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Technology-enhanced learning influence on chemical literacy: A systematic review

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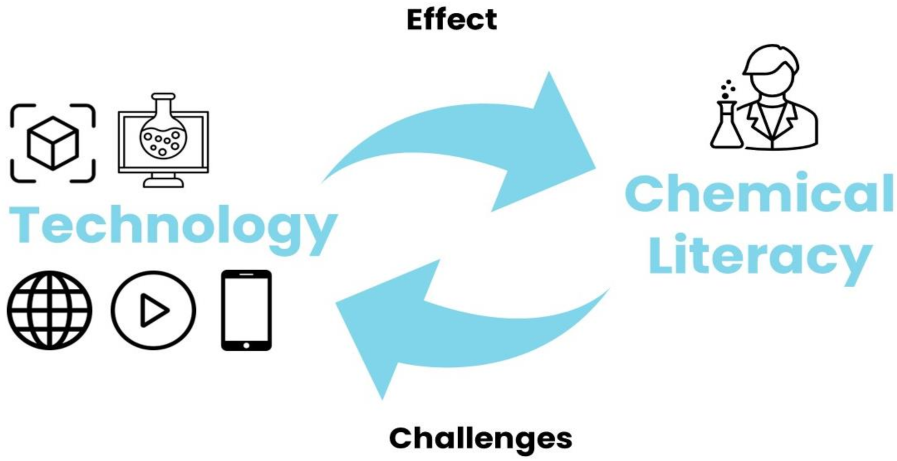
Abstract

Chemical literacy is essential to address socio-scientific issues arising today. Technology plays a key role in increasing students' chemical literacy. Understanding how technology improves chemical literacy can help teachers choose appropriate learning tools and strategies. A systematic review with PRISMA guidelines was conducted to map the technology widely used in current chemistry learning and know-how technology influences the development of chemical literacy based on the PISA framework. A total of 15 articles were identified as meeting the review criteria. The results show that based on the literature review, E-modules are the most commonly used technology to improve chemical literacy. Technologies such as augmented reality, Canva, e-modules, mobile apps, and websites are important for the ability to "explain phenomena scientifically". Adobe Flash Interactive Media and Virtual Laboratories are particularly effective for "constructing and evaluating designs for scientific investigation and critical interpretation of scientific data and evidence." Finally, search engine technology has a significant impact on the ability to "research, evaluate, and use scientific information for decision-making and action".



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Highlights

- The e-module is the most widely used technology to improve chemical literacy.
- The influence of each technology in improving chemical literacy is explained.
- Potential research gaps in using technology to improve chemical literacy are noted.

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1. Introduction

Science education aims not only to produce young scientists but also to benefit society in general (Reiss *et al.*, 1999). Everyone should have the necessary scientific knowledge and be able to use the knowledge to explain phenomena scientifically, evaluate and design scientific inquiry, and interpret data and evidence scientifically (OECD, 2023). These competencies are part of scientific literacy, which is important nowadays. Although widely used in science education literature, the term "scientific literacy" has no specific consensus on its definition. The term is used in research, discussions, and analyses of science education goals, assessment programs, curriculum policies, programs, and learning resources. However, everyone agrees that students cannot be scientifically literate if they know nothing about the science. Scientific literacy has several other terms, but scientific literacy is the most widely recognized (Roberts, 2007).

Regardless of its meaning, scientific literacy is important because it influences various meanings, assessment methods, and topics of interest (Laugksch, 2000). Increased scientific literacy improves students' intellect, character, communication, positive behavior, and responsible citizenship (Holbrook and Rannikmae, 2007). Studies show that scientific literacy can foster the principles of democratic education and involve the community in decision-making on socioscientific issues (Yacoubian, 2018). With mathematical literacy, scientific literacy is a means to prepare for adult life, which is expected to involve public discussions related to science, technology, environment, and society, thus creating a democratic society (Yore *et al.*, 2007). Scientific literacy also plays a role in improving communication skills, critical thinking, metacognitive awareness, and understanding of culture and practices in science (Cavagnetto, 2010). Some other studies mention that scientific literacy can build a better society (Roth and Barton, 2004), accelerate the realization of sustainable development goals (SDGs) (Queiruga-Dios *et al.*, 2020), and develop 21st-century transferable skills (Rahayu, 2017). Given the importance of scientific literacy, it has become one of the key learning objectives that education, teachers, and policies focus on today.

In the chemistry field, scientific literacy is referred to as chemical literacy, which is defined as students' ability to recognize, define, conceptualize, and analyze chemical concepts at a higher level (Shwartz *et al.*, 2006b). Chemical literacy is a crucial component of scientific literacy (Mozeika and Bilbokaite, 2011; Stašević *et al.*, 2023), and essential for addressing today's socio-scientific issues. It encompasses a broad chemistry-related context and is connected to other sciences (Shwartz *et al.*, 2006a). Improved chemical literacy enables students to use chemical knowledge and skills to solve everyday problems (Stašević *et al.*, 2023) and socio-scientific issues (Wiyarsi *et al.*, 2021). Chemical literacy is not only about understanding chemistry but also about implementing it in daily life (Primadianningsih *et al.*, 2023). Additionally, it involves the ability to understand and communicate chemical concepts effectively among scientists and chemistry teachers (Kohen *et al.*, 2020). Understanding chemical literacy has significant implications for distinguishing between basic and advanced chemical learning (Shwartz *et al.*, 2005). Therefore, developing chemical literacy should be considered one of the primary objectives in chemistry education.

A key understanding of chemical literacy is required to develop it. While there is no specific consensus on chemical literacy, it can be defined within a scientific framework because it is part of scientific literacy. The most widely used scientific literacy framework today is the PISA framework. The PISA framework focuses on developing the competencies of a science-literate person, namely explaining phenomena scientifically, constructing and evaluating designs for scientific inquiry and interpreting scientific data and evidence critically, and researching, evaluating, and using scientific information for decision-making and action (OECD, 2023). In developing this, students must also understand knowledge (content, procedural, and epistemic) context (personal, local, and global) and have a scientific identity. This concept can be applied to chemical literacy so that the improvement of chemical literacy can be more directed.

Technology is a significant contributor to the quality of education. Thus, there is a growing practice and research on technology-enhanced learning (TEL). Technology-enhanced learning refers to using information and communication technology in learning and teaching, using various approaches and ways to measure improvement (Kirkwood and Price, 2014). It also refers to how to design and evaluate effective technology for learning (Duval *et al.*, 2017). With the utilization of technology, learning can be more optimal. In addition to learning outcomes, TEL supports collaborative learning (Tawafak *et al.*, 2018) and increases the satisfaction of the learning process (Memon *et al.*, 2022). By understanding the role of technology in a learning objective, it can be understood how technology contributes to achieving learning objectives, including chemical literacy.

Technologies like videos, simulations, and student response systems in chemistry learning can help reduce cognitive load, encourage discussion and debate, and improve students' problem-solving skills (Seery and McDonnell, 2013). Digital technologies, especially digital applications, and virtual reality, are widely used in chemistry learning because they help provide visualizations, show chemical structures and models, and provide hands-on activities (Ali *et al.*, 2023; Bellou *et al.*, 2018). The role of technology in chemistry learning is not only as a medium that helps students access material but also as a learning companion that helps students learn in various contexts and use what they learn in everyday life. For example, virtual laboratories can perform experiments in certain contexts (Wu *et al.*, 2021). Thus, it is important to understand how technology plays a role in improving chemistry learning objectives, especially chemical literacy, which is a fundamental goal in much of world education.

Overall, this systematic review is essential for informing educators, policymakers, and researchers about the potential of technology-enhanced learning in promoting chemical literacy. By synthesizing the current evidence, this review aims to advance educational practices that effectively cultivate chemical literacy among students, preparing them to engage with the complexities of the modern world. Therefore, this systematic literature review aims to map the technology widely used in current chemistry learning and analyze its influence on chemistry learning in the context of chemical literacy.

2. Experimental

The framework for preferred reporting items for systematic reviews and meta-analyses (PRISMA) is applied in this literature review. The PRISMA method follows the guidelines provided by Moher *et al.* (2009).

2.1. Eligibility criteria

The study only used peer-reviewed papers from multiple indexed databases. The articles we selected had to satisfy the following requirements: (1) they had to address the use of technology in chemistry education or learning; (2) they had to discuss the chemistry literacy component (competencies aspect); and (3) they had to address the direct effects of the use of technology on chemical literacy (4) the selected articles are those published above the year 2000 (this year was chosen because it was the first time the PISA survey was conducted). This review excluded articles that only mentioned scientific literacy without measuring its components. Articles that lacked a clear explanation of their methodology were likewise excluded. We do not use review papers; only original, English-language articles are used.

2.2. Search query

Several keywords were combined using the Boolean operators and OR to search for articles that met the chosen parameters. To identify articles that discuss the use of technology in learning to improve chemical literacy, a series of word combinations were employed, as shown in **Table 1**. These were then entered into a database to retrieve the relevant articles with Boolean operators, those keywords are used.

Table 1. The following keywords were utilized in the article search.

Technology related keyword	Chemical literacy related keyword	Additional keyword
Technology	Chemical literacy	
Learning Media		Chemistry
ICT	Scientific literacy	Chemistry Learning
Digital		

The databases Taylor & Francis, semantic scholar, and ERIC were searched for articles using these keywords. To refine the search results, the search also made use of the attributes that were offered. For example, in the Taylor & Francis database, we could select "chemical literacy" in the title. We employed quotations on the term "chemical literacy" to further refine the results.

2.3. Study selection

From the initial search of 503 articles, 85 were sourced from ERIC, 316 from Semantic Scholar, and 102 from Taylor & Francis. Following the removal of duplicates, articles were selected based on the presence of technology and chemical literacy aspects. Titles and abstracts were reviewed, and some articles were excluded for not addressing chemical literacy, lacking technological elements, or not being in English. This process yielded 114 items meeting the initial criteria. These articles underwent a detailed analysis, focusing particularly on the methods and results sections. However, some articles were deemed ineligible due to inaccessible full texts or failure to integrate chemical literacy with technology. Consequently, 24 articles met the criteria. A subsequent review of these 24 articles revealed issues such as lack of clarity in results, inadequate description of chemical literacy, and insufficient incorporation of technology in learning. This refinement resulted in 15 articles that fully met the criteria (**Fig. 1**). These selected articles were then subjected to coding analysis and grouped based on similar themes. To facilitate this, Excel 365's Pivot Table was employed to summarize data, such as the number of articles in each category. Additionally, VosViewer provided an overview of the most popular keywords and terms used in the articles.

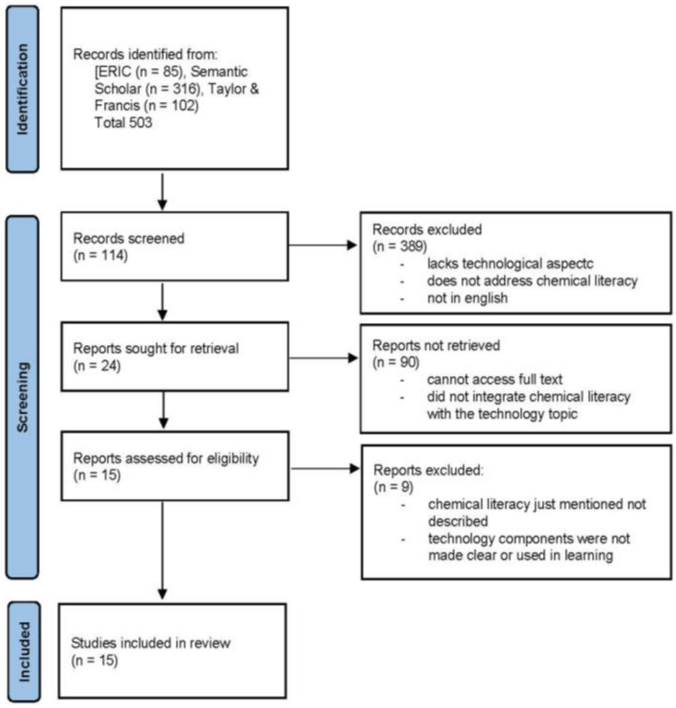

Figure 1. Flowchart of the literature selection process by PRISMA method.

3. Results and discussion

3.1. An overview of the empirical research included in the review

An overview of the 15 publications that are part of this study is provided in **Table 2**. The author and year, journal, subjects, type of research, and technology are all discussed in these articles. Here is the summary.

Most of the articles reviewed were published in 2022, totaling four articles. The research predominantly focused on senior high school students (n = 8). Regarding the research type, the articles were primarily characterized by "two-group experiment" studies (n = 5). In terms of technology, the most widely used technology was the E-module (n = 4). In detail, **Table 3** displays the technologies used in the selected articles.

Table 2. Overview of 15 articles that included on systematic review.

No.	Author	Journal	Subject	Type of research	Technology
1	Schultz *et al.* (2022)	Assess. Eval. High. Educ.	Undergraduate Student	Case Study	Search Engine
2	Frailich *et al.* (2007)	Res. Sci. Technol. Educ.	Senior High School Student	Two Group Experiment	Website
3	Sulistina and Hasanah (2024)	Int. J. Interact. Mob. Technol.	Senior High School Student	R&D One Group Pre-Post	Augmented Reality
4	Bortnik *et al.* (2017)	Res. Learn. Technol.	Undergraduate Student	Two Group Experiment	Virtual laboratory
5	Pulungan and Simamora (2024)	J. Inov. Pemb. Kim.	Senior High School Student	Two Group Experiment	Canva
6	Subarkah *et al.* (2020)	Proc. 1st Bandung Engl. Lang. Teach. Int. Conf.	Undergraduate Student	R&D Only	E-Module
7	Suliono *et al.* (2023)	J. Penelit. Pendidik.	Senior High School Student	R&D One Group Pre-Post	Mobile Apps
8	Techakosit and Wannapiroon (2015)	Procedia Soc. Behav. Sci.	Expert	R&D Only	Augmented Reality
9	Khery *et al.* (2020)	Int. Conf. Math. Sci. Educ.	Undergraduate Student	Two Group Experiment (Postest Only)	Mobile Apps
10	Sutiani and Pasaribu (2023)	J. Tadris Kimiya	Senior High School Student	R&D One Group Pre-Post	E-Module
11	Novitasari *et al.* (2022)	Eduvest J. Univ. Stud.	Senior High School Student	One Group Pretest-Postest	E-Module
12	Khairi and Ikhsan (2022)	J. Kimia Dan Pendidik. Kimia	Senior High School Student	Two Group Experiment (Postest Only)	E-Module
13	Yuendita and Dina (2024)	J. Penelit. Pendidik. IPA	Senior High School Student; Teacher	R&D Only	Augmented Reality
14	Heliawati *et al.* (2022)	J. Pendidik. IPA Indones.	Undergraduate Student	Two Group Experiment	Adobe Flash Interactive Media
15	Cahyana *et al.* (2019)	Int. J. Instr.	Senior High School Student	Two Group Experiment	Website

Table 3. Technologies were used in 15 articles that included on systematic review.

Technology	Frequency
Adobe Flash Interactive Media	1
Augmented Reality	3
Canva	1
E-Module	4
Mobile Apps	2
Search Engine	1
Virtual laboratory	1
Website	2

Another study found that the most widely used technology in chemistry learning is virtual reality. Virtual reality is considered essential in chemistry education because it meets students' needs for visualization, understanding chemical structures, and engaging in hands-on activities (Ali *et al.*, 2023). However, in this review, virtual reality was not one of the technologies examined, suggesting a gap in the utilization of virtual reality for enhancing chemical literacy. Another study indicates that the technologies widely used in chemistry learning include simulation-assembled technology, animation, and virtual labs. These three technologies are deemed effective in helping students understand abstract chemical concepts (Wu *et al.*, 2021). These technologies have either directly or indirectly been included in this review.

Based on an analysis using VosViewer (**Fig. 2**), the following is a comprehensive overview of the terminology used in the topic "effects of technology-enhanced learning on chemical literacy". In general, "chemical literacy," "scientific literacy", and "augmented reality" are the dominant keywords in the papers.

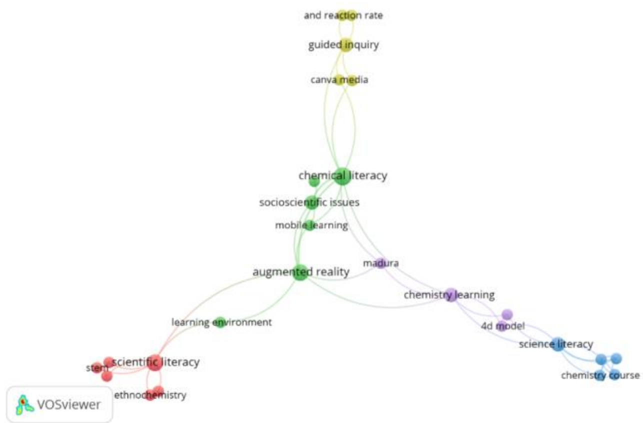

Figure 2. VosViewer Result of keywords of "effects of technology-enhanced learning on chemical literacy".

3.2. Technology's influence on chemical literacy based on PISA frameworks

To explain how technology impacts chemical literacy, the program for international student assessment (PISA) framework is used as the primary guide (OECD, 2023). The PISA framework is globally recognized, making it suitable for clarifying chemical literacy, which can be interpreted differently by various researchers. Moreover, PISA measurements have been conducted for a long time and encompass "scientific literacy," which is closely related to chemical literacy. According to this framework, chemical literacy is divided into three main competencies: (1) explaining phenomena scientifically, (2) constructing and evaluating designs for scientific inquiry and interpreting scientific data and evidence critically, and (3) researching, evaluating, and using scientific information for decision-making and action. The impact of TEL on chemical literacy (CL) will be discussed based on these competencies. The impact of technology will be linked to one of the most affected chemical literacy competencies, as explained in the reviewed articles. A summary of the effects of technology used in learning on chemical literacy is provided in **Table 4**.

Table 4. The impact of technology use on chemical literacy based on the reviewed articles.

No.	Technology	The role of technology	CL aspect	Effect
1	Adobe flash interactive media	Adobe flash technology has become an interactive learning media such as smartphone applications. Provides a variety of material presentations in various forms and is equipped with a virtual laboratory (Heliawati *et al.*, 2022)	CE	Adobe flash, designed as an app, allows students to access materials in various forms (video, text, audio) that facilitate comprehension. Furthermore, the virtual lab enables students to perform simulations, thereby reinforcing their inquiry skills, applying the concepts they have learned, and grasping the fundamental principles of science in everyday life.
2	Augmented reality	• AR enables the representation of submicroscopic objects on chemical bonding materials. AR represents a potential tool that allows users to represent and manipulate three-dimensional chemical structures (Techakosit and Wannapiroon, 2015). • AR facilitates the visualization of abstract chemical material, such as molecular shapes, thereby enabling students to readily comprehend the diverse representations of chemical compound shapes presented (Yuendita and Dina, 2024). • AR facilitates learning, and collaboration, and facilitates learning through technology easily, thereby enabling the development of students' understanding (Sulistina and Hasanah, 2024).	EP	• AR provides a visual representation of chemical 3D structures, which enables learners to explore and identify structures that facilitate the understanding of chemical phenomena. • AR provides a visual representation of chemical processes, allowing students to comprehend abstract chemical compounds in a more accessible manner. This facilitates the comprehension of chemical phenomena. • AR offers a more meaningful learning experience, facilitating the development of student comprehension and enabling them to grasp a phenomenon more easily.
3	Canva	The utilization of Canva as a pedagogical tool can facilitate the transfer of knowledge and enhance the ability of educators to engage students in the subject matter (Pulungan and Simamora, 2024).	EP	The increased interest in learning and the more organized materials provided by Canva have the potential to facilitate the development of student understanding.
4	E-module	• Electronic modules about the study of chemistry and its applications in everyday life may incorporate a multitude of forms of written, visual, and auditory content (Novitasari *et al.*, 2022) • The systematic publication of modules presents certain discourses in the form of scientific social issues sourced from electronic media, such as news and newspapers, which are accurate and reliable (Khairi and Ikhsan, 2022). • The objective of this learning resource is to assist students in comprehending the subject matter more effectively, provide contextualization, and enhance their reading abilities through an aesthetically pleasing design. The incorporation of visualizations, including images, videos, and graphs, in conjunction with factual examples, encourages students to develop and hone their science literacy skills (Sutiani and Pasaribu, 2023). • The e-module is designed to enhance student engagement and motivation by incorporating a range of engaging multimedia elements, including animated videos, images, and summary materials. This approach fosters a more enthusiastic and active participation in the learning process, which is crucial for facilitating deeper understanding and meaningful learning outcomes (Subarkah *et al.*, 2020).	EP	• E-modules can be utilized to summarize phenomena in a multimedia format (audio, video, images) that allows students to gain a comprehensive understanding of the context of a phenomenon. • The e-module presents a variety of real-world contexts through everyday media (news and articles) in a systematic manner that allows students to learn more effectively and comprehend science in the context of everyday life. • The incorporation of structured materials with diverse graphical representations allows students to gain deeper contextual insight, thereby facilitating their comprehension of the phenomenon in question. • E-modules present materials in a visually appealing manner, accompanied by instructions tailored to a specific model. This approach has been shown to enhance student motivation and facilitate comprehension of the material.
5	Mobile apps	• The results indicate that students appreciate the interactivity, accessibility, and convenience of mobile learning. The implementation of a mobile learning system as a supplement to the learning process is relatively straightforward and cost-effective. In designing mobile learning, it is essential to consider motivational factors such as interactivity and attractiveness (Suliono *et al.*, 2023). • The application is equipped with a variety of menus, including learning videos and special calculators. These resources allow students to enhance their factual, conceptual, procedural, and metacognitive knowledge about acid-base material through learning videos from the Acid-Base Multimedia. Consequently, students can comprehend scientific statements in various conceptual and contextual frameworks (Khery *et al.*, 2020).	EP	• With its various conveniences and interactivity, students become motivated to learn and make it easier to understand chemical concepts, enabling an increased understanding of a phenomenon. • In the application, problems are presented in various forms of visual and audio media that allow students to understand the phenomenon better.
6	Search Engine	The Internet offers a vast array of information, fostering an active capacity to assess data. The Internet can disseminate both accurate and inaccurate information in various formats, necessitating the critical examination and selection of such information (Schultz *et al.*, 2022).	RE	Students become trained in researching and finding the information they want. The veracity of information becomes important to determine an action. thus the importance of evaluating information.

7	Virtual laboratory	Virtual laboratories serve as a simulation medium that is learner-centered and inquiry-based, promoting higher levels of critical thinking and retention (Bortnik *et al.*, 2017).	CE	Virtual labs enable learners to perform simulations that enhance their comprehension during hands-on experiments and contribute to a deeper understanding of the material.
8	Website	• The use of web-based media encourages students to construct their knowledge, thereby enhancing their problem-solving and critical-thinking skills (Cahyana *et al.*, 2019). • The web can address the overly theoretical nature of current learning by providing more relevant, context-specific instruction. It offers interactive multimedia that surpasses the limitations of static resources like textbooks in conveying broad, complex, and dynamic subject matter (Frailich *et al.*, 2007).	EP	• Self-directed learning using the web requires students to actively construct their knowledge, which leads to a comprehensive understanding and enables them to explain phenomena scientifically. • The context presented on websites can train students to explain phenomena through interactive learning, thereby enhancing their understanding.

Note: EP = explaining phenomena scientifically; CE = constructing and evaluating designs for scientific inquiry and interpreting scientific data and evidence critically; RE = researching, evaluating, and using scientific information for decision-making and action.

In **Table 4**, the influence of technology on chemical literacy is explained based on three main competencies. The first competency, explaining phenomena scientifically, is the most impacted by TEL. Technologies such as augmented reality, Canva, E-modules, mobile apps, and websites contribute to the development of this competency. The details of the role of each of these technologies in enhancing chemical literacy will be discussed as follows. First, augmented reality plays a significant role by providing visualizations of compounds, molecules, or atoms at the submicroscopic level, enabling students to gain a more complete and concrete understanding. This enhanced visualization allows students to observe phenomena more effectively, thereby improving their ability to explain phenomena scientifically. Similarly, other studies have demonstrated that augmented reality (AR) can provide visualization of chemical structures, enabling students to develop a deeper understanding of the material (Abdinejad *et al.*, 2021; Fombona-Pascual *et al.*, 2022). This visualization capability can reduce cognitive load and enhance spatial ability (Habig, 2020).

Second, Canva can also contribute to the first competency of chemical literacy by increasing learning motivation and helping to present materials in a more organized manner, thereby enhancing student understanding. In general, Canva is useful for increasing motivation, understanding, active participation, and functionality (Vargas *et al.*, 2022). The attractively presented materials in Canva make it easier for students to grasp concepts, which aids in learning chemistry (Fatihah and Ruhiat, 2023). The engaging features of Canva are a crucial factor in its ability to improve students' chemical literacy competencies.

Furthermore, E-modules are the most widely used technology for improving chemical literacy. E-modules enhance students' ability to explain phenomena scientifically by providing comprehensive training through written, visual, and audio content. Their ease of creation and modification allows them to be associated with specific contexts, approaches, and learning models, enabling students to learn in various situations and stages. Another study explained that E-modules in chemistry learning make students more active participants, thereby improving their learning outcomes (Logan *et al.*, 2021; Nainggolan *et al.*, 2023). The use of E-modules has been shown to produce better learning outcomes and increase motivation compared to conventional media (Harefa and Silalahi, 2020). This increase in scientific literacy competence through E-modules is likely due to the enhanced student engagement stemming from the visual, written, and audio representations that capture their interest. Additionally, the use of specific models or approaches further encourages active student participation.

Furthermore, mobile apps are closely related to the first competency of chemical literacy. They offer high interactivity, which can increase student motivation. Additionally, mobile apps can be equipped with diverse menus and content, facilitating well-rounded learning and contributing to enhanced student understanding. These factors collectively improve students' ability to explain phenomena scientifically. Interactivity is the primary feature that supports the use of mobile apps in chemistry (Ewais *et al.*, 2021; Kim *et al.*, 2014; Sadykov *et al.*, 2021). Another study noted that mobile apps make materials more accessible and visible (Ekins *et al.*, 2013). Therefore, the high interactivity provided by mobile apps is a crucial factor in developing and improving scientific literacy.

Finally, is the website, which significantly influences the first competency of chemical literacy. Like E-modules and mobile apps, websites can be customized according to user needs. In terms of explaining phenomena scientifically, websites provide a variety of contexts, allowing students to practice applying their knowledge to different situations independently. Websites enhance student understanding, encourage self-learning, and offer resources that help students stay focused on their studies (Cole and Todd, 2003). Other research also emphasizes the web's ability to support student self-learning (Chamimmah *et al.*, 2023). Thus, the most notable role of websites is their ability to foster self-directed learning, which in turn increases students' active involvement in constructing their knowledge.

The second competency involves constructing and evaluating designs for scientific inquiry and critically interpreting scientific data and evidence. Based on the review of the selected articles, Adobe Flash Interactive Media and Virtual Laboratories can significantly enhance this competency. Adobe Flash Interactive Media contributes to this competency primarily due to its virtual laboratory feature. Although it is often compared to mobile apps, the virtual laboratory aspect is the most prominent. Virtual laboratories allow students to perform simulations, thereby strengthening their inquiry skills. Consistent with this, the research on virtual laboratories discussed in this review indicates that they act as simulation media that facilitate student learning. This ultimately improves their understanding of scientific inquiry and hands-on experimental techniques. This is reinforced by research showing that virtual laboratories can improve students' understanding of basic techniques and concepts (Martínez-Jiménez *et al.*, 2003). This technology facilitates the practice of chemistry fundamentals by allowing students to visualize, navigate, and simulate related processes and real laboratory environments (Almazaydeh *et al.*, 2016). Virtual labs are considered the best alternative for equipping students with essential laboratory knowledge and skills (Kartimi *et al.*, 2022). Thus, the simulation aspect is crucial for developing the second competency of scientific literacy. Virtual labs provide a means for students to explore the research process virtually, making them more familiar with real laboratory practices.

The third competency is researching, evaluating, and using scientific information for decision-making and action. This is the most recent addition to the PISA framework, emerging in response to the surge of information and the increasing importance of assessing this information critically. Search engines are a key technology that contributes to improving this competency (OECD, 2023). Search engines present a wide variety of information quickly, requiring students to assess the validity, accuracy, and appropriateness of the information they encounter. Research shows that search engines motivate students to gain navigational experience and increase their desire to learn chemistry by providing interesting, relevant, and challenging information (Murov, 2001). In chemistry education, students should be encouraged to search and read literature and to use online databases effectively (Gawalt and Adams, 2011). Thus, search engines that offer abundant data can effectively train students in the third competency of chemical literacy.

Each technology discussed has a unique role in enhancing chemical literacy. Based on this review, we can see how these technologies contribute to improving chemical literacy competencies as defined by the PISA framework. The results of this study can inform the implementation of TEL to improve chemical literacy. However, this study has several limitations. First, it only includes English articles, which may exclude other technologies developed to improve chemical literacy. Second, this review focuses solely on the technology used, potentially overlooking other factors that contribute to improving science literacy, such as learning models or specific approaches. Future research should examine the extent to which each technology affects chemical literacy, considering moderating variables to provide a more comprehensive understanding. Thirdly, although the research methodology was designed following established guidelines, the study's results predominantly feature articles from Indonesia. This geographical concentration suggests that the conclusions drawn may be most applicable to the Indonesian context. There is a potential for bias, necessitating caution when generalizing findings to other national contexts. Readers should take this into account. Nevertheless, the research provides valuable insights into how technology influences chemical literacy.

4. Conclusions

Based on the literature review, it is evident that the most widely used technology for improving chemical literacy is the E-module, especially in Indonesia, where most of the articles reviewed were from. E-modules are easy to develop and can be tailored to specific needs, making them the most prevalent technology for enhancing chemical literacy. For improving the competency of "explaining phenomena scientifically", technologies such as augmented reality, Canva, E-modules, mobile apps, and websites play a significant role. In enhancing the second competency, "constructing and evaluating designs for scientific inquiry and critically interpreting scientific data and evidence", Adobe Flash Interactive Media and Virtual Laboratories are particularly effective. Finally, for the competency of "researching, evaluating, and using scientific information for decision-making and action", search engine technology has a notable impact.

With this knowledge, educators can better address their students' needs by identifying specific deficiencies in chemical literacy and selecting the appropriate technology. Additionally, practitioners can proportionally combine different technologies in their teaching strategies based on these findings. The results of this study also highlight a gap in the use of certain technologies for improving chemical literacy. For example, the impact of virtual reality on chemical literacy has not been directly studied, indicating an area for future research.

Authors' contributions

Conceptualization: Ananta Ardyansyah; Sri Rahayu; **Data curation:** Ananta Ardyansyah; Sri Rahayu; **Formal Analysis:** Ananta Ardyansyah; **Funding acquisition:** Sri Rahayu; **Investigation:** Ananta Ardyansyah; **Methodology:** Ananta Ardyansyah; Sri Rahayu; **Project administration:** Ananta Ardyansyah; **Resources:** Sri Rahayu; **Software:** Ananta Ardyansyah; **Supervision:** Sri Rahayu; **Validation:** Ananta Ardyansyah; Sri Rahayu; **Visualization:** Ananta Ardyansyah; **Writing – original draft:** Ananta Ardyansyah; **Writing – review & editing:** Ananta Ardyansyah; Sri Rahayu.

Data availability statement

All data sets were generated or analyzed in the current study.

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Conflict of interest

The authors declare that there is no conflict of interest.

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