JMPF JURNAL MATERI DAN PEMBELAJARAN FISIKA

Jurnal Materi dan Pembelajaran Fisika
Volume 15, Number 1, pp. 25-32 2025
Website : https://jurnal.uns.ac.id/jmpf

Enhancing Technology Literacy and Creative Thinking through STEAM: A Comparative Study in Junior High Schools

Aulia Silvina Anandita[1*], Ridho Adi Negoro[1], Linda Dwi Astuti[2]
[1] *Physics Education Study Program, Semarang State University, Sekaran Gunungpati Semarang City 50229, Indonesia*
[2] *Physics Education Study Program, Sebelas Maret University, Kentingan Jebres Surakarta City 57126, Indonesia*
*Corresponding Author Email : auliaanandita@mail.unnes.ac.id

Article's Info
Received: 6th, May, 2025
Accepted: 9th, May, 2025
Published: 28th, May, 2025

DOI:
https://doi.org/10.20961/jmpf.v15i1.101905

How to Cite: Anandita, A. S., Negoro, R. A., Astuti, L. D. (2025). Enhancing Technology Literacy and Creative Thinking through STEAM: A Comparative Study in Junior High Schools. *Jurnal Materi dan Pembelajaran Fisika*, 15(1), 25-32

Abstract. This study aims to compare the effectiveness of conventional learning and STEAM-based learning in improving technology literacy and creative thinking skills among junior high school students. The STEAM (Science, Technology, Engineering, Art, and Mathematics) approach, integrated through a Project-Based Learning (PjBL) model, offers an interdisciplinary learning experience that directly supports students' critical thinking and technological literacy in line with 21st-century competencies. Using the Research and Development (R&D) method with the ADDIE model (Analysis, Design, Development, Implementation, Evaluation), the research involved 155 eighth-grade students from SMP N 3 Banguntapan. Two classes were randomly selected: one as the experimental group applying the STEAM-based learning device, and the other as the control group with conventional methods. Quantitative data from pretests and posttests showed a significant improvement in the experimental group's technology literacy (M = 83.96) and creative thinking (M = 73.44) compared to the control group (M = 72.93 and M = 68.62, respectively). These results indicate that the STEAM approach not only enhances conceptual understanding but also fosters active, collaborative, and innovative learning environments. This research supports the integration of STEAM in science education as a strategic response to educational challenges in the digital era.

Keywords: Creative thinking skills, Junior high school, project-based learning, science education, STEAM, technology literacy

INTRODUCTION

The rapid advancement of science and technology in the 21st century has transformed educational paradigms, requiring schools not only to transfer knowledge but also to develop critical skills relevant to global demands. In response to this transformation, educational systems are increasingly focusing on the cultivation of human capital capable of creative problem-solving, technological adaptation, and interdisciplinary collaboration (Goldin, 2015; Beers, 2011). One of the most pressing competencies in this context is Technology and Engineering Literacy (TEL), which encompasses the ability to understand, evaluate, and apply technological knowledge to real-world challenges (National Assessment Governing Board, 2018). TEL represents more than just digital fluency—it involves reasoning within systems, understanding technological impacts, and navigating engineering processes that affect daily life. In this regard, the integration of TEL into school curricula becomes not only desirable but necessary. This competency aligns naturally with the interdisciplinary goals of STEM (Science, Technology, Engineering, and Mathematics) education, which seeks to unify disciplinary knowledge into a more cohesive and application-oriented learning experience. However, STEM alone has been criticized for neglecting the affective and creative dimensions of learning. Therefore, the incorporation of the arts within STEM—resulting in the STEAM approach—has been proposed as a more holistic solution. STEAM fosters critical and creative thinking, collaboration, and communication, which are essential for tackling complex, real-world problems (Yakman & Lee, 2012; Margot & Kettler, 2019; Martin, 2008). Recent global discourse emphasizes that fostering creativity in conjunction with technological competence is a key determinant of future workforce readiness (OECD, 2019).

Nevertheless, while the promise of STEAM is widely acknowledged, the realities within many Indonesian classrooms reveal persistent challenges. Studies indicate that students still exhibit low levels of technology literacy and underdeveloped creative capacities (Lochner, 2013; Gu et al., 2019; Pratama & Rahmadani, 2019). These limitations are rooted not only in the absence of robust curriculum integration but also in the dominant pedagogical practices that emphasize rote memorization and teacher-centered instruction (Sumarni & Kadarwati, 2020; Purwanto & Kurniawan, 2020). Furthermore, national assessments and international benchmarks (such as PISA and TIMSS) show that Indonesian students often struggle with applying scientific and technological concepts in unfamiliar, contextualized situations—suggesting a disconnect between what is taught and what is required in life beyond the classroom (OECD, 2018). Despite some progress, most STEAM implementations in Indonesia have been limited to early childhood or primary education contexts, and often lack rigorous comparative frameworks to evaluate their effectiveness (Salsabila & Nurjanah, 2023; Hikmah et al., 2022). While some efforts have been made to implement STEAM through modular or digital tools, few studies have examined its effectiveness when delivered systematically via Project-Based Learning (PjBL), a model that naturally complements STEAM through hands-on, student-centered, and interdisciplinary engagement (Devina, 2023; Harahap et al., 2021). Despite the growing advocacy for STEAM in global education reform, little is known about its comparative advantage over traditional methods in fostering both technological and creative competencies at the lower secondary level. This highlights a significant gap in the literature, particularly in the Indonesian context where empirical data on middle school implementation is limited and urgently needed to inform instructional reform. Addressing this gap is essential for ensuring that innovation in pedagogy translates into measurable student outcomes in critical 21st-century skills.

In light of the aforementioned issues, this study aims to investigate and compare the effectiveness of STEAM-based learning—integrated with the PjBL model—and conventional instructional methods in improving junior high school students' technology literacy and creative thinking skills. The choice of PjBL as a pedagogical framework is grounded in its capacity to support inquiry, autonomy, and contextual learning—principles that align closely with both STEAM and constructivist educational theory (Honey & Hilton, 2011). Through the adoption of a quasi-experimental design, this research provides evidence-based insights on how integrated learning approaches influence complex skill development in adolescent learners. The expected contribution of this study extends beyond theoretical understanding; it provides practical guidance for educators, curriculum developers, and policymakers who seek to implement effective, engaging, and scalable instructional strategies in science education. By highlighting the comparative strengths of STEAM-PjBL versus conventional approaches, the study contributes to a broader educational reform agenda that prioritizes competency development, creativity, and innovation. Moreover, this research aims to reinforce the discourse on how to systematically embed 21st-century skills into the Indonesian curriculum and create transformative learning environments that prepare students for future societal and professional challenges.

METHOD

This study employs the Research and Development (R&D) method, a systematic approach designed to develop, design, and evaluate the effectiveness of Subject-Specific Pedagogy (SSP) learning tools in the context of science education. The R&D method was selected due to its capacity to produce educational products that are not only innovative but also aligned with the demands of modern education. The primary focus of this study is the implementation of the STEAM (Science, Technology, Engineering, Art, and Mathematics) approach, which is designed to provide students with an integrated, relevant, and engaging learning experience. This method ensures that the developed instructional tools meet feasibility standards while also assessing their effectiveness in enhancing the overall quality of teaching and student learning outcomes.

The ADDIE model serves as the development framework in this research, consisting of five key stages: Analysis, Design, Development, Implementation, and Evaluation. This model was chosen for its flexibility and systematic structure, which supports the continuous and iterative process of educational product development. The ADDIE framework, adapted from Lee and Owens (2004) and illustrated in Figure 1, ensures coherence among the stages—starting from needs analysis, instructional design, product development, classroom implementation, to comprehensive evaluation for refinement. This approach facilitates the comprehensive and targeted development of STEAM-based SSP, thereby improving the quality of science instruction and supporting the acquisition of 21st-century skills.

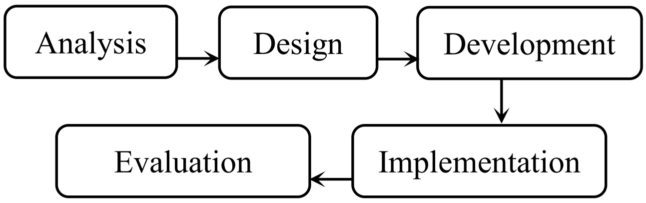

Figure 1. ADDIE Development Procedure Chart

The initial phase of this research began with an analysis aimed at identifying instructional needs and existing problems in the learning process. This stage involved assessing the needs of both students and teachers, as well as evaluating the availability of infrastructure and facilities that support the implementation of STEAM-based learning. To enrich this analysis, interviews were conducted with students and teachers to gather information regarding the challenges encountered in science learning, particularly those related to efforts in improving technology literacy and creative thinking skills. Additionally, this stage was intended to examine relevant core and basic competencies, while also reviewing the adequacy of resources that could support the implementation of STEAM-based Subject-Specific Pedagogy (SSP).

Building upon the insights obtained during the analysis, the design phase focused on developing instructional tools that included the syllabus, lesson plans (RPP), student worksheets (LKPD), and assessment instruments. These tools were crafted based on the STEAM approach and aligned with the 2013 national curriculum. The assessment instruments specifically targeted students' technology literacy and creative thinking skills. The creative thinking skills instrument was designed in essay format with 10 items, each assessing four core indicators: fluency, flexibility, originality, and elaboration (based on Winny & Erna, 2010), rated using a 4-point Likert scale (1 = very poor to 4 = very good). Meanwhile, the Technology and Engineering Literacy (TEL) instrument consisted of 10 multiple-choice items and 5 essay questions, derived and adapted from the NAEP TEL Framework (NAGB, 2018), covering three domains: understanding technological principles, developing solutions, and communicating and collaborating. A student observation sheet was also created to document behavioral indicators aligned with STEAM learning during implementation.

Subsequently, the development phase concentrated on creating a comprehensive set of science learning materials grounded in the STEAM framework. This included assembling a complete SSP product tailored to enhance students' creative and technological competencies. To ensure the validity and quality of the product, it was reviewed by three validators: two university science education lecturers and one middle school science teacher. Constructive feedback was used to revise content, language, and technical elements of the SSP. Validity testing for assessment instruments involved expert judgment to assess content and construct validity, while reliability testing employed Cronbach's alpha for essay-based instruments and KR-20 for multiple-choice tests. Instruments that met the minimum reliability coefficient standard (≥ 0.70) were used in the final implementation phase.

Following the development, the implementation phase was carried out to test the practicality and effectiveness of the STEAM-based SSP in a real classroom environment. A quasi-experimental design was employed using a pretest–posttest with nonequivalent control group structure (Ary et al., 2009). One eighth-grade class (n = 28) was assigned as the experimental group, receiving instruction using the developed STEAM-based SSP, while another class (n = 28) served as the control group, learning through conventional science instruction using the 5M scientific approach. Instruction was conducted over a four-week period, with pretests and posttests administered to measure changes in students' creative thinking and TEL.

Quantitative data were analyzed using descriptive statistics (mean and standard deviation) and inferential statistics. Shapiro–Wilk tests were conducted to assess data normality, and Levene's test was used to assess homogeneity of variance. Independent sample t-tests were applied to compare posttest results between the two groups. To interpret the practical significance of the findings, effect sizes were calculated using Cohen's d. Additionally, qualitative data such as student feedback, validator comments, and observational notes were thematically coded to support quantitative findings.

The final phase of the process, evaluation, focused on analyzing both the implementation outcomes and the overall effectiveness of the developed learning tools. This included a thorough review of quantitative and qualitative data, followed by revisions to the product based on feedback from validators and results of the limited trial. The effectiveness analysis examined the extent to which the STEAM-based SSP improved the targeted competencies. Findings from this evaluation were used as the foundation for further refinement, ensuring the learning tools could be implemented more broadly and effectively in future educational contexts.

The subjects of this study were eighth-grade students from SMP N 3 Banguntapan. A total of 155 students distributed across four classes were considered in the population. Two classes were selected using random sampling to serve as the experimental and control groups. The random assignment helped to reduce selection bias and increase the comparability between the two groups. This design enabled the researchers to rigorously evaluate the impact of the developed SSP on students' creative thinking and TEL through a controlled, school-based intervention.

RESULT AND DISCUSSION

The findings of this study indicate that the integration of the STEAM (Science, Technology, Engineering, Art, and Mathematics) approach into instructional practices is significantly more effective than traditional teaching methods in enhancing junior high school students' technology literacy and creative thinking skills. Post-test scores revealed that students in the experimental group achieved higher averages in both technology literacy (M = 83.96) and creative thinking skills (M = 73.44), compared to those in the control group (M = 72.93 and M = 68.62, respectively). This statistically significant difference can be attributed to the integration of the arts within the STEAM framework, which enriches students' learning experiences through interdisciplinary exploration. The inclusion of the arts not only deepens conceptual understanding in science, technology, engineering, and mathematics (STEM) but also fosters creativity and innovation.

Moreover, the application of Project-Based Learning (PjBL) as the core implementation strategy of STEAM enables students to engage collaboratively in addressing authentic problems. This process promotes active student involvement while simultaneously fostering their skills in identifying, analyzing, and resolving complex challenges. As a result, the STEAM approach establishes a more dynamic, student-centered learning environment that contributes meaningfully to the acquisition of 21st-century competencies.

Recent research by Devina Nindi Sri Sundari (2023) corroborates these findings, demonstrating that the PjBL model embedded within STEAM is effective in enhancing students' creative thinking skills in the context of molecular structure topics. The approach encourages learners to collaboratively explore abstract concepts through project activities grounded in real-world relevance. In the context of physics education, similar implementations can be applied to topics such as Newton's laws, energy, and wave phenomena. Through STEAM, students are not only able to understand theoretical physics concepts but also apply them in innovative projects—such as designing tools based on physical principles or conducting technology-based simulations—thus providing meaningful, contextual learning experiences.

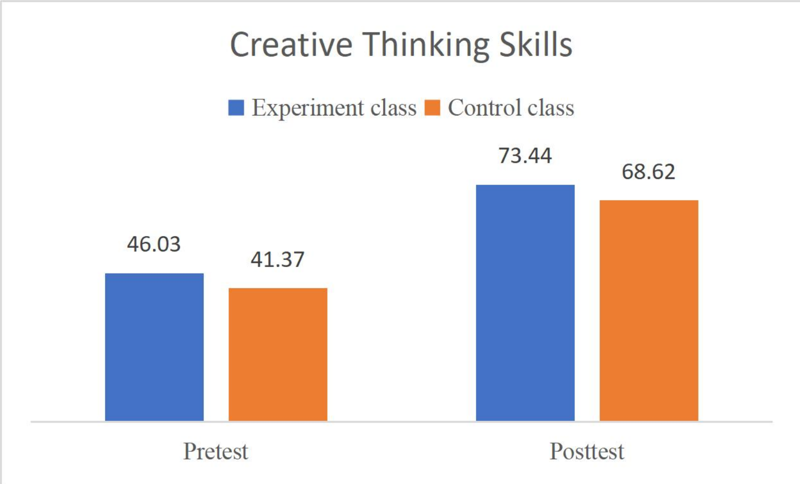

Figure 2. Average Results of Creative Thinking Skills

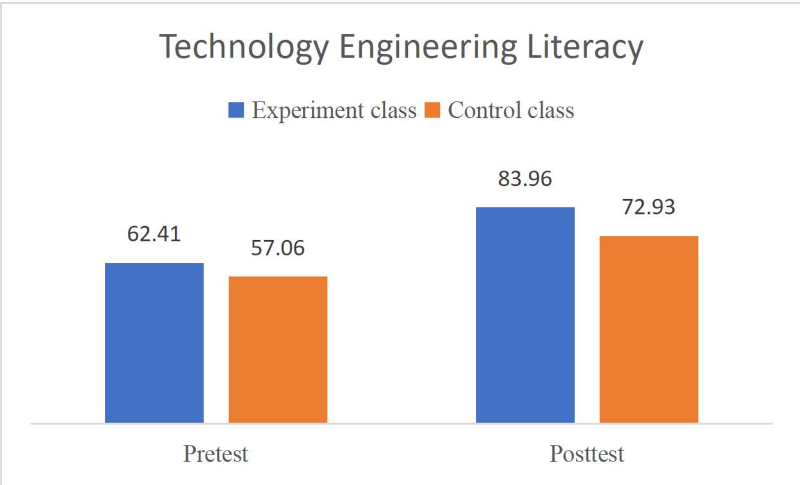

Figure 3. Average Results of Technology Engineering Literacy

Supporting this, a study by Nabila Salsabila and Nurjanah (2023) confirms that STEAM-based instruction significantly impacts creative thinking skills even at the early childhood level. These findings highlight the adaptability and scalability of the STEAM framework across educational stages, including its relevance for secondary-level physics education. In this domain, the integration of technological, artistic, and engineering components can be actualized through creative experimental designs, such as constructing models of Archimedes' principle or developing simulation tools to explore object motion. In essence, STEAM not only facilitates comprehensive conceptual understanding but also cultivates critical thinking, creativity, and problem-solving—skills that are indispensable in addressing contemporary global challenges.

In this study, the STEAM approach incorporated Project-Based Learning (PjBL) as its principal pedagogical strategy to foster student collaboration and innovation in problem-solving. This model enabled students to work independently and actively within groups while also enhancing their capacity to address real-world issues. This aligns with the findings of Muhammad Syahril Harahap et al. (2021), who found that the STEAM approach enhances students' cognitive abilities as well as their mathematical communication skills. Such evidence reinforces the assertion that STEAM offers a rich learning environment conducive to interdisciplinary skill development in the modern era.

Further supporting evidence is provided by Syifaurrahmadania et al. (2024), whose study revealed that interactive STEAM-based modules have a positive impact on students' mathematical literacy. This finding underscores that STEAM's contribution extends beyond creative thinking and technological proficiency, positively influencing literacy in other academic domains. Thus, STEAM presents a holistic instructional solution by integrating multiple dimensions of learning essential for preparing students to navigate complex global landscapes.

In the Indonesian education context, the STEAM approach has also demonstrated significant success. For example, research conducted by Nurul Hikmah et al. (2022) revealed that the use of STEAM-based e-modules and e-student worksheets (e-LKPD) on colloidal systems significantly improved students' cognitive learning outcomes. Such findings provide a strong foundation for educators and policymakers to consider the systemic integration of STEAM as a means to enhance both instructional quality and curriculum relevance in the 21st century.

Despite the demonstrated effectiveness of the STEAM approach, several challenges persist in its implementation. Chief among them is the need for intensive teacher training to ensure educators understand and are able to apply STEAM elements effectively in classroom instruction. Additionally, curriculum development must support the systematic adoption of STEAM across subjects and grade levels. Recent studies emphasize that continuous professional development for teachers is critical to the successful integration of STEAM. With adequate training and institutional support, educators will be better equipped to adopt this innovative approach and improve the overall quality of education.

CONCLUSION

This study confirms that STEAM-based science learning—integrating science, technology, engineering, art, and mathematics—significantly enhances junior high school students' technology and engineering literacy (TEL) and creative thinking skills compared to conventional instruction. The novelty of this research lies in the systematic integration of STEAM within a structured Subject-Specific Pedagogy (SSP), implemented using a project-based learning model tailored for secondary education. The findings contribute empirically to the body of knowledge on 21st-century skill development, particularly in demonstrating the dual effectiveness of STEAM in fostering both technological understanding and creative capacity.

The implementation of STEAM created a more interactive and contextual learning environment, enabling students to explore technological design and problem-solving through collaborative, art-enriched projects. These conditions directly supported the development of critical skills, such as originality, elaboration, and applied technological reasoning. This reinforces the potential of STEAM not only as a pedagogical innovation but also as a strategic response to the growing demand for future-ready competencies.

To optimize impact, educators are advised to adopt STEAM systematically in science instruction by integrating real-world problems, encouraging artistic expression, and emphasizing iterative project development. Schools should provide teacher training on STEAM design principles and allocate time for interdisciplinary planning. Curriculum developers should align learning objectives with STEAM competencies and promote flexible assessment strategies.

For future research, it is recommended to:

- Assess STEAM's influence on other literacies such as digital and environmental literacy across diverse student populations;
- Explore the integration of immersive technologies (e.g., augmented reality, virtual reality) into STEAM modules to deepen learning engagement;
- Conduct longitudinal studies to track sustained effects on student innovation skills and interest in STEM careers;
- Evaluate implementation feasibility in schools with limited resources to ensure equitable access to STEAM benefits.

Overall, the study highlights that STEAM-based learning is not solely a method to improve academic performance, but a transformative approach to nurture learners who are creative, technologically literate, and capable of contributing to innovation in a complex, global society.

REFERENCES

Beers, S. Z. (2011). 21st century skills: Preparing students for THEIR future. *Kappa Delta Pi Record*, 47(3), 121–123. https://doi.org/10.1080/00228958.2011.10516575

Brown, P., Lauder, H., & Ashton, D. (2011). *The global auction: The broken promises of education, jobs, and incomes*. Oxford University Press.

Casner-Lotto, J., Barrington, L., & Wright, M. (2006). Are They Really Ready to Work? Employers' Perspectives on The Basic Knowledge and Applied Skills of New Entrants to The 21st-Century U.S. Workforce. *The Conference Board*.

Darma, Y. (2014). *Literasi: Antara teori dan praktik*. Pustaka Pelajar.

Devina Nindi Sri Sundari. (2023). *Efektivitas model pembelajaran PjBL berbasis STEAM terhadap peningkatan keterampilan berpikir kreatif siswa pada materi bentuk molekul* (Skripsi, Universitas Islam Negeri Syarif Hidayatullah Jakarta). Retrieved from http://repository.uinjkt.ac.id

Du, H., Wang, L., & Lei, L. (2019). Literasi teknologi dalam pembentukan kualitas individu dimoderasi oleh transfer pengetahuan untuk peningkatan kinerja individu guru. *Jurnal Teknologi Pendidikan*, 15(2), 123–135.

Eryansyah, E., Ramadhani, D., & Sari, R. (2019). Peningkatan literasi digital peserta didik: Studi pembelajaran e-learning di SDN 7 Ampenan. *Jurnal Pendidikan Dasar*, 10(2), 45–56.

Goldin, C. (2015). Human capital. In C. Diebolt & M. Haupert (Eds.), *Handbook of cliometrics* (pp. 55–86). https://doi.org/10.1007/978-3-642-40458-0_3

Gu, J., Du, H., & Wang, L. (2019). Technology literacy and engineering literacy: A framework for education development. *Journal of Educational Research*, 32(4), 112–126.

Honey, M., & Hilton, M. (Eds.). (2011). *Learning science through computer games and simulations*. National Academies Press. https://doi.org/10.17226/13078

Kurnia, N., Astuti, S. I., & Suharno, P. (2019). Urgensi literasi digital bagi anak usia dini dan orang tua. *JET: Journal of Education and Technology*, 3(1), 11–20.

Lee, H., & Kim, H. (2014). The effects of STEAM-based science learning on the creative problem-solving abilities of students. *Journal of the Korean Association for Science Education*, 34(2), 135–144. https://doi.org/10.14697/jkase.2014.34.2.135

Lochner, B. (2013). Assessing technology literacy in secondary education: An empirical study on instructional practices. *Educational Technology Journal*, 15(2), 45–59.

Margot, K. C., & Kettler, T. (2019). Teachers' perception of STEM integration and education: A systematic literature review. *International Journal of STEM Education*, 6(1), 2. https://doi.org/10.1186/s40594-018-0151-2

Martin, A. (2008). Digital literacy and the "digital society". In C. Lankshear & M. Knobel (Eds.), *Digital literacies: Concepts, policies and practices* (pp. 151–176). Peter Lang.

Muhammad Syahril Harahap, et al. (2021). Pengaruh STEAM terhadap komunikasi matematis siswa. *Jurnal Pendidikan Matematika*, 19(1), 45–60.

Nabila Salsabila, & Nurjanah. (2023). Pengaruh pendekatan STEAM terhadap kemampuan berpikir kreatif anak usia dini. *Jurnal Pendidikan Anak*, 12(3), 56–70.

National Assessment Governing Board. (2018). *Technology and engineering literacy framework for the 2018 National Assessment of Educational Progress*. Retrieved from https://files.eric.ed.gov/fulltext/ED594359.pdf

Nurul Hikmah, et al. (2022). Penggunaan e-modul dan e-LKPD berbasis STEAM dalam pembelajaran sistem koloid. *Jurnal Sains & Teknologi Pendidikan*, 14(2), 90–110.

OECD. (2018). *Preparing our youth for an inclusive and sustainable world: The OECD PISA global competence framework*. Retrieved from https://www.oecd.org/education/Global-competency-for-an-inclusive-world.pdf

OECD. (2019). *Trends shaping education 2019*. OECD Publishing. https://doi.org/10.1787/trends_edu-2019-en

Payton, S., & Hague, C. (2010). Digital literacy in practice: Case studies of primary and secondary classrooms. *Futurelab*. https://www.nfer.ac.uk/publications/FUTL27/FUTL27.pdf

Pratama, A., & Rahmadani, S. (2019). Profil kemampuan literasi teknologi peserta didik sekolah menengah atas di Kota Bandung. *Jurnal Teknologi Literasi Pendidikan*, 2(1), 15–25.

Purwanto, E., & Kurniawan, A. (2020). Pengaruh literasi digital terhadap hasil belajar mahasiswa. *Jurnal Pendidikan Teknologi Informasi dan Komunikasi*, 12(2), 89–98.

RISTEKDIKTI. (2018). *Peta jalan revolusi industri 4.0 Indonesia*. Kementerian Riset, Teknologi, dan Pendidikan Tinggi.

Rose, M. A. (2007). Literasi teknologi: Pemahaman dan aplikasi dalam pembelajaran sains. *Science Education Journal*, 11(1), 40–50.

Sumarni, W., & Kadarwati, S. (2020). Teacher-centered vs. student-centered learning: Impact on technology literacy in high schools. *International Journal of Educational Studies*, 28(3), 89–105.

Syifaurrahmadania, et al. (2024). Modul interaktif berbasis STEAM dan literasi matematis siswa. *Jurnal Teknologi Pendidikan*, 29(1), 78–92.

Tampubolon, D. (2017). Tantangan literasi digital di Indonesia. *Jurnal Komunikasi Indonesia*, 5(1), 12–20.

Wijaya, T. T., et al. (2015). Project-based learning for technology literacy enhancement: A comparative study. *Journal of Science Education and Technology*, 23(1), 74–89. https://doi.org/10.1007/s10956-014-9521-0

Yakman, G., & Lee, H. (2012). Exploring the exemplary STEAM education in the U.S. as a practical educational framework for Korea. *Journal of the Korean Association for Science Education*, 32(6), 1072–1086. https://doi.org/10.14697/jkase.2012.32.6.1072

.