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Proceeding of International Conference on Islamic Education And Science Development (4th ICONSIDE)
Vol. 4 No. 1 (2026) 52 – 79 | E-ISSN: 3064-2310
Mataram, 10th – 11th June 2026

Technological literacy: Concept, assessment, and impact for physics learning in senior high school

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Abstract. *The main problem of this research is that the concept, assessment, and impact of technological literacy in physics learning have not been properly measured. The research aimed to examine the concept, dimensions, and the impact of technological literacy in physics at senior high school. The research method used is a Systematic Literature Review (SLR) with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) method. A total of 20,223 publications were identified, and 71 were included as journal samples in the SLR. Result defined technological literacy is the ability to access, understand, evaluate, use, and engineer technology. The assessment framework is divided into three dimensions: Technological Knowledge, Technological Capability, and Technological Ethics. The assessment indicators are divided into eight categories: Technology and Society, Technological Concept, Technological Analysis and Evaluation, Technology Procedural, Design, Maintenance and Troubleshooting, Technological Interest, Technological Value, Technological Ethics, Equity, and Responsibility. The context of physics-related technology is divided into seven categories: Medical, Agricultural and Biotechnology, Energy and Power, Information and Communication, Transportation, Manufacturing, and Construction. Technological literacy impacts teachers' ability to integrate technology into learning. Technological literacy also helps students develop a deeper understanding of technology, including its mechanisms, functions, social impacts, and broader implications.*

Keywords: Technological Literacy, Assessment, Physics Learning

INTRODUCTION

Physics learning emphasizes mastery of fundamental concepts and focuses on critical thinking, problem-solving, and technological proficiency as part of 21st-century competencies (Ellermeijer and Tran 2020; Greczyło 2023; Ellermeijer and Tran 2019; Theodorio, Mataka, and Shambare 2024; Martinez 2022; Ubaidillah et al. 2023). In this context, technological literacy has become essential for students to master in order to face increasingly complex contemporary challenges (Lestari and Santoso 2019; Doyle and Devon 2010; Santoso and Lestari 2019). Technological literacy encompasses the ability to use technological devices and an understanding of their working principles, social impacts, and design processes (ITEA 2007; Ghahfarokhi 2025; Korkeaniemi, Lindfors, and Kiviranta 2025). Therefore, educators must design learning experiences that train students' technological literacy through contextual approaches.

Physical technology is not limited to use in the learning process, but also includes the application of its laws and theories. Physics is inseparable from technological applications, as many implementations of physical laws and theories take the form of technology. Teachers have generally incorporated technological literacy into physics learning, for example, by linking the concept of an airplane as a technological application of Bernoulli's principle. Students' abilities should be measured based on their understanding of physics concepts in technological contexts; in other words, students' technological literacy needs to be assessed within the physics learning process. The implementation of technological literacy should be practiced and evaluated through valid assessments so that teachers and policymakers can determine the extent to which students' technological literacy skills have truly developed.

The lack of measurement of technological literacy is primarily due to the unavailability of valid and reliable assessment instruments (Pearson and Garmire 2006; Avsec and Jamšek 2015). In many cases, teachers have unconsciously implemented technological literacy in their teaching, such as linking physics theories and laws to their applications in technology during assessments; however, they have not explicitly assessed technological literacy (Bledsoe and Pilgrim 2013; Baek and Sung 2020; Deyoe, Newman, and Asaro-Saddler 2014). This issue results in a misalignment between teaching and assessment, causing learning objectives to be evaluated inconsistently with the actual learning outcomes (Krupczak et al. 2009). Several factors contribute to the absence of such measurements, including the perception that methods for assessing technological literacy are too complex, discouraging teachers from conducting such assessments (Avsec and Jamšek 2016).

Technological literacy can be measured using written tests adapted to several indicators from each dimension of technological literacy. This assessment aims to evaluate the extent to which students understand technological concepts, can assess their impacts, and demonstrate attitudes and skills in using and designing technology responsibly (Gu, Xu, and Hong 2019; Heywood 2023; Julia and Isrokatun 2019). Several dimensions and indicators have been developed in previous studies to measure students' technological literacy in general; however, no dimensions or indicators have been specifically designed to assess technological literacy in the context of physics subject matter. In this article, the authors analyse and synthesize technological literacy dimensions to enable teachers to assess technological literacy in physics learning effectively.

The concept of technological literacy at the senior high school level needs to be examined to facilitate teachers in effectively implementing instruction and assessing technological literacy. Teachers are required not only to master the subject matter but also to possess a deep understanding of technological literacy (Walach 2012; Deyoe, Newman, and Asaro-Saddler 2014; Korkeaniemi, Lindfors, and Kiviranta 2025). The core concept of technological literacy in high schools has not been clearly defined. It is not yet structured within the curriculum, resulting in technological literacy instruction often proceeding without measurable direction, making it difficult to determine how students truly master its essential aspects (Dakers 2016; Davies 2011; Mina et al. 2010). This is especially relevant in physics education, where applying physics concepts and theories can take the form of technology. Understanding, applying, and evaluating technology is crucial in physics learning so that students can meaningfully connect lessons to real-life contexts (Prahani and Dawana 2025; Kade et al. 2024; Muhammadova and Fayzieva 2025). A comprehensive examination of technological literacy must consider several factors, such as students' abilities and teachers' competencies. Therefore, the development and assessment of technological literacy should be carefully designed to avoid gaps that may impact students' overall learning achievement.

A comprehensive research is needed on the frameworks, instruments, and assessment practices of technological literacy in physics education to analyse this issue. The authors will identify instrument models to measure technological literacy and synthesize the developed indicators in this article. The article will also discuss the importance of technological literacy in the physics learning process and review the components that influence it. This research aims to formulate a conceptual framework of technological literacy relevant to physics learning at the senior high school level and synthesize the dimensions of technological literacy suitable for application in physics education. The findings of this research are expected to contribute to the development of the concept of technological literacy in education, particularly in the discipline of physics, and to strengthen the theoretical foundation for further research in this field. Practically, this research will benefit teachers as a reference in designing physics learning strategies based on technological literacy; for students, the findings can foster the development of critical, analytical, and adaptive thinking skills toward technological advancements; and in the broader context of physics education, this research can help design more relevant, contextual, and measurable approaches aligned with the demands of 21st-century education.

METHOD

This research is qualitative in nature, employing a literature research approach to gain an in-depth understanding of the framework for assessing technological literacy in the context of physics education. The literature review focuses on the fundamental concepts, components, and assessment of technological literacy directly related to physics learning at the secondary education level. The research process was conducted using the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) model of systematic literature review. (Asar et al. 2016; Mishra and Mishra 2023; Mateo 2020).

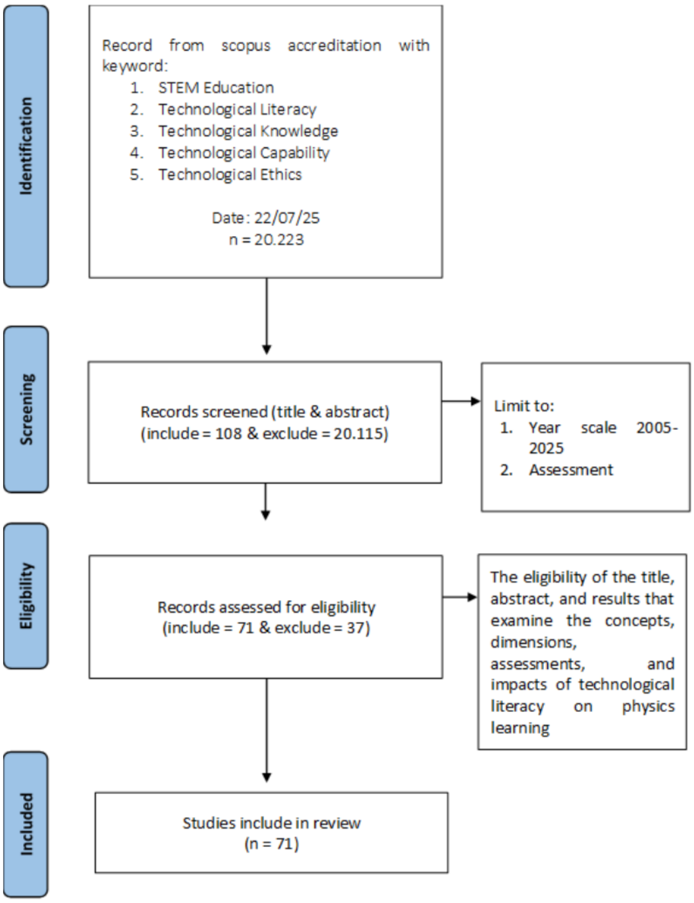

Figure 1. PRISMA Schematic

This research focuses on identifying technological literacy in STEM education, the role of technological literacy in physics learning, the dimensions of technological literacy assessment, and the impact of technological literacy on physics education in senior high schools. A literature review is employed within the context of education, particularly when discussing topics such as technological literacy, which continues to evolve and is influenced by technological trends and educational policies. Through the literature review, researchers can analyse various approaches and assessment indicators of technological literacy from different countries or educational systems and adapt them to the context of physics learning. This is a valuable theoretical basis for developing more contextual and applicable instruments or policies for assessing technological literacy.

Figure 1 illustrates the PRISMA stages, beginning with the identification phase, in which we used a combination of keywords: STEM Education, Technological Literacy, Technological Knowledge, Technological Capability, and Technological Ethics with a publication range from 2004 to 2026. This search yielded a total of 20,223 documents. The screening stage was carried out by limiting the content to technological literacy and assessment, and narrowing the publication years to 2005–2025. The screening results showed that 108 documents were included, while 20,115 were excluded. The eligibility stage focused on articles explicitly examining the concepts, dimensions, assessment methods, and impacts of technological literacy in physics education. 71 documents were deemed eligible from this stage, while 37 were excluded for not meeting the established criteria. Finally, in the inclusion stage, 71 documents were selected for in-depth analysis in the literature review.

RESULT AND DISCUSSION

Technological Literacy Trends

Research on technological literacy has been widely conducted across various topics. The authors present 71 research articles from the past 20 years that describe the implementation of technological literacy in education. These articles focus on STEM Education, Technological Literacy Concept, assessment of technological literacy in physics learning, and the impact of technological literacy. Over the past two decades, research on technological literacy peaked in 2010 and rose again in 2024. This concentration suggests that these years represent critical points in the development of technological literacy research, likely driven by prevailing educational priorities. Between 2010 and 2024, studies on technological literacy experienced a significant decline. The analysis indicates that technological literacy research gained popularity in 2010, decreased in subsequent years, and rose sharply again in 2024 and 2025—an era in which technological literacy needs to be re-emphasized. The results of this analysis are presented in Figure 1.

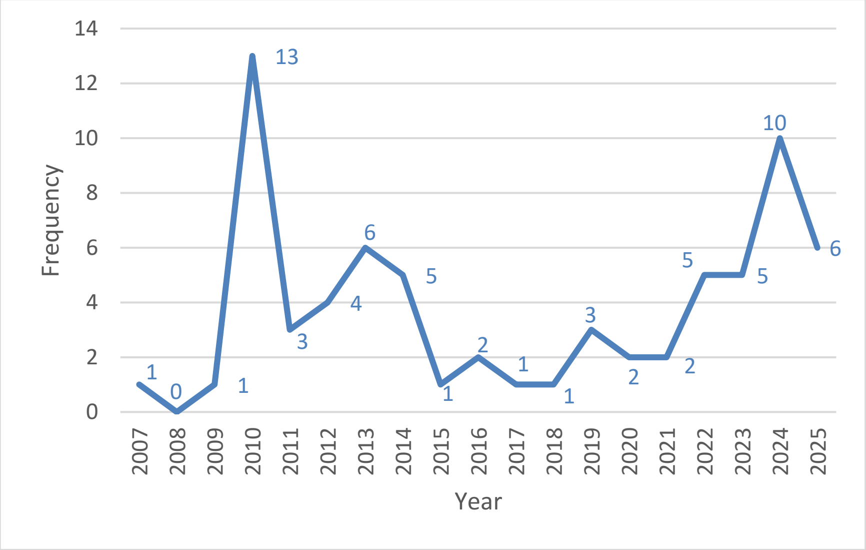

Figure 2. The year of publication

Our literature review found differences in research topics between technological literacy articles published in 2010 and 2025. The most significant difference lies in the main research domain. In 2010, article topics focused on technology in general and the concept of technology, such as the influence of technology on political and economic systems, which required ethical competence toward technology to evaluate these issues critically, referred to as technological literacy. In 2024–2025, articles focused on digital technology, such as using virtual laboratories to enhance students' technological literacy. This shift in the utilization of technology is driven by the fact that digital transformation has become a key driver of innovation across various sectors, including education, business, healthcare, and construction. (Gerster 2017; Liu et al. 2022; Gomez-Cruz, Montes, and Anzola 2022; Patil, Nayaka, and Scholar 2024).

Research on technological literacy has been conducted in various countries. Analysis of 71 articles shows that 24 countries have directly contributed to technological literacy research. The USA dominates the number of publications in this field, with around 28 articles. This figure far exceeds that of other countries and reflects the high academic attention and research investment in technological literacy in the USA. This may be influenced by advancements in education and technology in the country, making technology a priority in learning. Several countries, such as Germany, Indonesia, China, and Nigeria, have also shown considerable interest, each producing around 4 to 6 publications. The presence of publications from these countries indicates that the issue of technological literacy is becoming a focus in various regions of the world, both in developed and developing nations. The results of the analysis are presented in Figure 3.

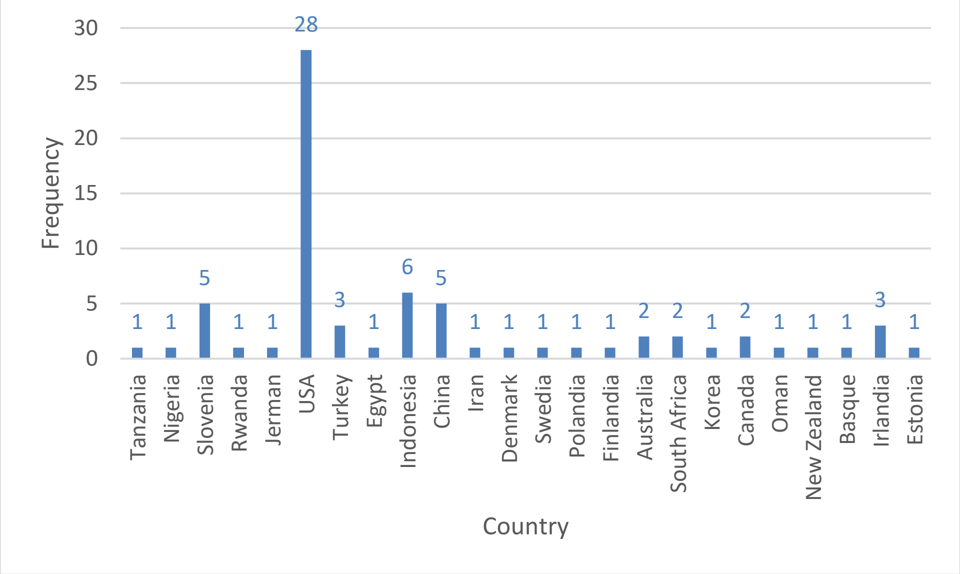

Figure 3. The Countries of Publication

The research articles were conducted across various disciplinary topics. Based on the analysis of 71 articles, the authors classified all articles into seven research topics, as shown in Figure 3. The most frequently studied topic is Implementation of Technological Literacy, with 33 out of 71 publications. This figure indicates that researchers' main focus is on how technological literacy is applied in educational contexts, including strategies, policies, and practices in the field. The dominance of this topic reflects the urgency to understand the practical implementation of technological literacy in addressing the challenges of 21st-century education. Meanwhile, Technological Literacy in STEM Education and Dimensions of Technological Literacy each account for only three articles, indicating that there is still limited research specifically addressing the integration of technological literacy within the STEM context or exploring its conceptual dimensions.

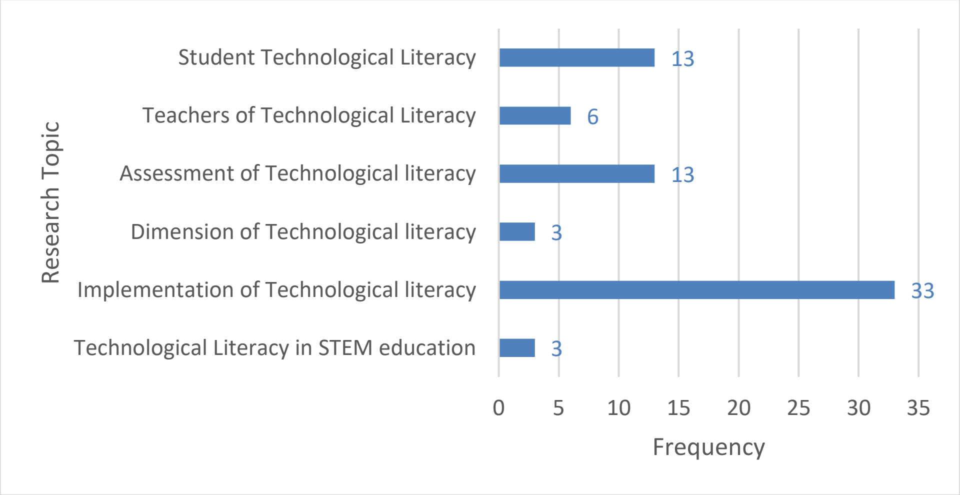

Figure 4. The Topic of Publication

From the perspective of research approaches, the data show that most studies on technological literacy employ qualitative methods, with 54 out of 71 articles. This dominance of qualitative approaches suggests that research in this field focuses more on in-depth exploration of phenomena, understanding social contexts, behaviors, and individual or group perceptions of technological literacy. Only 12 articles used quantitative methods, emphasizing measurement, statistical analysis, and broader data generalization. Meanwhile, five other articles adopted a mixed methods approach, combining quantitative and qualitative techniques. The results of the analysis are presented in Figure 4.

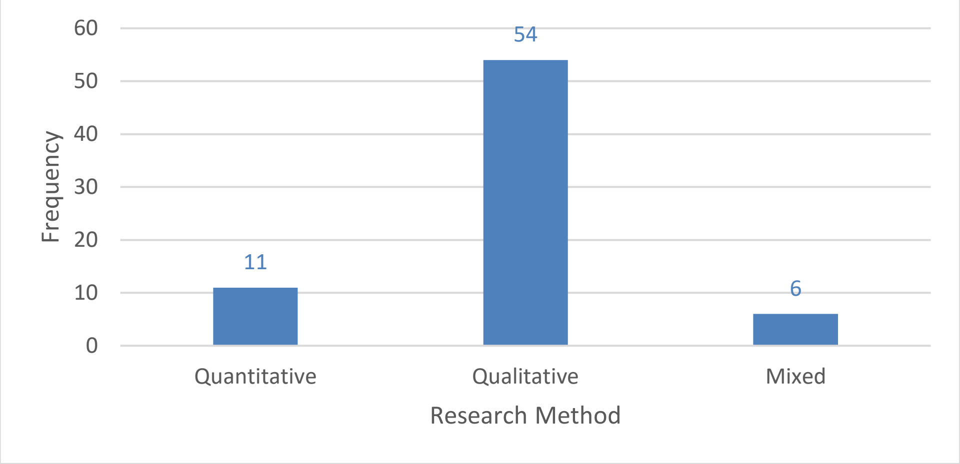

Figure 5. The Methods of Publication

The results of the literature research indicate that research topics focus on implementing technological literacy. Implementing technological literacy refers to how technological literacy skills are applied within and outside educational contexts. The review of research approaches shows that qualitative research is more dominant than quantitative or mixed methods. The qualitative methods used generally involve discussing and synthesizing journal articles on specific topics, such as the importance of technological literacy for teachers. Most qualitative studies were conducted using the systematic literature review method on certain topics. In quantitative studies, all articles examined the influence of technological literacy on certain skills. These studies generally fell into the category of experimental research, comparing experimental and control classes. The instruments used were primarily technological literacy, either in the form of tests or surveys previously developed by other researchers. Meanwhile, mixed methods studies focused on the research and development of technological literacy instruments based on previously established dimensions. Overall, the dominance of qualitative approaches indicates that technological literacy is still largely understood as a contextual social and pedagogical phenomenon requiring in-depth and interpretive approaches in its research. However, in the future, more quantitative and mixed methods studies are needed to obtain more diverse and comprehensive data to support evidence-based policymaking.

Technological Literacy Dimension

A total of 71 articles from Scopus were analyzed in this research. These articles contain definitions of technological literacy that we synthesized to develop a concept of technological literacy suitable for physics education. The authors compiled several definitions of technological literacy that serve as a foundation aligned with technological literacy in physics learning (Table 1).

Table 1. Definition of Technological Literacy

No	Definition	References
1	Technological literacy is understanding, interpreting, analyzing, and evaluating technology comprehensively.	(W. R. Loendorf, Geyer, and Richter 2013; Wells 2013; Madigan, Goodfellow, and Stone 2007; Shachak et al. 2024; Shannaq et al. 2025; Mawson 2013; Plaza et al. 2024; Heywood 2024; Hamka et al. 2024; Heywood 2014; Cortés and Cortés 2014; W. R. Loendorf and Durfee 2014; Mina et al. 2010; Krupczak et al. 2009; Avsec and Jamšek 2018)
2	Technological literacy is the ability to use	(Hasse 2017; Park 2022; Shachak et al.

No	Definition	References
	technology effectively (i.e., any tools, equipment, or devices, whether electronic or mechanical) to accomplish required learning tasks.	2024; Abdon, William, and Tandika 2023; Banda and Nzabahimana 2021; Bengel and Peter 2024; Durak 2021; El Nagdi and Roehrig 2022; Fahmi et al. 2024; Gao et al. 2020; Hong et al. 2012; Kelley and Knowles 2016; Kirtley 2012; Korkeaniemi, Lindfors, and Kiviranta 2025; Lin and Wong 2024; Öztürk, Yiğit, and Karaduman 2012; Qazi et al. 2022; Saputra et al. 2025; Begen and Atasoy 2024; Heywood 2023; Roberts and Kruse 2023b; Mina 2022; Cheville and Heywood 2022; Doyle and Devon 2010)
3	Technological literacy is students' perception of and interest in the impacts of technology.	(Ingerman and Collier-Reed 2011; Rupnik and Avsec 2019; 2020; Mei, Bodog, and Badulescu 2024; Walach 2012; Avsec and Jamšek 2015; Gu, Xu, and Hong 2019)
4	Technological literacy is using, managing, evaluating, and understanding technology.	(Gu, Xu, and Hong 2019; Davies 2011; Luckay and Collier-Reed 2014; Avsec and Kocijancic 2014; Herman et al. 2019; Whitman et al. 2012; Adigüzel 2013; Lochner 2013; Brooks, Cetin, and Kavuturu 2013; Yang et al. 2025; Jumini et al. 2024; Eisenkraft 2010; Wright et al. 2010; Macho 2010; Blake 2010; Mina et al. 2010; McGrann 2010; O'brien 2010; Walk 2010; Castillo 2010; Howell, Backer, and Wei 2010; Dischino et al. 2010; W. Loendorf and Geyer 2010)
5	Technological literacy is the ability to understand how technology works, how it shapes interactions, and how it relates to society. It encompasses not only knowledge of how to use technology but also an understanding of how technology works, how it shapes interactions, and how it relates to society.	(Moore 2011; Suyanto et al. 2023; Ajayi and Luckay 2023; Ghahfarokhi 2025; Ingerman and Collier-Reed 2011; NAEP 2018; ITEEA 2020; ITEA 2007)

Expert definitions of technological literacy serve as a reference in developing the framework and assessment dimensions used. We compiled several dimensions to assess students' technological literacy (Table 2).

Table 2. Overview Dimension of Technological Literacy

No	Dimension	References
1	**Dimension:** Knowledge, capability, and critical thinking and decision making. **Content:** Technology and society, design, product and system, and characteristics; core concepts; and connections	(Pearson and Garmire 2006; Avsec and Jamšek 2018)
2	Technological knowledge, technological capacity, and technological attitude.	(Whitman et al. 2012; Luckay and Collier-Reed 2014; Gu, Xu, and Hong 2019; Davies 2011; Ingerman and Collier-Reed 2011)
3	Identifying technology, functional analysis, and structural analysis	(Moore 2011)

The definitions provided by experts and the dimensions developed in previous studies helped us synthesize the three domains of technological literacy: knowledge, capability, and attitude.

The knowledge domain encompasses physics students' understanding of technology, with "understanding" interpreted broadly. A technologically literate individual must possess technology knowledge, which includes knowing, analyzing, and evaluating technology (Krupczak et al. 2009; Avsec and Jamšek 2018). Table 2 illustrates the dimensions of technological literacy developed in previous research regarding students' understanding. In essence, students' understanding can be measured through the dimensions of knowledge in the revised Bloom's taxonomy (L. W. Anderson and Krathwohl 2001). Thus, knowledge, critical thinking, and decision making can be unified into a single knowledge dimension. We believe that students' understanding of technology should be divided into several indicators, as the concept is too broad to assess without subdivision. Based on the dimensions analysed, we divided the knowledge dimension into three indicators: Technology and Society, which is part of factual knowledge; Technological Concept, which is part of conceptual knowledge; and Technological Analysis and Evaluation, which is part of procedural and metacognitive knowledge (Pearson and Garmire 2006; Ingerman and Collier-Reed 2011; Whitman et al. 2012; Moore 2011).

The capability domain of technological literacy is defined as the ability to use technology; however, in this dimension, cognitive skill is assessed. Technology knowledge is a fundamental component of technological literacy, and the process of understanding it can be evaluated through the cognitive domain of the revised Bloom's Taxonomy. This ability falls within the cognitive domain, focusing on procedural aspects of using technology, such as operating technology, designing technology, and solving problems within the technological context (Hasse 2017; Banda and Nzabahimana 2021). Thus, the capability domain is defined as the knowledge required to use technology (Avsec and Jamšek 2015). The ability in question focuses on operating technology and encompasses technology maintenance and problem-solving processes (Gu, Xu, and Hong 2019). In the context of physics learning, students are expected to design effective technological solutions to address problems, with designs that may be procedural or in 3D form. Based on the analysed dimensions, we divided the capability dimension into three indicators: Technology Procedural, corresponding to cognitive levels C1–C3; design, corresponding to cognitive level C6; and maintenance and troubleshooting, corresponding to cognitive levels C4–C5 (Moore 2011; Whitman et al. 2012; Davies 2011). This dimension can be assessed through Bloom's Taxonomy, which includes higher-order thinking skills.

The third domain is the attitude domain, which is assessed based on students' attitudes toward technology. This domain is evaluated through students' behavior, interest, curiosity, active participation, and willingness to solve problems in technological contexts. The assessment of the attitude domain is grounded in Krathwohl & Bloom (1964) affective domain, which categorizes the affective domain into five levels. These levels were then adapted to fit the attitude domain in technological literacy. We divided this domain into three indicators: interest (A1–A2), value (A3), and ethics, equity, and responsibility (A4–A5) (NAEP 2018; Macho 2010; Avsec and Jamšek 2016; Pearson and Garmire 2006; Davies 2011). The attitude domain is measured using a Likert scale of 1–4, with the criteria: strongly agree, agree, neutral, disagree, and strongly disagree (Gu, Xu, and Hong 2019). We define technological literacy as the ability that encompasses conceptual understanding, skills to use and critically solve technological problems, and ethical awareness of the social impacts and values associated with the use of technology. We also attempted to formulate the dimensions and indicators of technological literacy based on previous studies.

Technological literacy in physics education refers to the components of dimensions, contexts, and physics content to be assessed. The physics content to be measured must be adjusted according to the relevant context. We adapted the technological contexts from the International Technology Education Association (2007), which classifies technology into seven categories: medical technology, agricultural and biotechnology, energy and power technology, information and communication technology, transportation technology, manufacturing technology, and construction technology. The application of physical laws can take the form of applied technology, and the context of technological literacy serves to classify the specific area of applied technology. We developed the dimensions for assessing technological literacy in physics education, as shown in Figure 6.

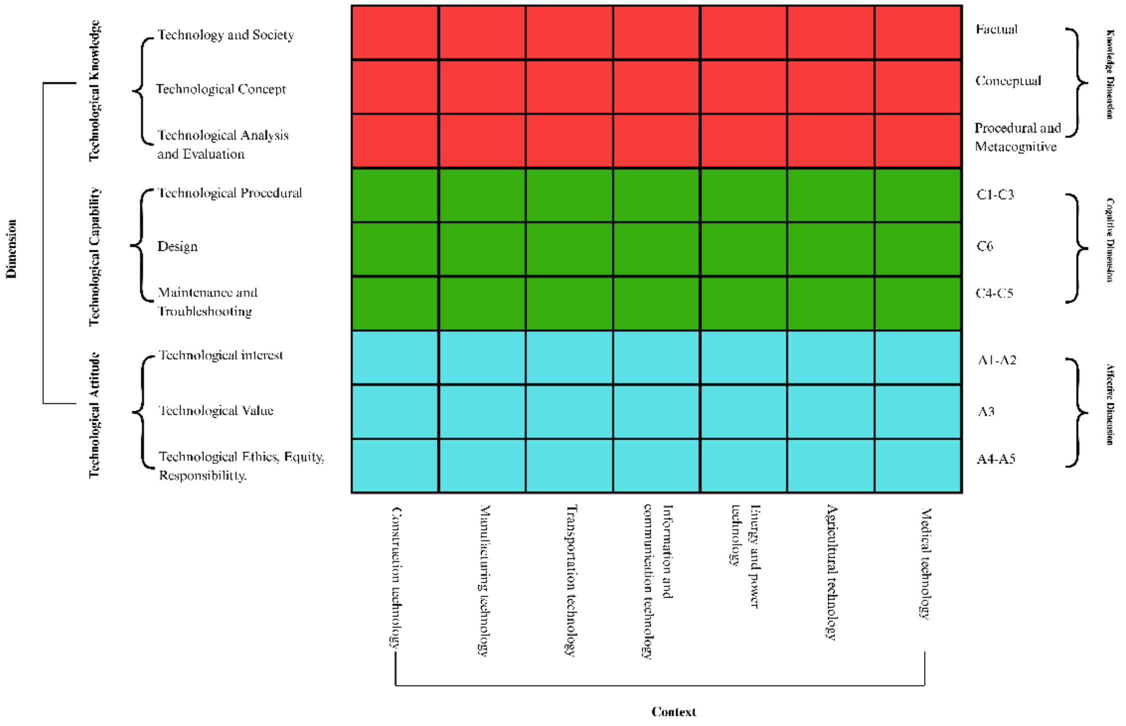

Figure 6. Technological Literacy Dimension in Physics Education

Discussion

Technological Literacy Trends

The review of 71 articles over the past 20 years reveals a developmental pattern in technological literacy research. Interest peaked around 2010, declined in the following decade, and resurged in 2024–2025, linked to a shift in focus toward digital technology and AI. These findings suggest a wave-like trend influenced by changing educational priorities and global technological developments, moving from general conceptual studies of technology in the 2010 era to research on digital/AI and virtual laboratories in the 2024–2025 period.

The geographical distribution of publications shows the dominance of the United States (around 28 articles), while other countries such as Germany, Indonesia, China, and Nigeria contributed moderately (4–6 articles each). This disparity likely reflects differences in research capacity, educational policy priorities, and technological investment between countries (Korytkowski and Kulczycki 2019; Checchi, Malgarini, and Sarlo 2019; Amirbekova, Narbaev, and Kussaiyn 2022; Matveeva, Sterligov, and Yudkevich 2019).

Regarding topics, most studies (33 out of 71) focused on implementing technological literacy—how it is applied in educational practice. In contrast, integrating technological literacy into STEM contexts and exploring its conceptual dimensions remain relatively limited (about three articles each). This highlights the need for deeper research in three key areas: (1) curricular integration (how to embed technological literacy into STEM), (2) development of consistent theoretical dimensions, and (3) creation of adequate assessment frameworks for various contexts.

Methodological analysis shows a dominance of qualitative studies (54 articles), fewer quantitative studies (12 articles), and some mixed methods research (5 articles). The prevalence of qualitative approaches indicates that technological literacy is often studied as a contextual, social, and pedagogical phenomenon, with researchers favoring exploration, case studies, and systematic reviews. However, the scarcity of quantitative and mixed methods research limits the ability to generalize findings and provide strong empirical evidence to support policy interventions or large-scale applications. Therefore, there is a need for more experimental studies, large-scale surveys, and longitudinal research to strengthen the evidence base.

Technological Literacy Concept

Literacy was originally defined as the ability to read and write. In the present era, however, the definition of literacy extends beyond that. Literacy has evolved into the ability to access, understand, evaluate, and use information in various forms (UNESCO 2004). Dibner & Snow (2016) distinguish between foundational literacies, which refer to reading literacy and numeracy skills, and disciplinary literacy, or knowledge within a specific domain such as scientific literacy, ethnobotanical literacy, ethnomedicine literacy, and others (A.R.F Gani et al. 2024; Fang 2012; Shanahan and Shanahan 2012; Washburn et al. 2023; Green 2019; del Mar Sánchez-Pérez 2021; Zou et al. 2021; Gümüş and KARA 2025). One of the literacy skills within disciplinary literacy is technological literacy, which is defined as the ability to use, manage, evaluate, and understand technology (ITEA 2007).

Technology is generally defined as any modification of the natural world made to meet human needs or desires (ITEEA 2020; Aracil 2018; Biltgen 2017; Swanson 2016; Waters 2017; Edwards and Fogelman 2018; Pimentel 1989; Hammond, Kolasa, and Fung 2023). Technology is one of the continuously evolving entities; therefore, technological literacy is essential for individuals to keep up with technological advancements (Kern and Malinowski 2016; Tran 2016; Moore 2011; Avsec and Jamšek 2015; 2016). To be technologically literate, one must adopt a utilitarian perspective toward technology, which involves knowing how technology works and how to use it and analyzing its values and benefits. Being literate in technology requires understanding the technology used, how it functions, how different technologies are interconnected, and even analyzing the consequences of its use.

Technological literacy is one of the components of STEM education (Science, Technology, Engineering, and Mathematics). Kelley & Knowles (2016) divide STEM components into four categories: scientific inquiry, technological literacy, engineering design, and mathematical thinking. In practice, STEM learning often focuses its assessment on the science and mathematics components, while technological literacy and engineering design receive relatively less attention (El Nagdi and Roehrig 2022; Gao et al. 2020). However, STEM learning is inherently multidisciplinary, and assessments focusing on only one or two components do not fully represent STEM education. Assessing technological literacy is essential to achieving the goals of integrated STEM learning. Technological literacy is considered a crucial foundation in STEM education, as STEM not only requires an understanding of science and mathematics but also skills in critically using, understanding, and evaluating technology (Suyanto et al. 2023; Heywood 2014).

Physics learning studies the characteristics and phenomena that occur in nature. Teachers should relate the subject matter to real-life applications in the learning process. Applying physical laws and theories refers to natural phenomena and technologies that apply these laws of physics. Technology results from applying scientific knowledge, and physics plays a major role in technological development. For example, before the discovery of electricity, people used candles to illuminate rooms at night. Candles themselves are a form of technology that applies physical concepts. However, once electricity was discovered, technological development accelerated. In its time, the incandescent light bulb invented by Thomas Alva Edison provided a means to light rooms at night. Candles then began to be abandoned and were only used in emergencies. Today, lighting technology has evolved into LED (Light Emitting Diode) lamps, making electric lighting more efficient. Technology development is closely linked to physics; in other words, teachers and students must develop a deeper understanding of technology within the learning process (Öztürk, Yiğit, and Karaduman 2012).

In physics education, technological literacy emphasizes investigation, critical thinking, and decision-making throughout the learning process. Technology may require modification or complete abandonment if it is ineffective in addressing a problem. Contextual learning connects lessons to everyday life. For instance, students might be asked to analyse why Indonesia has not yet adopted nuclear technology and whether it could become relevant. Such questions can only be answered when students understand how a technology works and can analyse its impacts. In other words, technological literacy plays a crucial role and is one of the components that should be assessed in physics education. Physics learning also often involves using technology found in laboratories. For example, in lessons on static fluids where the goal is to measure the density of an object, students typically need technology to measure the object’s mass and the change in liquid volume, enabling them to compare these results. However, some physics topics cannot be experimented with directly due to limitations such as a lack of equipment. In such cases, technology can be used for virtual laboratory simulations (Hamka et al. 2024; Bengel and Peter 2024; Banda and Nzabahimana 2021; Adigüzel 2013). In practice, technological literacy is essential for operating these tools. Students who lack technological literacy will find it difficult to use equipment for experiments, whether physical or simulated. Since technology use is an integral part of the learning process, assessing technological literacy becomes necessary to measure the achievement of learning objectives in physics learning.

Technological Literacy Assessment

Figure 6 presents the dimensions used to measure technological literacy in physics education. The assessment of technological literacy should be aligned with both the dimensions and the specific technological context.

Technological Knowledge

Technological knowledge is evaluated based on the knowledge dimension developed by L. W. Anderson & Krathwohl (2001). This dimension serves as a reference for designing the technological literacy test to be developed. We have formulated three indicators of technological literacy derived from the four knowledge dimensions outlined in their framework.

1) Technology and Society

In this indicator, students learn how technological developments influence society. Since the dawn of human civilization, technology and society have been closely interconnected. Technology results from human engineering, which aims to fulfill desires and solve problems. Some theories assert that technology is an autonomous force that independently shapes society (Van De Poel 2020). Another perspective views technology as a human construct that can be shaped by human values and decisions (Roncevic and Makarovic 2020). A more integrated view suggests that technology and society evolve together, influencing each other reciprocally (Alfaraz and Tully 2025; Abdul Rasyid Fakhrun Gani et al. 2024). Students with strong technological literacy should be able to understand the relationship between technology and society, an ability useful for fostering deeper thinking about technology's impacts (Rupnik and Avsec 2019). Knowledge and ability in this area are essential for understanding issues surrounding the development and use of various technologies and participating in decision-making related to their application (Ingerman and Collier-Reed 2011).

We classify this dimension under factual knowledge. Factual knowledge contains basic information and elements that must be known (Rachmawati, Suharno, and Roemintoyo 2023; Bardet and Ragusa 2009; Mathumbu, Rauscher, and Braun 2014). The "technology and society" indicator may include fundamental elements of how technology affects society. In this domain, students must recognize that technology and society remain interdependent (Alsaleh 2024; Tafreshi 2014; da Silva Leite and Almeida 2019; Dub et al. 2023). Knowledge of facts, data, and terminology falls under the factual knowledge dimension (L. W. Anderson and Krathwohl 2001). Competence in "technology and society" includes understanding the interaction between technology and humans, the impact of technology on the natural world, and the impact of technology on science (NAEP 2018).

2) Technological Concept

In this indicator, students learn about the concept of technology. Technology aims to meet human needs and solve problems, a concept that students must understand to become technologically literate. Students should view technology as a tool to use resources that humans need(Gasparski and Airaksinen 2008; Franke and Zoubir 2020). This perspective encourages a human-centered approach to technological innovation. In addition, students should understand the concept of trade-offs, in which every technology has advantages and disadvantages. Trade-offs are inherent in technological design and engineering, where multiple criteria often cannot be satisfied simultaneously (Parolin, McAloone, and Pigosso 2024; Parolin et al. 2024). For example, solar panel technology, while offering a clean and renewable energy source, has the drawbacks of high cost and vulnerability to damage. To be technologically literate, students must understand the fundamental concepts of technology and its role in society. This includes recognizing how technology fulfills human needs and the inevitable trade-offs present in every technological solution.

This dimension falls under conceptual knowledge, which examines the relationships among facts, categories, and principles, thereby forming a structured framework for thinking (Puma et al. 2023; Schmidmaier et al. 2013; Y. Wang 2017; Rittle-Johnson, Schneider, and Star 2015). Technology knowledge is built from multiple facts that together form the overarching idea of technology. The indicators include its characteristics and scope, the core concepts that define it, and the interrelationships among different technologies and their connections to other fields of knowledge. This knowledge includes concepts, principles, generalizations, models, and the structural relationships between ideas within a field (Mills 2016; Lambon Ralph 2014; Crooks and Alibali 2014). Therefore, we categorize this indicator within the dimension of conceptual knowledge..

3) Technological Analysis and Evaluation

This indicator emphasizes how students can analyze and evaluate the impacts of technology. Students who can analyze and evaluate technology effectively will be able to think critically and make sound decisions (Lind, Pelger, and Jakobsson 2019). Individuals with strong abilities in this area tend to ask questions about risks and benefits when confronted with new technologies (Nes et al. 2021; Shachak et al. 2024; Suyanto et al. 2023; Avsec and Jamšek 2015).

We classify this indicator under procedural and metacognitive knowledge. Procedural knowledge relates to performing tasks and solving problems (Ziqi Zhang, Uren, and Ciravegna 2010; Knowlton and Schorn 2024; Pirttimaa, Husu, and Metsärinne 2017). Metacognitive knowledge refers to an individual's awareness and understanding of their knowledge (Rohwer and Kloo 2013; Latha Lavanya 2019; Desautel 2009). This indicator focuses on guiding students to analyze and evaluate their procedures and metacognition. For example, students may critique the procedures involved in technological development in Indonesia and then reflect on the technology itself. Therefore, we categorize this indicator within procedural and metacognitive knowledge dimensions.

Technological Capability

This dimension refers to students' ability to know how to use technology, design technology, and solve problems in technology. This domain is assessed using the cognitive dimensions developed by L. W. Anderson & Krathwohl (2001). We divide the capability indicator into three sub-indicators encompassing all six cognitive dimensions.

1) Technological Procedural

This ability emphasizes how students follow proper procedures for using technology. The focus on procedural aspects aims to help students understand the correct procedures for ensuring workplace safety and the effective use of technology (Gu, Xu, and Hong 2019; Avsec and Jamšek 2018; Davies 2011). For example, when using physics laboratory equipment, students must follow strict protocols to prioritize their safety (L. S. Anderson, Ferri, and Cramer 2016; Viitaharju et al. 2021). One example is when students follow the protocol for constructing series and parallel circuits on a breadboard, from selecting resistors, soldering or clamping, to measuring current and voltage with a multimeter.

This indicator emphasizes students' ability to recall, understand, and apply technological procedures. We classify this indicator under dimensions C1–C3. It highlights how students can apply proper procedures for using technology. These three levels are interconnected: mastery of C1 is the foundation for understanding C2, and strong comprehension enables effective application in C3 (Sofiana and Arifin 2012; Bechard, Karvonen, and Erickson 2021). In this indicator, students are expected to remember, comprehend, and follow technological procedures accurately.

2) Design

This ability emphasizes guiding students to design technology to solve problems (Julia and Isrokatun 2019; Krupczak et al. 2009). This indicator encourages students to design technology effectively using physics-related calculations. It requires students to create 3D drawings of technological designs according to their capabilities, from initial sketches to detailed specifications. Therefore, when applied in assessment, this domain can only be measured through subjective essay questions (Saputra et al. 2025; Castillo 2010; NAEP 2018). For example, students might be tasked with designing a fluid flow from a certain height to maximize the pressure. They would first create a sketch of the design and then accurately calculate the resulting water pressure.

This indicator falls under the ability to create technology, in which students are expected to design specific technological solutions based on the problems presented. We classify this indicator within the C6 cognitive dimension, focusing on students’ ability to generate new ideas (Collins 2024; Berková, Boruvková, and Lízalová 2018; Di Stasio and Miotti 2021). At this stage, students design, plan, or modify solutions for complex problems; thus, we categorize this indicator under the C6 cognitive dimension.

3) Maintenance and Troubleshooting

This ability refers to the skills in maintaining and repairing technological equipment or systems. It encompasses diagnosing malfunctions, identifying the source of problems, and carrying out repairs or calibrations to restore optimal functionality (Sabuncu, Anand, and Abel 2023; Martins et al. 2023). In the physics learning context, this ability is important for developing students' understanding of technological tools' operating principles and for fostering the application of analytical logic when addressing technical issues (W. R. Loendorf, Geyer, and Richter 2013; Heywood 2023). Teachers can design problem-based questions or projects that simulate technical malfunctions, thereby training students to identify damage symptoms, trace their causes, and systematically determine repair solutions.

This indicator emphasizes the problem-solving process; therefore, we classify it under the C4–C5 cognitive dimensions (Y. Wang and Chiew 2010). To solve a problem, individuals must be able to analyze and evaluate the problem-solving process itself (Jonassen 2013; M. Zhang, Andersson, and Greiff 2023; De Mast 2013). C4 refers to breaking information into parts, identifying the relationships among them, and understanding the underlying structure or patterns (El-Sayed 2008; Qolfathiriyus, Sujadi, and Indriati 2019). C5 refers to the ability to assess the quality, credibility, or effectiveness of an idea, method, or product based on specific criteria (Warren 2005; Tai et al. 2018; Buckley et al. 2015). These abilities are essential for enabling students to diagnose and resolve problems. Teachers can design assessments aligned with the C4–C5 dimensions, specifically targeting students' problem-solving skills in physics-related technology.

Technological Attitude

Technological attitude refers to students’ affective responses toward technology. The affective domain involves feelings, emotions, and attitudes (Ziyan Zhang et al. 2022; Vankúš 2021; Potgieter, Filmalter, and Maree 2025; Lamb et al. 2021). Students’ feelings toward physics-related technology must be considered to understand their attitudes toward using technology (Gu, Xu, and Hong 2019). We divide this dimension into three indicators aligned with the affective levels A1–A6 described by Krathwohl & Bloom (1964). The technological ethics dimension can be assessed using a 4-point Likert scale to measure students’ attitudes.

1) Technological Interest

Interest in technology in education refers to students’ curiosity and enthusiasm to explore, learn, and experiment with new technologies (Ilyas et al. 2023; Yücesoy et al. 2021; Mustapha 2018). This interest fosters creative initiative and enhances the learning experience (Gambrell 2013; Wong et al. 2020). Teachers can assess students’ technological interest through various methods, including direct questions about the technology they are learning in class. This domain focuses on how students receive and respond to technology according to their interests; in other words, it aims to measure how students engage with physics-related technology.

We categorize this indicator under the affective domain, specifically within dimensions A1 and A2. A1 refers to the willingness to attend to or accept a stimulus (Soysal, Yalçın, and Can 2008; Villa et al. 2020). A2 refers to active participation, where students pay attention and respond through action (Miller and Metz 2014; Pahl and Kenny 2008). Interest is directly linked to the affective dimensions A1 and A2. At the A1 level, students focus on a relevant category, meaning that in this indicator, they will concentrate on technology and reduce distracting thoughts (Soemer, Gericke, and Schiefele 2024). At the A2 level, interest supports sustained participation in learning activities, so students will be more actively engaged in study physics-related technology (Harackiewicz, Smith, and Priniski 2016). Therefore, we classify this domain within the affective dimensions A1–A2, emphasizing students' ability to receive and respond (Kiruthiga and Christopher 2022; Cea 2023; Coffman and Kittur 2024).

2) Technological Value

This skill refers to how students perceive technology as an empowering tool, a potential risk, or a combination of both, influencing their decisions and actions in its use (Gu, Xu, and Hong 2019; Gerdsri 2016; Nishihara 2017). In this indicator, students are asked to evaluate whether applied technology holds value in social and cultural contexts. Assessing technological value involves judging its benefits, limitations, and impacts within social, cultural, and environmental contexts. For example, students might be asked whether technology-based physics learning is necessary.

We classify this indicator under the affective dimension A3, which refers to students' attitudes of valuing, believing in, or demonstrating commitment to a particular value, such that this value influences their behavior and choices (Barbara et al. 2019; Syaiful, Ismail, and Abd Aziz 2019; Gałajda 2017). This domain reflects students' beliefs regarding the benefits of technology, referring to their inclination to evaluate technology positively or negatively (Gardner et al. 2004; Kohnke and Moorhouse 2025; Kiruthiga and Christopher 2022). Therefore, we place this indicator within the A3 affective domain.

3) Technological Ethics, Equity, Responsibility

This ability refers to how students can apply personal and ethical values in using and developing technology, such as fairness, inclusivity, transparency, sustainability, and social responsibility. Students must understand that technology is not neutral; its use must consider long-term impacts on individuals, society, and the environment. Teachers can assess this aspect through questions that stimulate students' moral awareness (Morante et al. 2024; Mattiello, Mattiello, and Wittberg 2025; Thapa 2025; V. Wang 2025; Dundua 2024). For example, a student strongly committed to environmental sustainability will consistently demonstrate energy-saving behaviors.

We classify this indicator under the affective dimensions A4 and A5. A4 refers to the attitude of integrating various held values into a consistent personal value system (Vecchione et al. 2011; DeYoung and Tiberius 2023). A5 refers to the attitude in which the values one believes in become part of one's personality and are consistently reflected in daily behavior (Bechler, Tormala, and Rucker 2021; Glasman and Albarracín 2006). This indicator specifies students' ability to practice ethical values, equality, and responsibility regarding technology. Therefore, we classify this ability within the affective domain at levels A4–A5, focusing on students' capacity to self-regulate and apply ethics, equality, and responsibility in physics-related technology (Jones 2024; Brocos and Jiménez-Aleixandre 2020; Thomsen 2007; Kofoed 2006).

Impact of Technological Literacy in Physics Learning

Technological literacy is not only important for students but is also a crucial skill for teachers. Teachers are the key figures in the learning process, and effective teaching depends on their ability to manage the classroom well. Technology is a significant aspect as a medium for student learning. The TPACK framework (Technological, Pedagogical, and Content Knowledge) requires teachers to master the domain of technology, in addition to content and pedagogy. Technology must be effectively integrated into the learning process (McKenney and Voogt 2017). Durak (2021) states that the TPACK framework demands the ability to synergize content, pedagogical, and technological knowledge collectively, rather than simply knowing how to operate technology. A teacher may be proficient in using various applications, but this does not necessarily mean they can design learning experiences that effectively integrate all three domains. Teachers who understand and apply TPACK do not merely use technology as a teaching aid; they also teach students how to think critically about technology (Niess 2011; Yurdakul et al. 2013). This means that students not only learn how to use technology but also understand how it works, how it impacts society, and how to evaluate and make informed decisions regarding its use.

From a knowledge perspective, teachers must thoroughly understand technological content to explain concepts accurately and guide student experiments. They must also implement multidisciplinary approaches such as STEM, which integrates technological literacy skills. The quality of classroom learning heavily depends on teachers' technological literacy (Korkeaniemi, Lindfors, and Kiviranta 2025). A teacher’s level of technological literacy influences how they access, select, and utilize technology. Low literacy often results in technology being used merely as a substitute for traditional methods, rather than as a tool for learning transform (Ajayi and Luckay 2023; Roberts and Kruse 2023a; Macho 2010; O’brien 2010). For example, if a teacher intends to use a virtual laboratory in the learning process, they must analyze supporting components (Fahmi et al. 2024; Temirkhanova, Abildinova, and Karaca 2024) such as students’ predominant learning styles. If most students are visual learners, a virtual lab may be the best choice; if not, conducting a simpler hands-on experiment may be better. Other factors, such as the availability of technology, are also important; if equipment is unavailable, the use of digital media is limited. Teachers can develop simple media if digital technology is not used in learning. This can be done either through analog methods or digitally with the assistance of Arduino or other microcontrollers (Abdul Rafid Fakhrun Gani and Gani 2022). However, teachers with strong technological literacy can select or adapt materials as needed, using available resources effectively. Teachers’ skills are a key component in selecting technology for learning (Shannaq et al. 2025; Hasse 2017; Blau, Shamir-Inbal, and Avdiel 2020; Ghahfarokhi 2025; Rozo and Ramírez-Montoya 2025; Alyousef and Picard 2011). Therefore, technological literacy is essential for teachers, enabling more effective and purposeful use of technology in education.

Technological literacy is also important for students in preparing them for future changes (Mawson 2013). Education should teach students how to use specific tools or technologies and foster an understanding of their purposes, impacts, and the values associated with their use. With this approach, students acquire practical skills and develop critical, creative, and wise thinking abilities to select and utilize various forms of technology responsibly in everyday life and across different professional fields (Shachak et al. 2024). Achieving the highest level of technological literacy for students goes beyond knowing how to use laboratory equipment, turn on a computer, or open a virtual lab application. Students are expected to use various technologies strategically to achieve concrete learning goals at this level. In other words, the learning process is designed as a real-world situation in which students engage with written materials and hands-on projects (Davies 2011; Eisenkraft 2010). For example, in a physics class, students may be tasked with building an excavator that applies Pascal’s law. Through such learning processes, students perceive technology as a tool and a means to solve real problems.

Most members of society, including students, can only operate simple technologies such as mobile phones. Ironically, students often use phones solely for voice calls and text messaging, while the utilization of more advanced features such as internet access, financial transactions, or information retrieval remains very limited (Abdon, William, and Tandika 2023; Gros, Garcia, and Escofet 2012; Miao and Zhang 2023; Bledsoe and Pilgrim 2013; Vlasenko and Ivanova 2019). This indicates that technological literacy is very low and needs to be improved. The role of teachers in creating authentic learning situations is therefore crucial. Teachers can assign inquiry-based or problem-based learning tasks (Eltanahy and Forawi 2019; Nagaraj and Raja 2025; Lower-Hoppe et al. 2021; He et al. 2022). For example, a teacher might present a local environmental issue related to an energy crisis and ask students to analyze data, conduct surveys, and propose solutions through designs or models. In doing so, the teacher establishes a framework of challenges that encourages students to decide which technology to use, whether creating a 3D design of a technological solution or constructing a tangible model (Saputra et al. 2025; Reymen, Vermunt, and Brans 2023; Dikilitaş, Marshall, and Shahverdi 2025; Bohm et al. 2020). Technology literacy instruction aims to help students understand that technology is not merely a tool but also opens up new possibilities and may carry hidden risks if not critically and reflectively examined (Park 2022; Parmigiani, Benigno, and Hidi 2019; Ikpeze 2010; Lionenko and Huzar 2023; Chan and Ridgway 2005).

Physics education is inherently rich in technological applications. In technology-literacy-based physics learning, students learn to evaluate when and why one technology is more appropriate and how to optimize its components. Achieve effective and efficient outcomes (Yang et al. 2025; Lu and Li 2025). When assessing students’ technological literacy, teachers should not focus solely on technical skills, such as how proficient they are at measuring electricity using a multimeter or other instruments. The first step is to explore the “why” behind the students’ choice of technology. Key questions include: “Do students understand the learning objectives they aim to achieve?”, “Why did they choose a digital multimeter rather than an analog one?”, and “How does this support their reasoning and ultimate learning goals?” Once the rationale behind each technological choice is understood, the assessment shifts to the “how” or how well students use the technology. For example, teachers evaluate whether students can measure voltage accurately (Moore 2011). By adopting a stepwise approach from understanding the reasons for selecting a technology to assessing the outcomes of its use students' technological literacy can be measured more accurately (Blake 2010).

CONCLUSION

Technological literacy in physics learning refers to understanding, analyzing, and evaluating technology in high school physics. This research divides technological literacy into three main dimensions: knowledge, capability, and attitude, and then separates them into nine assessment indicators. We divide the context of physics technological literacy into nine contexts: Medical Technology, Agricultural and Biotechnology, Energy and Power Technology, Information and Communication Technology, Transportation Technology, Manufacturing Technology, and Construction Technology. The literature review results indicate that understanding technological literacy plays a crucial role for students and teachers in physics learning. For teachers, technological literacy is a foundation for designing physics learning strategies that are more contextual, innovative, and relevant to technological developments. Teachers with high technological literacy can select, adapt, and develop learning media or tools appropriately, and assess the achievement of learning objectives more accurately. For students, technological literacy encourages adaptive skills to technology and equips them with the 21st-century competencies needed to compete in the future. By integrating technological literacy assessment into physics learning, schools can ensure that the learning process focuses on mastering concepts and applying that knowledge in real-world contexts that are beneficial to everyday life and career development in science and technology.

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