014). Thus, students become not only users of technology, but also reflective and innovative digital content creators. This condition is very important in

building digital literacy as a basic competency needed in the increasingly digitized world of work and social life. Sub analysis based on education level shows that the influence of this model is strongest at the secondary school level, compared to the elementary or tertiary level. This can be due to the cognitive and affective readiness of secondary school students who are more mature in using and understanding digital technology devices in a complex way, as well as the encouragement of a more explicit curriculum towards mastery of ICT skills and critical thinking (Widiyatmoko et al., 2025; Indriani et al., 2024). A study by Özdemir et al. (2021) also supports these findings, stating that high school students engaged in digital-based STEM projects show rapid progress in digital literacy and online collaboration skills.

However, the level of effectiveness is also influenced by the context of implementation, such as the readiness of school infrastructure, teacher training in implementing technology-based STEM learning, and school policy support. Several studies involved in this analysis show that technical constraints and lack of teacher competence in digital technology are factors that hinder the achievement of maximum results (Suswandari, 2023; Morachat & Seechaliao, 2024). Therefore, continuous training for teachers as well as explicit curriculum integration on digital literacy are

needed to ensure the effective implementation of this learning model.

Overall, the results of this study reinforce the importance of integrating STEM and digital technology in designing learning strategies that not only transmit knowledge, but also form students who are able to think critically, creatively, and digitally literate (Morachat & Seechaliao, 2024; Zainil et al., 2023). The practical implications of these findings are the need to develop education policies that support the widespread adoption of digital STEM models, teacher capacity building, and the provision of technology-based learning facilities (Swandana et al., 2023). In the long term, strengthening digital literacy through STEM learning will be an important foundation in preparing the younger generation to face the challenges of the Industrial Revolution 4.0 and technology-based society.

Conclusion

Based on the results of this study, it can be concluded that the digital-based STEM learning model has a significant influence on improving students' digital literacy, with an average effect size value of 0.904 which is included in the large category. Sub analysis based on education level indicates that the strongest influence occurs at the secondary education level. These findings imply that the development of STEM-based learning curricula and strategies that are integrated with digital technology needs to be continuously encouraged to strengthen students' readiness to face the challenges of the digital world.

Conflicts of Interest
The authors declare no conflict of interest.

References

Amin, A. M., Karmila, F., Laode, Z. A., Ermin, E., Akbar, A. Y., & Ahmed, M. A. (2023). The WE-ARe Model's Potential to Enhance Digital Literacy of Preservice Biology Teachers. *JPBI (Jurnal Pendidikan Biologi Indonesia)*, *9*(1), 36–45. https://doi.org/10.22219/jpbi.v9i1.23061

Angraini, E., Zubaidah, S., & Susanto, H. (2023). TPACK-Based Active Learning to Promote Digital and Scientific Literacy in Genetics. *Pegem Egitim ve Ogretim Dergisi*, *13*(2), 50–61. https://doi.org/10.47750/pegegog.13.02.07

Ardianti, S., Sulisworo, D., Pramudya, Y., & Raharjo, W. (2020). The Impact of the Use of STEM Education Approach on the Blended Learning to Improve Student's Critical Thinking Skills. *Universal Journal of Educational Research*, *8*(3 B), 24–32. https://doi.org/10.13189/ujer.2020.081503

Asnur, L., Jalinus, N., Faridah, A., Santosa, T. A., Ambiyar, R. D., & Utami, F. (2024). Video-Blogs (Vlogs)-Based Project : A Meta Analysis. *Int. J. Adv. Sci. Eng. Inf. Technol.*, *14*(5), 1553–1557. https://doi.org/10.18517/ijaseit.14.5.16804

Borenstein, M., Hedges, L., & Rothstein, H. (2007). *Introduction to Meta-Analysis*. Retrieved from www.Meta-Analysis.com

Bulut, M., Bulut, A., Kaban, A., & Kirbas, A. (2023). Exploring the Nexus of Technology, Digital, and Visual Literacy: A Bibliometric Analysis. *International Journal of Education in Mathematics, Science and Technology*, *12*(2), 345–363. https://doi.org/10.46328/ijemst.3777

Castañeda, L., & Villar-Onrubia, D. (2023). Beyond Functionality: Building Critical Digital Teaching Competence Among Future Primary Education Teachers. *Contemporary Educational Technology*, *15*(1), 1–17. https://doi.org/10.30935/cedtech/12599

Chai, C. S., Lin, P-Y., Jong, M., Dai, Y., Chiu, T. K. F., & Huang, B. (2020). Factors Influencing Students' Behavioral Intention to Continue Artificial Intelligence Learning. *Conference: 2020 International Symposium on Educational Technology (ISET)*. http://dx.doi.org/10.1109/ISET49818.2020.00040

Coker, C., Harper, H., Campbell, T., Tonners-Saunders, L., Waghorn, S., & Robertson, L. (2024). Developing Digital Literacies in Teacher Education: A Collaborative Enquiry Examining Teacher Educators' Experiences of Teaching Online During the Pandemic. *TEAN Journal*, *15*(1), 1–17. Retrieved from https://files.eric.ed.gov/fulltext/EJ1416182.pdf

Dewanto, D., Santosa, T. A., Ratih, A., Asrizal, A., & Hardeli, H. (2024). The Influence of the STEM-Based Guided Inquiry Model on Students' Creative Thinking Skills in Science Learning: A Meta-Analysis Study. *Jurnal Penelitian Pendidikan IPA*, *10*(3), 88–95. https://doi.org/10.29303/jppipa.v10i3.6777

Dewi, A. M., & Kamaludin, A. (2022). Development of Audiovisual-Based PowToon Animation Video on Chemical Bonds for Tenth Grade. *Jurnal Penelitian Pendidikan IPA*, *8*(1), 222–229. https://doi.org/10.29303/jppipa.v8i1.865

El Messaoudi, M. (2024). The Impact of a Blended Learning Model on Undergraduate University Students' Digital Literacy Skills: Empirical Evidence from Higher Education. *Educational Process: International Journal*, *13*(4), 84–101. https://doi.org/10.22521/edupij.2024.134.5

Elfira, I., & Santosa, T. A. (2023). Literature Study: Utilization of the PjBL Model in Science Education to Improve Creativity and Critical Thinking Skills. *Jurnal Penelitian Pendidikan IPA*, *9*(1), 133–143. https://doi.org/10.29303/jppipa.v9i1.2555

Gholami, R., & Salahshour, S. (2025). Effect of Using Digital Media for Language Learning on Reduction of Anxiety and Boost of Proficiency among Immigrating Students: A Case Study. *International Journal of Education and Literacy Studies*, *13*(1), 279–292. https://doi.org/10.7575/aiac.ijels.v.13n.1p.279

Glass, G. V. (1976). Primary, Secondary, and Meta-Analysis of Research. *Educational Researcher*, *5*(10), 3-8. http://dx.doi.org/10.3102/0013189X005010003

Helmi, M., Asrial, A., & Hariyadi, B. (2023). Effect of Problem-Based Learning Model on High School Students' Critical Thinking Ability in Biotechnology Viewed from the Level of Confidence. *Jurnal Penelitian Pendidikan IPA*, *9*(9), 6870–6876. https://doi.org/10.29303/jppipa.v9i9.4067

Hukom, J. (2023). Integration of Blended Learning and Project-Based Learning (BPjBL) on Achievement of Students' Learning Goals: A Meta-Analysis Study. *Pegem Journal of Education and Instruction*, *13*(4), 274–281. https://doi.org/10.47750/pegegog.13.04.32

Ichsan, I., Suharyat, Y., Santosa, T. A., & Satria, E. (2023). Effectiveness of STEM-Based Learning in Teaching 21st Century Skills in Generation Z Student in Science Learning: A Meta-Analysis. *Jurnal Penelitian Pendidikan IPA*, *9*(1), 150–166. https://doi.org/10.29303/jppipa.v9i1.2517

Ilić, J., Ivanović, M., & Klašnja-Milićević, A. (2024). Effects of Digital Game-Based Learning in STEM Education on Students' Motivation: A Systematic Literature Review. *Journal of Baltic Science Education*, *23*(1), 20–36. https://doi.org/10.33225/jbse/24.23.20

Indriani, B. S., Saptono, S., Mustikaningtyas, D., & Yuniastuti, A. (2024). Effectiveness of Creative Problem Solving (CPS)-STEM Learning Model on Students' Computational Thinking and Digital Literacy Skills in Biotechnology Material. *Unnes Science Education Journal*, *13*(2), 61–68. Retrieved from https://journal.unnes.ac.id/journals/usej

Ismail, H. (2025). Exploring Students' Needs for STEM Based Digital Learning Models to Enhance English Academic Reading in 21st Century. *Indonesian EFL Journal*, *11*(1), 109–120. https://doi.org/10.25134/ieflj.v11i1.11439

Joseph, G. V., Athira, P., Thomas, M. A., Jose, D., Roy, T. V., & Prasad, M. (2024). Impact of Digital Literacy, Use of AI Tools and Peer Collaboration on AI Assisted Learning: Perceptions of the University Students. *Digital Education Review*, *45*, 43–49. https://doi.org/10.1344/der.2024.45.43-49

Kiryakova-Dineva, T., & Yaneva, D. (2025). Top 6 Literacies in Marketing Education: State-of-the-Art Approach. *Contemporary Educational Technology*, *17*(1), 1–12. https://doi.org/10.30935/cedtech/15636

Lachner, A., Backfisch, I., & Franke, U. (2024). Towards an Integrated Perspective of Teachers' Technology Integration: A Preliminary Model and Future Research Directions. *Frontline Learning Research*, *12*(1), 1–15. https://doi.org/10.14786/flr.v12i1.1179

Laila, R., & Asrizal, A. (2021). Analysis of Need for Development of Physics Teaching Materials Assisted by a Learning House Portal Integrating STEM and Contextual Models to Improve Student Digital Literacy. *Journal of Physics: Conference Series*, *1876*(1). https://doi.org/10.1088/1742-6596/1876/1/012043

Le, B., Lawrie, G. A., & Wang, J. T. H. (2022). Student Self-Perception on Digital Literacy in STEM Blended Learning Environments. *Journal of Science Education and Technology*, *31*(3), 303–321. https://doi.org/10.1007/s10956-022-09956-1

Lestari, H., & Rahmawati, I. (2020). Integrated STEM Through Project Based Learning and Guided Inquiry on Scientific Literacy Abilities in Terms of Self-Efficacy Levels. *Al Ibtida: Jurnal Pendidikan Guru MI*, *7*(1), 19. https://doi.org/10.24235/al.ibtida.snj.v7i1.5883

Lestari, H., Rahmawati, I., Siskandar, R., & Dafenta, H. (2021). Implementation of Blended Learning with A STEM Approach to Improve Student Scientific Literacy Skills During The Covid-19 Pandemic. *Jurnal Penelitian Pendidikan IPA*, *7*(2), 224–231. https://doi.org/10.29303/jppipa.v7i2.654

Luciana, O., Sjoraida, D. F., Santosa, T. A., Nugraha, A. R., & Zain, A. (2024). The Effect of Technology-Based Management Learning on Children's Organizational Skills Development: A Meta-Analysis Approach. *Jurnal Obsesi: Jurnal Pendidikan*

Anak Usia Dini, *8*(6), 1777–1786. https://doi.org/10.31004/obsesi.v8i6.6593

Miliou, O., & Angeli, C. (2023). the Impact of a Project-Based Learning Environment on the Development of Undergraduate Students' Digital Literacy Skills. *20th International Conference on Cognition and Exploratory Learning in Digital Age, CELDA 2023, Celda*, 171–178. https://doi.org/10.3102/2107845

Morachat, W., & Seechaliao, T. (2024). The Development of an Instructional Model Based on Flipped Using Technology-Based Learning to Enhance the Digital Literacy for Undergraduate Students in the Faculty of Education, Rajabhat University. *Higher Education Studies*, *14*(3), 189. https://doi.org/10.5539/hes.v14n3p189

Muzana, S. R., Wilujeng, I., Yanto, B. E., & Mustamin, A. A. (2021). E-STEM Project-Based Learning in Teaching Science to Increase ICT Literacy and Problem Solving. *International Journal of Evaluation and Research in Education (IJERE)*, *10*(4), 1386–1394. https://doi.org/10.11591/ijere.v10i4.21942

Net, W. W. W. P., Muskania, R. T., Maksum, A., & Astra, I. M. (2024). A Qualitative Study of Teacher's Perspective About Digital STEM-PjBL Teaching Material Based on Local Wisdom to Improve Scientific Literacy. *Pegem Journal of Education and Instruction*, *14*(2), 94–103. https://doi.org/10.47750/pegegog.14.02.11

Özdemir, A., Mirici, S., & Cigdemoglu, C. (2021). The Effect of Project Supervision Training on Teachers' Views of Nature of Scientific Inquiry. *International Online Journal of Education and Teaching (IOJET)*, *8*(4). 2927-2948. Retrieved from https://files.eric.ed.gov/fulltext/EJ1319382.pdf

Rahmi, U., Mahande, R. D., & Azrul, A. (2024). the Role of Support System, Digital Literacy and Learning Strategy on Learning Outcomes for Preservice Teachers in a Blended Learning Environment. *Journal of Educators Online*, *21*(3). https://doi.org/10.9743/JEO.2024.21.3.12

Redhana, I. W., Sudria, I. B. N., & Suardana, I. N. (2024). A Digital Instructional Book: A Tool for Improving Students' Learning Outcomes on the Reduction and Oxidation Reactions. *Science Education International*, *35*(1), 61–70. https://doi.org/10.33828/sei.v35.i1.7

Şahin, M. D., & Öztürk, G. (2019). Mixed Method Research: Theoretical Foundations, Designs and Its Use in Educational Research. *International Journal of Contemporary Educational Research*, *6*(2), 301-310. https://doi.org/10.33200/ijcer.574002

Saleh, H., Nopitasari, D., Fadillah, A., Bilda, W., & Haswati, D. (2025). Optimization of Digital Literacy Through STEM-Based Learning. *Prima: Jurnal Pendidikan Matematika*, *9*(1), 16-29. Retrieved from https://jurnal.umt.ac.id/index.php/prima/article/download/12851/5883

Santosa, T. A., Agustina, N., & Yulianti, S. (2020). Jenis Tumbuhan Liar dalam Upacara Adat Kenduri Seko di Kerinci. *Pendekar: Jurnal Pendidikan Berkarakter*, *3*(1), 6–10. Retrieved from http://journal.ummat.ac.id/index.php/pendekar/article/view/2798

Santosa, T. A., & Sepriyani, E. M. (2020). Analisis Masalah Pendidikan Biologi pada Sekolah Menengah Pertama di Era Pandemi Covid-19. *Jurnal Review Pendidikan dan Pengajaran*, *3*(2), 273–278. https://doi.org/10.31004/jrpp.v3i2.1278

Santosa, W. H., & Sudirman, A. (2023). Factors Influencing the Implementation of Cooperative Learning: Elementary School Teacher Education Department Students' Perspectives. *Edunesia: Jurnal Ilmiah Pendidikan*, *4*(3), 1031–1048. https://doi.org/10.51276/edu.v4i3.501

Sawilowsky, S. S. (2009). Very Large and Huge Effect Sizes. *Journal of Modern Applied Statistical Methods*, *8*(2), 597–599. https://doi.org/10.22237/jmasm/1257035100

Siiman, L. A., Cortés, C. M. P., & Pedaste, M. (2014). Digital Literacy for All Through Integrative STEM. *Lecture Notes in Computer Science (Including Subseries Lecture Notes in Artificial Intelligence and Lecture Notes in Bioinformatics)*, *8523 LNCS*(PART 1), 119–127. https://doi.org/10.1007/978-3-319-07482-5_12

Soeswoyo, D. M., Jeneetica, M., Dewi, L., Dewantara, M. H., & Asparini, P. S. (2021). Tourism Potential and Strategy to Develop Competitive Rural Tourism in Indonesia. *International Journal of Applied Sciences in Tourism and Events*, *5*(2), 131–141. https://doi.org/10.31940/ijaste.v5i2.131-141

Suswandari, A. F. (2023). The Effect of Using STEM Learning Models for Students to Improve Digital Literacy Skills in Elementary Schools. *Research and Innovation in Social Science Education Journal (RISSEJ)*, *1*(1), 11–18. https://doi.org/10.30595/rissej.v1i1.114

Swandana, H., Tindangen, M., & Herliani, H. (2023). High School Students' Perceptions About Implementation of the Merdeka Curriculum in Biology Lessons in Samarinda. *Jurnal Penelitian Pendidikan IPA*, *9*(10), 8235–8244. https://doi.org/10.29303/jppipa.v9i10.4585

Sydorenko, V. V., Akhnovska, I. O., Smirnov, S. V., Verbovskyi, I. A., & Melnychuk, O. V. (2024). Improvement of Higher Education: How to Bridge the Digital Divide During the Transformation? *Journal of Education and Learning*, *18*(3), 1001–1014. https://doi.org/10.11591/edulearn.v18i3.21078

Tamur, M., Juandi, D., & Kusumah, Y. S. (2020). The Effectiveness of the Application of Mathematical Software in Indonesia; A Meta-Analysis Study. *International Journal of Instruction*, *13*(4), 867–884. https://doi.org/10.29333/iji.2020.13453a

Utomo, W., Suryono, W., Santosa, T. A., & Agustina, I. (2023). The Effect of STEAM-Based Hybrid Based Learning Model on Students' Critical Thinking Skills. *Jurnal Penelitian Pendidikan IPA*, *9*(9), 742–750. https://doi.org/10.29303/jppipa.v9i9.5147

Widiyatmoko, A., Wulandari, T. D., Darmawan, M. S., & Mayanti, A. N. R. (2025). *Analysis of Pre-Service Teachers' Digital Literacy in Creating STEM-Based Science Learning Tools: Literature Review* (Issue Icei 2024). Atlantis Press SARL. https://doi.org/10.2991/978-2-38476-360-3_110

Zainil, M., Kenedi, A. K., Rahmatina, R., Indrawati, T., & Handrianto, C. (2023). The Influence of a STEM-Based Digital Classroom Learning Model and High-Order Thinking Skills on the 21st-Century Skills of Elementary School Students in Indonesia. *Journal of Education and E-Learning Research*, *10*(1), 29–35. https://doi.org/10.20448/jeelr.v10i1.4336

Zulkifli, Z., Satria, E., Supriyadi, A., & Santosa, T. A. (2022). Meta-Analysis: The Effectiveness of the Integrated STEM Technology Pedagogical Content Knowledge Learning Model on the 21st Century Skills of High School Students in the Science Department. *Psychology, Evaluation, and Technology in Educational Research*, *5*(1), 32–42. https://doi.org/10.33292/petier.v5i1.144

Zulyusri, Z., Santosa, T. A., Festiyed, F., Yerimadesi, Y., Yohandri, Y., Razak, A., & Sofianora, A. (2023). Effectiveness of STEM Learning Based on Design Thinking in Improving Critical Thinking Skills in Science Learning: A Meta-Analysis. *Jurnal Penelitian Pendidikan IPA*, *9*(6), 112–119. https://doi.org/10.29303/jppipa.v9i6.3709