Jurnal Materi dan Pembelajaran Fisika
Volume 15, Number 2, pp. 66-71 2025
Website : https://jurnal.uns.ac.id/jmpf

Trends in Technology Literacy Research in STEM Education (2021-2025): A Bibliometric Analysis with VOSviewer

Frendi Ihwan Syamsudin[1*], Ketang Wiyono[1], Evelina Astra Patriot[1], Ismet[1], Saparini[1], Azlan Kamari[2]

[1]*Physics Education Study Program, Universitas Sriwijaya, Indralaya, 30662, Indonesia*
[2] *Department of Chemistry, Universiti Pendidikan Sultan Idris, Tanjong Malim, 35900, Malaysia*
*Corresponding Author Email : frendiihwan@fkip.unsri.ac.id

Article's Info
Received: 18th, September, 2025
Accepted: 1st, October, 2025
Published: 30th, November, 2025

DOI:
https://doi.org/10.20961/jmpf.v15i2.109121

How to Cite : Syamsudin, F.I., Wiyono, K., Patriot, E.A., Ismet, I., Saparini, S., & Kamari, A. (2025). Trends in Technology Literacy Research in STEM Education (2021-2025): A Bibliometric Analysis with VOSviewer. *Jurnal Materi dan Pembelajaran Fisika*, 15(2), 66-71

Abstract. Technology literacy is a crucial competency in addressing digital transformation and the challenges of 21st-century learning. This study aims to analyze research trends in technology literacy within the field of education, particularly in STEM learning, through a bibliometric approach using VOSviewer. Data were collected from international publication databases for the period 2021–2025 using the keywords technology literacy, digital literacy, and STEM education. The analysis identified five main research clusters: (1) effects and impacts (effect, impact, relationship), (2) learning contexts and student engagement (student engagement, experience, perception), (3) digital adoption and mechanisms (adoption, tool, competency, mechanism), (4) sustainability and management (sustainability, management, industry), and (5) emerging technological innovations (virtual reality, healthcare, engineering, artificial intelligence). The findings indicate that technology literacy is not only associated with pedagogical practices and student learning in STEM but also extends to sustainability, industry, and advanced technologies. This broader scope highlights the novelty of this study, showing how technology literacy connects education with global technological advancements. The study provides valuable insights for academics and practitioners in developing adaptive and future-oriented learning strategies aligned with educational needs and technological change.

Keywords: technology literacy, bibliometric analysis, VOSviewer, digital learning, research trends

INTRODUCTION

The advancement of digital technology has brought significant changes to the paradigm of 21st-century learning. In this context, technology literacy has become one of the essential skills, not only for students but also for educators and the workforce (Nguyen, 2022). Technology literacy extends beyond the ability to operate digital devices; it also encompasses critical, ethical, and innovative thinking skills in utilizing technology (Hsiao, 2021). These competencies align with the Sustainable Development Goals (SDGs), particularly SDG 4, which emphasizes quality education (UNESCO, 2021).

As the role of technology in education and industry continues to grow, studies on the development of technology literacy have become increasingly important. Bibliometric analysis can be employed to map research trends, conceptual interconnections, and emerging topics (Khine, 2019). Using VOSviewer software, keyword co-occurrence analysis can reveal the structure and dynamics of technology literacy research comprehensively (Van, 2020).

Previous studies have mostly examined technology literacy from a pedagogical perspective, such as students' digital skills, engagement in learning, and the adoption of digital tools (Quigley, 2020; Widya, 2019). However, research exploring the broader landscape of technology literacy, including its relevance to sustainability, industry, and the integration of advanced technologies such as artificial intelligence and virtual reality remains limited (Olivato, 2023; Syamsudin, 2023). In addition, regional studies in Southeast Asia highlight that challenges such as unequal access, limited teacher readiness, and policy implementation gaps significantly affect the development of technology literacy (Suwarto, 2022; Rahman, 2023). These findings indicate the need for research that not only captures global trends but also connects with regional educational contexts.

The urgency of this study also lies in its alignment with digital education policies that are being widely promoted worldwide, including in developing countries. Strengthening technology literacy research can provide evidence-based insights to support the design and implementation of digital learning policies that respond to rapid technological change (ASEAN, 2022; Kemendikbudristek, 2023).

This study seeks to fill this gap by analyzing recent international publications (2021 to 2025) to identify the main clusters in technology literacy research. The novelty of this study lies in its more comprehensive bibliometric mapping, which not only highlights pedagogical implications but also demonstrates the expansion of research into sustainability, industry, and advanced technologies. Thus, this study is expected to provide valuable insights for academics and practitioners in developing adaptive learning strategies in response to global digital transformation.

METHOD

This study employed a bibliometric approach combined with qualitative analysis of scientific publication metadata. This approach was chosen as it enables the mapping of research trends, the identification of conceptual relationships, and the clustering of research domains through keyword co-occurrence network visualizations using VOSviewer software (Van, 2020).

The research data were collected from the Springer database, one of the major international repositories of scholarly publications that includes journal articles, conference proceedings, and indexed academic books. The data retrieval covered the period from 2021 to 2025, using three main keywords: "technology literacy," "digital literacy," and "STEM". Searches were conducted through Springer's advanced search feature with Boolean operators (AND/OR) to ensure specificity and accuracy.

The data collection procedure involved four steps: (1) defining the publication period 2021 to 2025, (2) entering the selected keywords into the Springer, (3) filtering the results by selecting relevant articles and book chapters related to technology literacy, and (4) exporting the metadata (title, authors, year, keywords, DOI, abstract, and references) in RIS format for analysis in VOSviewer. The initial search yielded 1,042 publications. After applying inclusion and exclusion criteria such as including only peer-reviewed journal articles and book chapters directly related to technology literacy in education or STEM, while excluding editorials, non-academic reports, and duplicate records a total of 312 publications were retained for analysis.

Data analysis was conducted using VOSviewer. The exported metadata were imported into the software and analyzed using the keyword technique with a minimum threshold of five occurrences. The results were visualized in three formats: network visualization to examine the interconnections among keywords, overlay visualization to trace research trends by publication year, and density visualization to identify dominant keywords. Subsequently, related keywords were grouped into clusters, serving as the basis for identifying the main themes of technology literacy research during the 2021 to 2025 period.

RESULT AND DISCUSSION

Result

The results of the VOSviewer visualization analysis are presented in Figure 1.

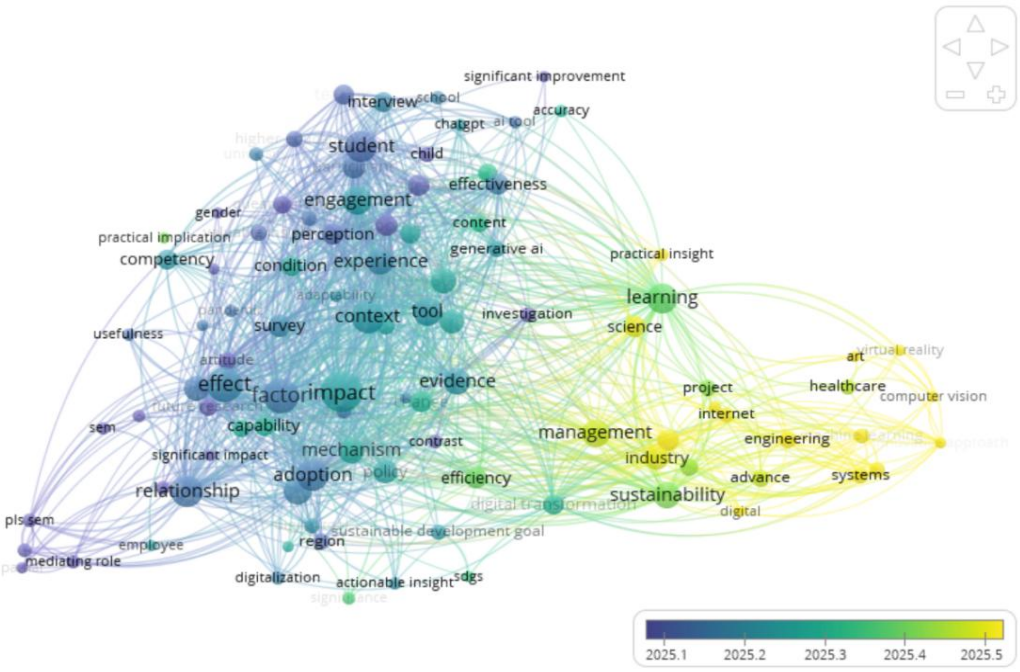

Figure 1. VOSviewer visualization results

Figure 1 presents the bibliometric mapping of technology literacy research generated using VOSviewer. The visualization displays five major clusters represented by different colors, where each node corresponds to a keyword, and the size of the node reflects its frequency of occurrence. The proximity of nodes indicates the strength of co-occurrence between keywords, allowing the identification of conceptual relationships within the research landscape. For readers less familiar with bibliometric mapping, it is important to note that larger nodes represent more frequently used keywords, while thicker connecting lines indicate stronger associations.

Based on the analysis, five main clusters were identified and are summarized in Table 1, which reports the dominant keywords and their frequency of occurrence. The clusters are discussed in order of prominence, starting with the largest cluster:

1. Blue Cluster (Effects and Relationships, 105 keywords): Focuses on effect, impact, relationship, adoption, and competency, highlighting studies on the impact of technology literacy on learning, skills, and digital adoption.
2. Green Cluster (Learning Context, 87 keywords): Consists of student, engagement, experience, perception, tool, and context, emphasizing the importance of student experiences and digital-based pedagogical strategies.
3. Yellow Cluster (Sustainability and Industry, 56 keywords): Includes sustainability, management, industry, and project, reflecting the growing link between technology literacy and sustainable development.
4. Purple Cluster (Methodology and Analysis, 42 keywords): Related to survey, SEM, PLS-SEM, and adoption mechanism, pointing to the quantitative methods frequently used in measuring technology literacy.

5. Orange Cluster (Advanced Technological Innovation, 38 keywords): Covers virtual reality, healthcare, artificial intelligence, engineering, and computer vision, indicating the shift of technology literacy toward the integration of advanced technologies in education and industry.

The summarize of technology literacy clusters are shown in Table 1.

Table 1. Summary of Technology Literacy Clusters

Cluster	Dominant Keywords	Frequency	Main Theme
Blue	effect, impact, relationship, adoption, competency	105	Effects and Relationships
Green	student, engagement, experience, perception, context	87	Learning Context
Yellow	sustainability, management, industry, project	56	Sustainability and Industry
Purple	survey, SEM, PLS-SEM, adoption mechanism	42	Methodology and Analysis
Orange	virtual reality, healthcare, AI, engineering, computer	38	Technological Innovation

Discussion

The findings of this study highlight two dominant directions in technology literacy research during 2021–2025: (1) its growing integration with sustainability and management, and (2) its expansion into advanced technological innovations such as artificial intelligence, virtual reality, and healthcare applications. These themes represent a significant shift from earlier pedagogical perspectives, showing that technology literacy is increasingly positioned as both an educational and socio-industrial competence aligned with global digital transformation and the Sustainable Development Goals (SDGs). By foregrounding these trends, this study underscores the urgency of rethinking curricula and educational policies to accommodate broader dimensions of technology literacy.

The trend of technology literacy has evolved from basic digital skills toward the integration of advanced technologies that align with the demands of Industry 4.0. Technology literacy is no longer understood merely as technical proficiency but has become a crucial prerequisite for fostering active, collaborative, and innovative learning. This aligns with Quigley et al. (2020), who emphasized the significance of technology literacy in STEM education to support complex problem-solving. Similarly, Khine and Areepattamannil (2019) highlighted that digital literacy significantly contributes to the development of 21st-century competencies such as critical thinking, collaboration, and creativity. More recently, Tene et al. (2024) demonstrated that the integration of immersive technologies such as virtual reality in education can enhance student motivation and engagement.

A bibliometric analysis using VOSviewer for the period 2021–2025 identified five major clusters of technology literacy research. Among these, the sustainability and industry cluster and the advanced technological innovation cluster are particularly noteworthy, as they reflect the broader relevance of technology literacy beyond education. The sustainability and management cluster reflects a growing orientation of technology literacy toward addressing global challenges. UNESCO (2021) stressed that digital literacy must be linked to sustainability and the SDGs to promote inclusive and equitable education. In line with this, Sormunen et al. (2022) highlighted the strategic role of technology literacy in building environmental awareness through sustainable digital practices. Consequently, technology literacy is now positioned as a vital foundation not only for education but also for strengthening industrial competitiveness and supporting the transition to a green economy.

The emerging technological innovations cluster demonstrates the expansion of technology literacy into domains such as artificial intelligence, virtual reality, healthcare, and engineering. Bekteshi and Barleti (2025) reported that the integration of AI and immersive technologies has a positive impact on learning experiences, retention, and conceptual understanding. Likewise, Huang et al. (2023) showed that AI-driven learning enhances personalization and educational efficiency. This indicates a paradigm shift in technology literacy research, where advanced technologies are no longer peripheral but central to shaping both educational and industrial futures.

The other three clusters serve as important supporting contexts for these transformations. The effects and relationships cluster emphasizes the role of technology literacy in enhancing digital competence and learning effectiveness. This finding is consistent with Redecker (2020), who

underscored digital literacy as a key factor in supporting lifelong learning, and with Aesaert et al. (2021), who noted its close relationship with academic achievement and employability. The learning context and student engagement cluster highlights how meaningful digital learning experiences foster reflective and collaborative learning (Bond et al., 2021; Herro et al., 2019). Meanwhile, the digital adoption and mechanisms cluster focuses on implementation processes, stressing that institutional readiness and user competence are critical for sustainable technology integration (Ifenthaler & Schweinbenz, 2019; Kimmons, 2020).

Taken together, these clusters reveal that while pedagogical perspectives remain essential, the most transformative contributions of technology literacy research now emerge from its alignment with sustainability agendas and its integration with advanced technologies. The implications of these trends underscore the urgent need for comprehensive educational transformation, focusing not only on basic technical skills but also on cultivating 21st-century competencies such as critical thinking, creativity, collaboration, and sustainability awareness. The integration of advanced technologies such as AI, VR, and big data requires adaptive, inclusive, and industry-relevant curricula and teaching strategies, while simultaneously supporting global agendas such as the SDGs (Quigley et al., 2020; Syamsudin, 2020; Huang et al., 2023). This highlights the pivotal role of educational institutions in providing infrastructure, training, and policy support to ensure effective technology adoption (Ifenthaler, 2019; Kimmons, 2020; Syamsudin, 2022). Accordingly, technology literacy should be viewed not only as an individual competence but also as a collective strategy to enhance educational quality, graduate competitiveness, and contributions to sustainable development.

CONCLUSION

This study shows that technology literacy has shifted from basic digital skills to the integration of advanced technologies that align with Industry 4.0 and global agendas. Through a bibliometric analysis of the 2021–2025 period, five main clusters were identified: influence and impact, learning context and student engagement, digital adoption and mechanisms, sustainability and management, and technological innovation. The findings highlight that technology literacy is crucial for building 21st-century skills, improving learning effectiveness, enhancing employability, and supporting sustainable education, while the integration of artificial intelligence, virtual reality, and other advanced technologies demonstrates its growing role across sectors. Overall, technology literacy serves as a strategic foundation for educational transformation and sustainable development, and future research could investigate its implementation in diverse educational contexts or complement bibliometric results with qualitative studies.

ACKNOWLEDGMENTS

The authors would like to express their sincere gratitude to Universitas Sriwijaya for providing the opportunity and support to conduct this research through the Independent Research Program.

REFERENCES

Aesaert, K., Voogt, J., Kuiper, E., & van Braak, J. (2021). Accuracy and bias of ICT self-efficacy: An empirical study into students' over- and underestimation of their ICT competences. *Computers in Human Behavior*, 122, 106835. https://doi.org/10.1016/j.chb.2021.106835

Bond, M., Buntins, K., Bedenlier, S., Zawacki-Richter, O., & Kerres, M. (2021). Mapping research in student engagement and educational technology in higher education: A systematic evidence map. *International Journal of Educational Technology in Higher Education*, 18(1), 1–30. https://doi.org/10.1186/s41239-021-00260-3

Herro, D., Quigley, C., Andrews, J., & Delacruz, G. (2019). Co-Measure: Developing an assessment for student collaboration in STEAM activities. *International Journal of STEM Education*, 6(1), 1–12. https://doi.org/10.1186/s40594-019-0180-5

Hsiao, C. H., & Su, Y. S. (2021). Exploring the critical factors influencing students' technology literacy. *Computers & Education*, 166, 104154. https://doi.org/10.1016/j.compedu.2021.104154

Huang, R. H., Liu, D. J., Tlili, A., Knyazeva, S., Chang, T. W., Zhang, X., & Burgos, D. (2023). *Artificial Intelligence in Education: Guidance for Policy Makers*. UNESCO Publishing.

Ifenthaler, D., & Schweinbenz, V. (2019). Teachers' perspectives on digital media and digital games for learning in higher education. *Technology, Knowledge and Learning*, 24, 39–55. https://doi.org/10.1007/s10758-017-9349-9

Khine, M. S., & Areepattamannil, S. (2019). *Digital literacy: Concepts, methodologies, tools, and applications*. Springer. https://doi.org/10.1007/978-981-13-7177-0

Kimmons, R. (2020). Current trends (and missing links) in educational technology research and practice. *TechTrends*, 64(4), 508–510. https://doi.org/10.1007/s11528-020-00519-3

Nguyen, T., Netto, C. L. M., Wilkins, J. F., Bröker, P., Vargas, E. E., Sealfon, C. D., & Puthipiroj, P. (2022). Impacts of digital transformation on higher education: Technology literacy as a key competence. *Education and Information Technologies*, 27(5), 6051–6068. https://doi.org/10.1007/s10639-021-10863-z

Olivato, A., & Silva, J. (2023). Digital literacy and technology integration in higher education: Challenges and opportunities. *Journal of Education and Information Technologies*, 28(4), 5123–5142. https://doi.org/10.1007/s10639-023-11891-4

Quigley, C. F., Herro, D., & Jamil, F. (2020). Developing a conceptual framework for STEAM teaching practices. *International Journal of STEM Education*, 7(1), 1–11. https://doi.org/10.1186/s40594-020-00221-8

Redecker, C. (2020). *European framework for the digital competence of educators: DigCompEdu*. Joint Research Centre (JRC).

Sormunen, E., Heinonen, J., & Mikkonen, I. (2022). Digital literacy for sustainability: Teachers as facilitators of students' critical engagement with digital technologies. *Education and Information Technologies*, 27(6), 8021–8044. https://doi.org/10.1007/s10639-022-10939-5

Syamsudin, F. I., Budiharti, R., & Pujayanto, P. (2020). Pengembangan perangkat pembelajaran eksperimen listrik statis berbasis inkuiri terbimbing dengan PhET Colorado untuk mahasiswa. Jurnal Materi dan Pembelajaran Fisika, 10(2), 68–75. https://doi.org/10.20961/jmpf.v10i2.43132

Syamsudin, F. I., Sukarmin, S., & Sarwanto, S. (2022). Adapting of virtual learning during COVID 19 pandemic: Development of e modules based STEM EDP on dynamic fluids teaching to improve student creative thinking skills. Specialusis Ugdymas, 1(43), 2716–2733.

Syamsudin, F. I., Sukarmin, S., & Sarwanto, S. (2023). Effectiveness PhET Colorado in virtual physics learning experiments during the COVID 19 pandemic: A systematic review based on the five stages framework. *In Proceedings of the 3rd International Conference on Science Education and Technology (ISET 2023, Vol. 2751, Issue 1, Article 040002)*. American Institute of Physics. https://doi.org/10.1063/5.0143199

Tene, T., Tixi, J. A. M., Palacios Robalino, M. de L., Salazar, M. J. M., Vacacela Gomez, C., & Bellucci, S. (2024). Integrating immersive technologies with STEM education: A systematic review. *Frontiers in Education*, 9, 1410163. https://doi.org/10.3389/feduc.2024.1410163

UNESCO. (2021). *Reimagining our futures together: A new social contract for education*. UNESCO Publishing. https://unesdoc.unesco.org/ark:/48223/pf0000379707

Van, N. J., & Waltman, L. (2020). *VOSviewer manual*. Leiden University. https://www.vosviewer.com/documentation/Manual_VOSviewer_1.6.16.pdf

Widya, R., Rifandi, R., & Rahmi, L. (2019). Digital literacy of pre-service teachers in mathematics education: A case study. *Infinity Journal*, 8(1), 11–20. https://doi.org/10.22460/infinity.v8i1.1231