

Artificial Intelligence Literacy in Engineering and Technical Education: A Systematic Review of Research Trends, Competencies, and Emerging Directions

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Abstract—As AI technologies are incorporated into professional practice, learning, and technologically advanced educational settings, artificial intelligence (AI) literacy has grown in significance. The evolution of AI literacy research is methodically reviewed in this work, along with its applicability to engineering and technical education. To determine publishing trends, target audiences, study issues, and the development of AI literacy studies, bibliometric analysis was integrated with a PRISMA-based systematic literature review. The results demonstrate how conceptual knowledge and pedagogical approaches toward curriculum integration, real-world application, generative AI, ethical awareness, and critical review have evolved into AI literacy. Higher education continues to be the primary focus of research, which increasingly focuses on the skills needed to comprehend, apply, assess, and ethically interact with AI technologies. The shift from fundamental AI literacy concepts to technology-enhanced learning and new AI-related competencies is further demonstrated by bibliometric mapping. These advancements emphasize the significance of fusing technical expertise with critical, practical, and ethical skills from the standpoint of engineering and technical education. The results offer a foundation for improving AI literacy in technical curricula and suggest future lines of inquiry to equip technical students to interact with AI-driven devices in an ethical manner.

Keywords—artificial intelligence literacy, engineering education, technical education, technical students, systematic literature review, technology-enhanced learning, VOSviewer.

I. INTRODUCTION

Artificial intelligence (AI) has changed educational methods over the past ten years, and the significance of AI literacy has increased (Schmidt et al., 2025; Nandiyanto & Sidik, 2026; Al Husaeni & Haristiani, 2024; Nandiyanto, 2026). In engineering and technical education, where students are required to not only use AI-based technologies but also comprehend how they operate, assess their results, and think about their ethical and societal implications, this trend is especially pertinent (Alkhatir et al., 2025). However, definitions, competence models, and measuring indicators for AI literacy are still in the early stages of development (Chiu et al., 2024; Laupichler et al., 2022a).

The ability to comprehend basic AI concepts, use AI-based technologies responsibly, critically assess their

outputs, and recognize their wider ramifications are all considered aspects of AI literacy (Ng et al., 2021). Because technical students engage with AI through computational tools, automated systems, data analysis, modeling, design, and other technology-intensive learning activities, these competencies are becoming more crucial in engineering and technical education.

Research on AI literacy remains fragmented across educational contexts and conceptual frameworks (Ng et al., 2021). Some focus on models and skills, while others explore curriculum implementation, learning programs, assessment tools, and future challenges (Yim & Su, 2025). Previous studies also found that AI literacy should include cognitive, technical, practical, critical, and ethical dimensions instead of only focusing on technological knowledge (Kong et al., 2021; Kong et al., 2024). These differences call for a systematic synthesis of the field.

Systematic reviews may be useful for identifying research gaps, conceptual development, publication trends, and emerging directions in AI literacy research (Su et al., 2023). Within the scope of engineering education, this type of synthesis is useful for understanding which research fields and competencies are relevant for technology-intensive learning environments and technical students.

Therefore, this paper provides an overview of the development of AI literacy research in the last decade through analysis of the publication trend, geographical distribution, publication types and target groups, main themes, and the evolution of the field. The objective of this study is to respond to the following research questions:

- (i) RQ1: What trends can be identified in AI literacy research based on publication growth, geographical distribution, and publication type?
- (ii) RQ2: What target groups have been investigated in AI literacy research?
- (iii) RQ3: What major themes and research areas characterise the development of AI literacy research?
- (iv) RQ4: How has AI literacy research evolved from foundational concepts toward emerging technological and educational applications?

The findings are expected to give a systematic overview of the research on AI literacy and shed light on its implications for engineering and technical education,

especially in terms of the skills technical students need to understand, use, evaluate, and responsibly engage with AI-based technologies.

II. RESEARCH METHODS

In this study, we applied a systematic literature review approach to analyse the development of research on AI literacy in an educational context over the past decade. This approach was chosen because it allows the systematic and transparent identification, evaluation, and synthesis of research findings based on available scientific evidence. The systematic review process is conducted through a few main steps, namely, formulating research questions, identifying relevant studies, assessing the quality and quantity of articles, gathering and summarising research evidence, and analysing findings to answer the research questions that have been set (Snyder, 2019). This enables investigators to get an overall picture of the publication trends, concepts and definitions of AI literacy, the competency dimensions comprising it, and the research methods adopted in previous studies (Hackl et al., 2026). Additionally, systematic review has been widely adopted in AI literacy research to systematically map the growth of knowledge and identify research gaps (Collins et al., 2021). This way of working thus provides a high degree of confidence in presenting a relevant knowledge synthesis and thus allows the research objectives to be achieved. The choice of the PRISMA model was based on systematic methods for screening and assessing scientific literature, which increase the validity and reliability of the research synthesis findings (Albhirat et al., 2024). This approach enables investigators to systematically trace the development of research on AI literacy in education by locating sources of literature, screening relevant articles, determining eligibility, and ultimately selecting publications that satisfy the inclusion criteria (Park, 2025).

The study was conducted in four main phases (identification, screening, eligibility, and inclusion) following the PRISMA flowchart (Liberati et al., 2009). We searched scientific databases for articles that contained the keywords “Artificial Intelligence Literacy”, “AI Literacy”, “AIL (Artificial Intelligence Literacy)”, “education”, “learning”, “student”, and “curriculum”. The screening process was done by reviewing the articles by title and abstract to ensure that the papers were related to the research topic. The screening process was carried out using Google Scholar and Scopus databases.

During the screening stage, papers were chosen according to their abstracts and titles to assess their applicability to the study question (Gusenbauer & Gauster, 2025). Here, we eliminated duplicate articles and those with overlapping data between the databases used, such as Scopus and Google Scholar. The titles, author names, publication years, and publisher sources were compared to ensure that each article analysed was unique while also removing duplicates. Thus, the screening stage was to generate a collection of valid, relevant, and non-redundant articles before moving to the eligibility stage (Salari et al., 2025).

According to Frampton et al. (2017), the eligibility stage entails a thorough evaluation of publications that have made

it beyond the screening stage to ascertain their applicability to the research topic. To assess whether the content is appropriate for the subject of AI literacy in an educational setting, we now read each article in its entirety. Articles that are not directly relevant to the research topics, do not expressly address AI literacy, or are not in an educational setting will be disqualified. We also assessed the methodology quality, the clarity of the study’s aims, and the importance of the findings to the field of AI literacy research. Hence, the eligibility step is designed to ensure that only relevant, quality papers aligned with the research’s purpose are carried over to the inclusion phase.

The inclusion step is the last step of the procedure for selecting articles for a systematic review. In this phase, the articles that meet the eligibility criteria for further analysis are the primary sources. The publications were selected according to the following inclusion criteria: relevance to AI literacy in education; relevance to the themes of the study; and adequate methodological quality. Selected publications are reviewed in detail to extract key information, such as publishing trends, conceptualizations, competence dimensions, research methods, and main findings. The analysis is summarized to answer the research issues, and to provide an in-depth review of the development of AI literacy in education. The PRISMA model provides a clear and reproducible framework for the conduct of systematic reviews (Randles and Finnegan, 2023). This approach also allows us to detect patterns in publications, conceptions and definitions of AI literacy, competency aspects that form AI literacy, research methods used, and research gaps that have appeared in educational literature over the last decade.

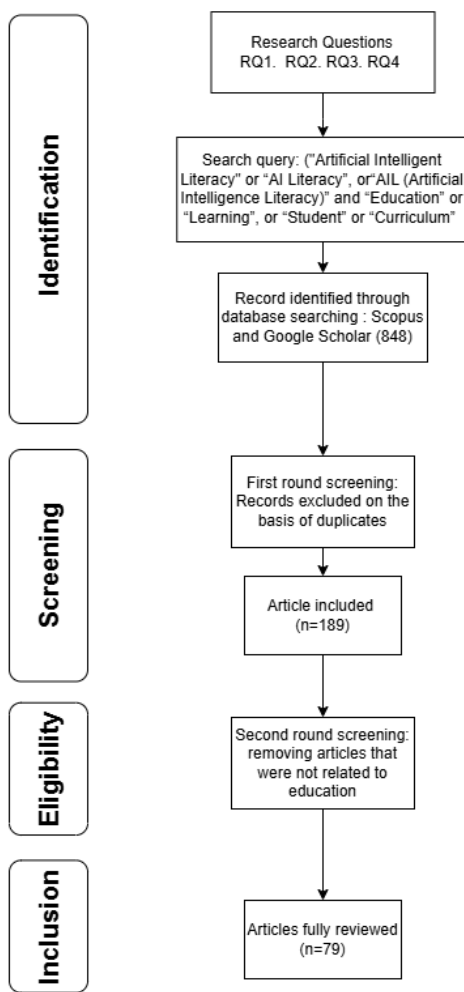


Fig. 1. PRISMA.

The inclusion criteria were set up in a way that the articles analysed are conceptually relevant to the objectives of the study. Included studies are those that clearly focus on AI literacy as a topic in an educational context. These criteria are set to keep the scope of the study consistent and to ensure that all articles contribute in a meaningful way to the development of knowledge about AI literacy in education. Hence, the results of the study are expected to capture the state of the art systematically and purposefully.

In addition, this study only included articles indexed in the Scopus database and peer-reviewed in the form of journal articles or conference proceedings. The criteria ensure the scientific quality, validity, and credibility of data sources used. The peer-review process is a rigorous academic process that ensures a high degree of reliability for the articles that get published. An important basis for scientifically accountable results is a valid source of information.

TABLE I
INCLUSION AND EXCLUSION CRITERIA.

No	Inclusion Criteria	Exclusion Criteria
1	A study examining artificial intelligence (AI) literacy	Studies that address other types of literacy were not included
2	Articles indexed in Scopus and that have undergone a peer-review process (journal articles and conference proceedings)	Editorials, preprints (arXiv), and books are not included because they do not undergo a peer-review process.
3	The use of AI in education is the main topic of articles that discuss "AI literacy."	Articles that discuss "AI literacy" but concentrate on using AI in non-educational domains were not included.

This study also restricts its focus to the investigation of AI literacy in educational contexts. We excluded articles that mentioned "AI literacy" but discussed its uses in fields other than education. In an effort to promote uniformity in comprehension and to minimize potential for interpretive bias, included publications were limited to English-language articles. The restrictions were imposed to ensure that the literature synthesis procedure is conducted accurately and systematically.

Articles that did not adhere to the research standards were thoroughly excluded as part of the selection process using exclusion criteria. Since they are unrelated to AI literacy, studies pertaining to other forms of literacy, such as reading and writing literacy, were disregarded. Additionally, due to possible issues with scientific legitimacy, non-peer-reviewed publications like books, editorials, and preprints (like arXiv) were not included. To keep the study domain consistent, articles that discussed AI literacy but concentrated on non-educational situations were also eliminated. Lastly, publications written in languages other than English were not included in order to lower the possibility of misunderstandings and guarantee consistency in the study. By using these exclusion criteria, this systematic review ensures that only pertinent, high-quality papers that align with the study's goals are examined.

A bibliometric network is a systematic representation of the relations between scientific elements that are studied quantitatively through publishing data such as keywords, authors, or documents (Van Eck and Waltman, 2010). The main method used to build the bibliometric network in this study was keyword co-occurrence analysis. Each node in the network represents a keyword, and ties indicate how often keywords appear together in the same article. The association between two terms is indicated by the distance between the terms and the thickness of the lines between them, with higher association meaning more frequent co-occurrence (Martins et al., 2024; McAllister et al., 2022). Besides, this network has a cluster (community) structure. It implies that a set of closely related keywords forms specific thematic groups. These clusters are the research fields or the main areas of e-learning adoption. Therefore, bibliometric networks not only reveal relationships between concepts but also allow us to see patterns, trends, and evolution of the research in a domain.

This network enables us to 1) identify the main themes in the literature; 2) see how research topics are connected; 3) discover new research areas or those that have not been fully explored. This is done by visualization using VOSviewer. This article systematically and comprehensively maps the

intellectual structure of a research field using bibliometric networks as analytical and visual tools (Verma et al., 2025).

III. RESULTS AND DISCUSSION

- A. *RQ1*. What has been the trend in research publications on artificial intelligence literacy in education over the past decade, as measured by the number of publications, country, and type of publication?

The first research question (RQ1) of this study is to identify and analyze patterns in the publications over the last ten years related to AI literacy within the framework of education. The analysis deals with three main topics: the number of publications per year, the distribution of countries of origin, and the types of publications published. The distribution of the number of publications indicates that the research on AI literacy in education has increased substantially during the past decade. The first term (2016-2020) had very few publications, with an average of one per year. The number of publications rose from ten in 2021 to a peak in the following years. We see a slow rise from 2022 to 2025, peaking at 22 papers in 2025. This pattern suggests a rising interest in AI literacy in the classroom on the part of scholars. Overall, this data indicates that the discipline is improving and is a major focus of educational study worldwide.

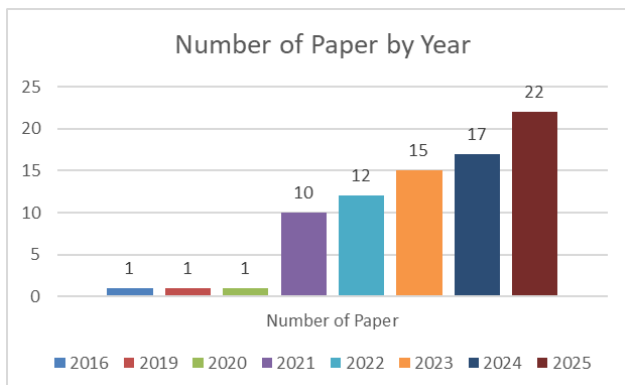


Fig. 2. Number of Papers by Year.

The distribution of publications by country is shown in Figure 3. The research on artificial intelligence literacy has been concentrated in several major regions, among which Hong Kong has the largest contribution (18 papers), followed by China (13 papers), the United States (12 papers) and Germany (12 papers). Austria and others are moderate contributors. South Korea and Taiwan have a small number of publications. There are one or two publications from other countries. This trend indicates that the research on AI literacy is still concentrated in countries with a strong research and development background in technology. The distribution is uneven around the world, with East Asia and the US and Europe accounting for most of the research output.

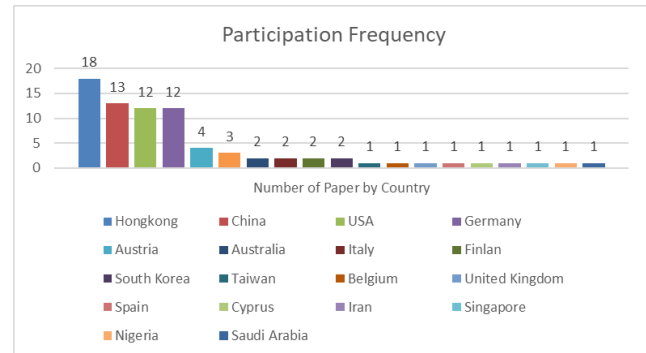


Fig. 3. Number of Papers by Country.

It can be seen from Figure 4 that most publications on artificial intelligence literacy are journal papers rather than conference papers. There are 79 total publications, including 20 conference presentations and 59 journal articles. Research on artificial intelligence literacy can be divided into two major categories based on the classification of all journal articles in the metadata: empirical studies and non-empirical studies. Of the 59 journal articles, 39 are empirical; that is, they are based on data and research methodologies such as experiments, surveys, or statistical analysis. In addition, 20 papers are classified as non-empirical, such as reviews, conceptual studies, and frameworks or guidelines development without direct data analysis. This distribution shows how much work has been done on AI literacy in a data-driven manner, as opposed to the non-empirical contributions that aim to refine concepts and synthesize the literature.

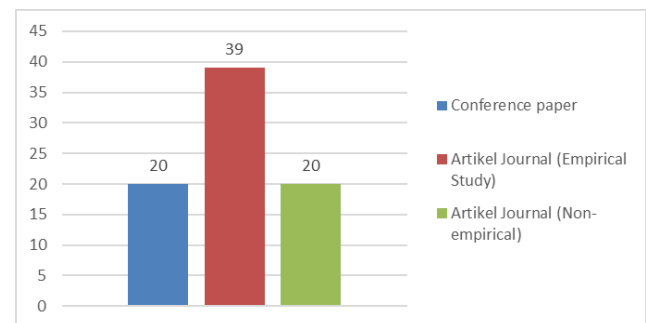


Fig. 4. Type of Contribution: Number of Papers by Type.

Empirical studies in AI literacy are studies that examine data from the real world through experiments, surveys, case studies, or other quantitative and qualitative methods. The studies are designed to test hypotheses, evaluate the effectiveness of learning programs, or examine relationships between variables relevant to AI literacy. Most publications in the dataset are within this category. Multi-method research is also empirical in that it involves data collection and analysis. The body of empirical research suggests that the evolution of this domain is toward evidence-based validation and real-world implementation in traditional educational environments.

In contrast, non-empirical studies are articles that do not involve data collection or analysis but focus on developing concepts, theoretical frameworks, or synthesizing existing literature. This category includes systematic reviews,

scoping reviews, meta-reviews, conceptual papers, perspective papers, and guideline or framework papers. Non-empirical research is required to create a theoretical foundation, recognize research gaps, and direct the future development of the field of AI literacy. The high number of studies that are non-empirical suggests that this field is advancing not only in practical terms but also conceptually and theoretically.

B. RQ2. What is the distribution of the target group in the study on artificial intelligence literacy in education?

As shown in Table III, the distribution of target groups in research on AI literacy is relatively diverse in terms of focus, but with a dominant tendency towards the context of formal education, particularly higher education. The classification of 79 articles shows that the student group (higher education) is in the most dominant position with 28 studies, which means that the development of AI literacy is mostly aimed at people with a higher level of cognitive readiness and access to more complex technologies. The K-12 student group also generally has a large proportion of the student population, with 18 studies, suggesting that there is increasing attention to the integration of AI literacy across educational levels, from early childhood to secondary education.

At the level of elementary and secondary education, we have conducted only a limited number of studies. There are 5 studies with secondary school students, and only 3 with elementary school students. The early childhood group has 9 studies. This shows that the interest in introducing AI literacy at an early age is starting to surface, but is still in its

infancy. The findings show that the implementation of AI literacy across the educational path from early childhood to secondary education has not been addressed in the literature, although building the foundation of technological literacy from an early age is of strategic importance.

The pre-service and in-service teacher groups each included sixteen studies related to teacher education. This implies that although educators are essential in incorporating AI into the classroom, there is still very little research that focuses on educators' acquisition of AI literacy skills. However, a crucial element in the effective application of AI literacy in the classroom is teacher preparedness. In order to enable AI-based educational change, more research in this area is crucial.

C. RQ3. What research has been conducted on the topic of artificial intelligence literacy in the context of education?

Using a co-occurrence approach to the 100 most frequently occurring keywords from 79 selected articles, a bibliometric network analysis is used to determine the thematic structure of a field. VOSviewer visualizations reveal that research on AI literacy in education comprises several interconnected main clusters that form an integrated research structure. The core cluster is about AI Literacy, with a very strong link to higher education, curriculum, and teacher education, with a clear focus on implementation in the formal education system. This core cluster represents the dominant themes in the literature on AI literacy in education.

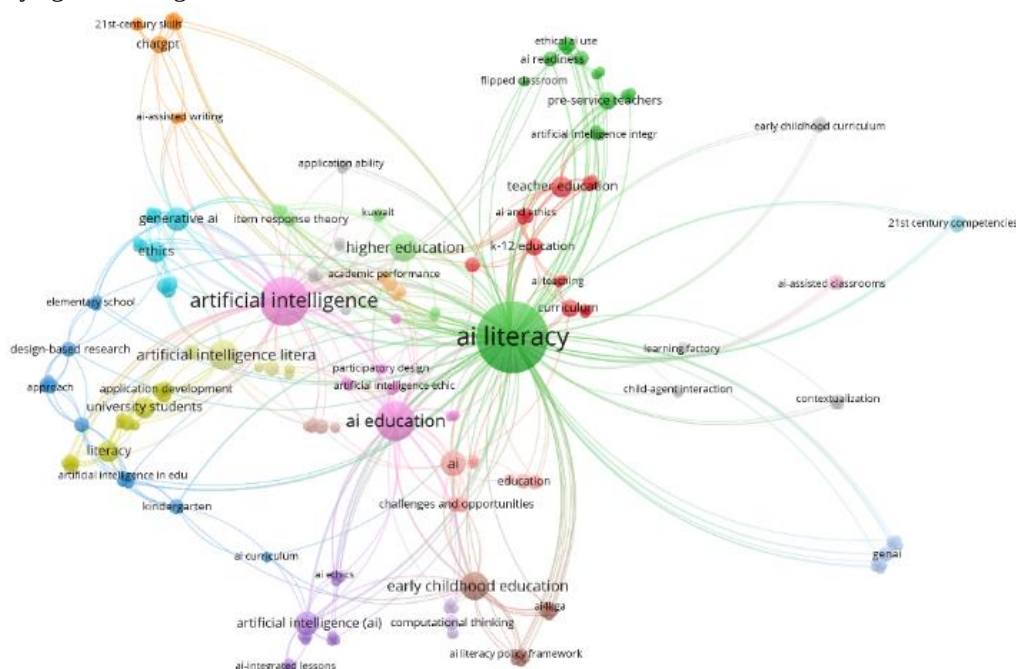


Fig. 5. VOSviewer AI Literacy - Network Visualization.

The theoretical basis of the link between conceptual development and learning practices is the conceptual cluster, which includes artificial intelligence and AI education. The connection between emerging technology and the need for

critical and ethical literacy in education is exemplified by technology clusters such as generative AI, ChatGPT, and ethics. Moreover, there are differences in application contexts, especially among target group clusters, such as

university students, K-12 education, and early childhood education, but higher education still dominates. In general, the cluster correlations indicate a progression of AI literacy research from conceptual to technology implementation and integration.

Based on the VOSviewer visualization, emerging research areas are evident in the topics of generative AI, ChatGPT, and ethics, which are connected to AI literacy but remain in relatively separate clusters, indicating increased attention in recent literature. These topics signal a shift in research toward the utilization of the latest AI technologies as well as the need for critical and ethical literacy in learning.

Additionally, connections to 21st-century competencies and AI-assisted classrooms also indicate a developmental trajectory toward the integration of AI within the context of future skills. On the other hand, under-explored areas are evident in the clusters of early childhood education, elementary school, and K-12 education, which exhibit more limited connections compared to higher education. Research on teacher education is also relatively underrepresented, despite its crucial role in implementing AI literacy. Overall, these findings suggest that research remains focused on specific contexts and requires expansion into early education levels as well as strengthening educators' competencies.

TABLE II
ARTICLE SPECIFICATIONS BY TYPE.

No	Article Type	Specification	Sub-specification	Studies
1	Conference Paper			"(Eguchi, 2021) (Wilton et al., 2022)."
2	Article Journal	Empirical Studies	General	Eguchi et al., 2021)"(Kong et al., 2021)"(A. Lee, 2021)"(Laupichler et al., 2022b)"(Shih et al., 2021)"(Zhao et al., 2022)"(Kong et al., 2022)" (Mertala et al., 2022) "(Ng et al., 2022)" (Kong et al., 2023)" (Southworth et al., 2023)" (Relmasira et al., 2023)" (Su, 2024a)"(Yang et al., 2024)"(Su, 2024b)"(Su, Yang, et al., 2024)"(Kong et al., 2024)"(Tzirides et al., 2024)"(Schiavo et al., 2024)"(Al-Abdullatif, 2024)"(Young et al., 2024)"(K. Wang et al., 2025)"(Schmidt et al., 2025)"(Pei et al., 2025)"(Kohnke et al., 2025)"(Zhong & Liu, 2025)"(Bećirović et al., 2025)"(Markus et al., 2025)"(Jin et al., 2025)"(D. Zhang et al., 2025)"(Hornberger et al., 2025)"(X. Wang et al., 2025b)"(C. Wang & Wang, 2025)"(Kelley & Wenzel, 2025)"(Younis, 2025)"(Q. Zhang et al., 2025b)"
			Multi-method Study	"(Pan et al., 2025)"
			General	"(Steinbauer et al., 2021) (Casal-Otero et al., 2023) (Su et al., 2023) (Hornberger et al., 2023) (Hwang et al., 2023) (Kimiafar et al., 2023) (Park et al., 2023) (Su & Yang, 2024) (Ng, Su, & Chu, 2024) (Bewersdorff, Hornberger, et al., 2025)"
		Non-empirical Studies	Meta Review	"(Su et al., 2022)"
			Scoping Review	"(Laupichler et al., 2022a) (Su, Guo, et al., 2024)"
			Systematic Review	"(Bewersdorff, Nerdel, et al., 2025)"
			Conceptual Study	"(Su & Zhong, 2022) (Nguyen et al., 2025) (Simms, 2025) (Daher, 2025) (De Silva et al., 2024) (Walter, 2024) (Z. Wang & Wang, 2025a)"

TABLE III
CLASSIFICATION OF PAPERS BY TARGET GROUP.

No	Target Group	Number of Papers	Studies
1	Early Childhood	9	"(Su & Zhong, 2022) (Su et al., 2023) (Su & Yang, 2024) (Relmasira et al., 2023) (Yang et al., 2024) (Su, 2024a) (Su, Yang, et al., 2024)"
2	Primary school students	3	"(Mertala et al., 2022) (Ng et al., 2022) "
3	Secondary school students	5	"(Kong et al., 2023) (Ng, Su, & Chu, 2024) (Ng, Su, Leung, et al., 2024) (Zhong & Liu, 2025) (Kong et al., 2024)"
4	Higher education (university students)	28	"(Kong et al., 2021) (A. Lee, 2021) (Shih et al., 2021) (Kong et al., 2022) (Laupichler et al., 2022a) (Laupichler et al., 2022b) (Southworth et al., 2023) (Hornberger et al., 2023) (Hwang et al., 2023) (Schmidt et al., 2025) (Bewersdorff et al., 2025) (Bećirović et al., 2025) (Jin et al., 2025) (Pan et al., 2025) (Hornberger et al., 2025) (Kimiafar et al., 2023) (Z. Wang & Wang, 2025a) (Tzirides et al., 2024) (De Silva et al., 2024) (Young et al., 2024) (Walter, 2024) (Simms, 2025) (X. Wang et al., 2025b) (Q. Zhang et al., 2025b)"
5	K-12 students (general)	18	"(Eguchi, 2021) (Eguchi et al., 2021) (Steinbauer et al., 2021) (Casal-Otero et al., 2023) (Bewersdorff, Nerdel, et al., 2025) (Su et al., 2022) (Su, Guo, et al., 2024) (Nguyen et al., 2025) (Schiavo et al., 2024) (Markus et al., 2025) (Kong et al., 2023b) (Ng et al., 2023)"
6	Pre-service teachers	6	"(Pei et al., 2025) (Kohnke et al., 2025) (D. Zhang et al., 2025) (Kelley & Wenzel, 2025)"
7	In-service teachers/educators	10	"(Wilton et al., 2022) (Park et al., 2023) (Daher, 2025) (Zhao et al., 2022) (Su, 2024) (Al-Abdullatif, 2024) (Younis, 2025) (Park et al., 2023)"

D. RQ4. How has research on artificial intelligence literacy evolved?

The overlay visualization of VOSviewer depicts the development of the research on artificial intelligence literacy in education through the color gradation, which represents

the time of publication from 2021 to 2025. The first phase around 2021 (blue) was characterized by the exploration of basic topics such as literacy, artificial intelligence in education, and design-based research, indicating a stage of conceptual and pedagogical exploration. The mid-period

around 2022-2023 (green) highlighted a move of research toward integration (e.g., AI literacy, Higher Education, curriculum and teacher education, i.e., implementation in the education system). The next phase (2024-5ish, yellow) includes generative AI, ChatGPT, AI-aided writing, ethics, and the possible intersection of modern technology and ethics. The phase relation suggests that the preliminary topics are the basis for the later developments. Furthermore, the interconnection ensures the continuity of the research. In the research on AI literacy, the latest technologies have been used to move from conceptualization to implementation and innovation.

The density visualization in the figure reflects the distribution of research intensity on AI literacy in education, based on the frequency of occurrence of keywords and their links. The light-yellow highlights artificial intelligence and

AI literacy. The literature is mainly and predominantly focused on the two topics. The green areas are of moderate density, including higher education, AI education, teacher education, and curriculum, which show that research on the implementation aspects of education is relatively mature but not yet a core topic. However, the dark blue areas are low-density topics such as early childhood education, elementary school, contextualization, and AI-assisted classrooms, which indicates that exploration in these contexts is still limited. This trend reflects that we are still focusing on conceptual development and application in higher education, with an uneven distribution across all levels of education. In general, this visualization indicates a gap in research that offers opportunities to develop studies within the framework of basic education and to strengthen more general implementation.

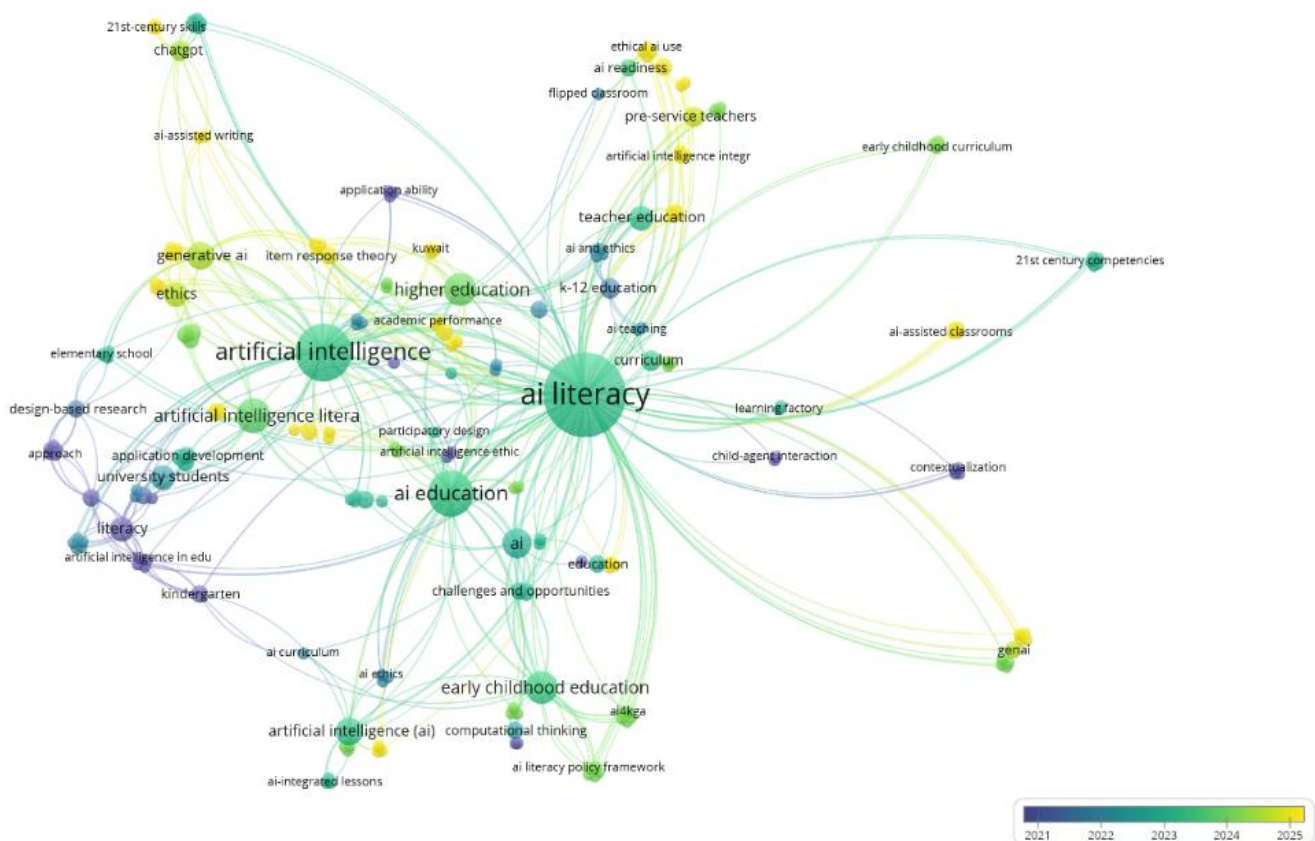


Fig. 6. VOSviewer AI Literacy - Overlay Visualization.

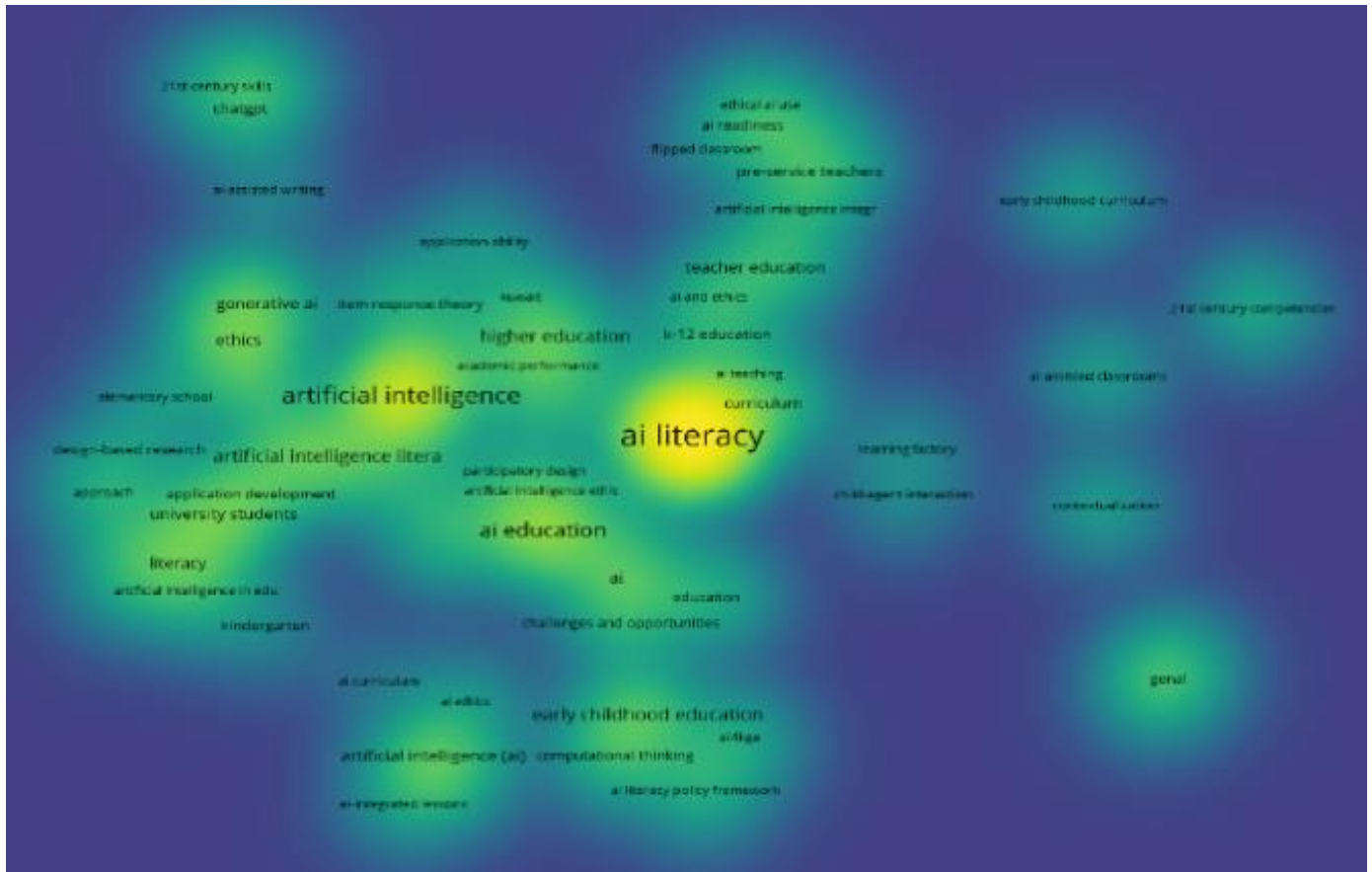


Fig. 7. VOSviewer AI Literacy - Density Visualization.

A. Discussion

1. Discussion on the Growth of AI Literacy Research

The number of publications about AI literacy has grown considerably since 2020, which points to AI literacy becoming an increasingly important field of study in education. This evolution can be credited to the quick adoption of AI in instructional strategies and, more recently, the widespread use of generative artificial intelligence (AI) technology. These findings are consistent with earlier reviews that outline the evolution of AI literacy from a nascent concept to a broader educational competency that includes ethical awareness, practical application, conceptual understanding, and critical evaluation (Chiu et al., 2024).

The big jump in publications in the recent period indicates that the advent of generative AI has quickened the need to reexamine what educators and students need to know about AI. Recent research has highlighted the need for AI literacy to extend beyond technical understanding to include critical evaluation of AI-generated output, awareness of the limitations of artificial intelligence systems, and responsible usage of artificial intelligence technology (Biagini, 2025; Jin et al., 2025). Thus, the growth noted in this review indicates an increase in the number of publications and a change in the conceptual scope of AI literacy research.

The uneven global development of AI literacy research is also reflected in the dominance of publications from technologically advanced countries such as Hong Kong, China, the U.S., and Europe. This pattern can be explained

by changes in educational policy, research capacity, technology infrastructure, and institutional readiness for the integration of AI. The future research agenda should look at how to conceptualize and operationalize AI literacy in different and changing educational contexts, beyond technologically advanced disciplines. Such dissemination is needed to avoid the development of AI literacy frameworks that are largely shaped by the educational systems and worldviews of technologically advanced countries.

2. Discussion on the Dominance of Empirical Studies

The inclusion of empirical studies in this review suggests that the AI literacy research space has transitioned from conceptual frameworks to understanding learner competencies, educational interventions, and factors shaping the use of AI. This is salient when considering the fast development of artificial intelligence (AI) technology that requires evidence of the successful development and assessment of AI literacy in various educational contexts. Research on AI literacy and its relationship to different educational outcomes is growing. Recently, several studies have examined AI literacy of university students around the world and its impact on academic performance, self-efficacy, use of AI, and quality of AI-generated results (Bećirović et al., 2025; Bewersdorff et al., 2025; Hornberger et al., 2025). These results indicate that AI literacy is moving from a conceptual construct to a measurable educational skill.

But it is also important not to forget that non-empirical research is important too. While there has been some recent conceptual and review work (Chiu et al., 2024), consensus on definitions, competency frameworks, and assessment tools of AI literacy is lacking. The field is moving in two directions. 1. Theoretical refinement. 2. Empirical confirmation. Future research should therefore integrate both approaches by developing theory-based frameworks that can be empirically tested across different educational contexts and cultural settings.

3. Talk about Target Group Distribution

The review found that research on AI literacy tends to focus on students in higher education. The emphasis is because digital technology and AI tools are relatively abundant in universities, and there is increasing pressure on institutions of higher education to prepare graduates for work environments driven by AI. More recently, research has also focused more on college students, developing and validating assessments of AI literacy and exploring students' understanding, attitudes, and use of artificial intelligence (AI) tools (Hornberger et al., 2023; Hornberger et al., 2025; Jin et al., 2025). But the overemphasis on higher education may cause an imbalance in the research development on AI literacy.

This neglect of elementary, secondary, and early childhood education is all the more surprising given that there is an increasing recognition of AI literacy as a core skill that should be developed progressively across the educational lifespan. Prior research has emphasized the need for developmentally and age-appropriate approaches when teaching AI in K-12 settings (Casal-Otero et al., 2023). Hence, future research should extend its university-centric approach to explore how AI literacy may be scaffolded from early childhood to secondary and higher education.

The findings also suggest the need for more research involving teachers. Instructors are critical to integrating an AI literacy framework into classroom practice; a lack of attention to teacher AI literacy may hinder the application of AI education. Recent studies (Al-Abdullatif, 2024; Kelley & Wenzel, 2025; Daher, 2025) emphasized the need for pre-service and in-service teachers to be prepared to understand and critically integrate AI into their teaching approaches. Thus, future research on AI literacy should pay more attention to teacher education and professional development.

4. Discussion on Emerging Themes: Generative AI and Ethics

The bibliometric data indicate a notable change in favor of emerging technologies, particularly generative AI and ChatGPT, as well as a rise in interest in ethical concerns. The understanding of how humans interact with more accessible and autonomous artificial intelligence systems has replaced the view of AI as a general technological phenomenon, as seen in the change in research on AI literacy. Generative AI has led to the emergence of new literacy requirements, including how to provide effective prompts, evaluate information produced by AI, identify bias and errors, understand data and privacy issues, and use AI responsibly.

The development of new assessment techniques that specifically target generative AI literacy suggests that traditional conceptions of AI literacy may no longer be adequate to meet the competencies required in the modern technological world (Jin et al., 2025).

The increasing focus on ethics in the scientific domain implies that AI literacy is not limited to technical competence. "Educators and learners need to be able to think critically about bias, accountability, privacy, transparency, and the impact of using AI on society. This aligns with existing theories regarding AI literacy as a multidimensional competence encompassing cognitive, ethical, critical, and practical dimensions (Chiu et al., 2024). Therefore, future educational programs should foster broad AI literacy (equipping students to use, evaluate, critique, and manage AI responsibly) rather than focusing solely on the artificial intelligence (AI) technology itself.

B. Implications

1. Theoretical Implications

The review also offers some theoretical implications for the development of research on AI literacy. First, results show that AI literacy has evolved from a mainly conceptual and technological skill to a multidimensional educational competence. As generative AI, ethics, critical review, and practical application become more important, future frameworks for AI literacy should include cognitive, technical, critical, and ethical aspects, as well as knowledge of artificial intelligence (AI) technology. This is consistent with emerging efforts to develop more comprehensive frameworks of AI competence and literacy (Chiu et al., 2024). Secondly, the unequal distribution of research across educational levels indicates the progressive approach to AI literacy. Future theoretical models should consider the ongoing development of AI literacy skills from childhood through higher education. Such models could help us move beyond limited studies of particular educational groups to a more comprehensive understanding of how lifelong AI literacy forms.

2. Educational and Curriculum Implications

This poses serious challenges for educational institutions and curriculum developers. The high concentration of research in higher education indicates that universities are the primary context for AI literacy development, at least for now. Yet a dearth of research in elementary, secondary, and early childhood education suggests the need to build age-appropriate AI literacy curricula throughout the education system. Therefore, educational institutions need to gradually integrate AI literacy into the educational programs and not view it as an isolated or optional technological skill. The curriculum should include basic knowledge of AI, skills to work with artificial intelligence systems, critical thinking about content produced by AI, and ethical considerations around privacy, bias, accountability, and responsible use. The rise of generative AI also means curriculum developers need to rethink existing online literacy curricula. Students need competencies to access digital information, but they also increasingly need competencies to evaluate the content

produced by artificial intelligence (AI) systems. This includes the ability to identify misinformation, identify potential bias, understand the limitations of AI-generated outputs, and make informed choices about when and how to use AI.

3. *Implications for Teacher Education and Professional Development*

The findings also demonstrate how important educators are to the successful application of AI literacy. Research involving pre-service and in-service teachers is less prevalent than research involving university students, despite their critical role. This imbalance has serious consequences since AI literacy cannot be successfully implemented in classrooms without teachers who have sufficient knowledge, confidence, pedagogical ability, and ethical consciousness regarding AI.

AI literacy should therefore be incorporated into teacher education programs through pre-service coursework and in-service professional development. Teachers should have the opportunity to learn about the principles of AI, evaluate instructional AI tools, create learning activities that are supported by AI, and think about the ethical ramifications of utilizing AI in the classroom. AI education rollouts at all educational levels may be more equitable and successful as a result of increased teacher AI literacy.

4. *Policy Implications*

At the level of policy, the results point to the importance of clearer national and institutional strategies for AI literacy education. The lack of standardisation in definitions, competency frameworks and measurement instruments may lead to disjointed implementation across institutions and educational systems.

Policymakers may want to develop flexible guidelines for AI literacy that specify shared competency domains but allow for local adaptation to educational, cultural, and technological contexts. Such policies should also tackle equity in access to technological advances in artificial intelligence and learning opportunities. In view of the geographical concentration of current research, international and national policies should give special attention to reducing disparities between technologically advanced and developing educational contexts.

5. *Implications for Future Research*

Several priorities for future research are identified in this review. First, more research is needed in early childhood, elementary, and secondary education. Second, more research is needed on teachers, particularly the effects of teacher AI literacy on classroom implementation and student learning. Third, future studies should develop and validate comprehensive AI literacy instruments, including cognitive, practical, and critical and ethical competencies. Cross-cultural validation is particularly important because existing AI literacy frameworks may not adequately capture differences in technological access, educational systems, and cultural values.

Finally, the fast pace of generative AI development necessitates longitudinal research to investigate the continued relevance of existing AI literacy frameworks as artificial intelligence (AI) technologies keep evolving. Hence, future research should focus not only on how individuals understand and use AI, but also on how AI literacy competencies need to adapt to emerging technologies and changing educational environments.

CONCLUSION

The outcomes of this systematic review answer the four research questions posed and provide an overview of the evolution of research on AI literacy in education over the last decade. The number of publications is increasing rapidly, particularly after 2020, indicating that academic interest in AI literacy is beginning to catch up with the exponential growth of technologies such as machine learning and generative AI. The distribution of the publications also shows the predominance of countries with strong technological and research capacities such as Hong Kong, China, the US, and European countries. Also, the publication type is mainly journal articles, especially the empirical ones. This shows that the field has moved from the exploratory phase to evidence-based validation, although the conceptual contributions are still relevant for the theoretical background.

The distribution of target groups shows that research on AI literacy is still mainly carried out in the framework of higher education. Students are the biggest group of participants. But there is still precious little research in elementary, secondary, and early childhood education. And again, the number of studies on teachers (pre-service and in-service) is disproportionate to their strategic role in the implementation of AI literacy. This suggests a bias in research focus that needs to be addressed in the interest of more inclusive and equitable AI literacy development across all education levels.

Furthermore, the bibliometric network analysis showed that the research field of AI literacy has developed into several large clusters that represent the thematic structure of the field. The cluster focuses on embedding AI literacy in formal education, including curriculum, higher education, and teacher education. The conceptual cluster points to an extension of the theoretical base, and the technology cluster points to emerging topics such as Generative AI, ChatGPT, and ethical issues. The application contexts of the target groups also differ, with higher education being the most salient one. The results reveal that research on AI literacy is moving in different directions and has conceptual, pedagogical, and technological dimensions.

Clearly, the trend of AI literacy research has evolved. The first phase of research is based on the study of pedagogy and basic concepts. It then looked at its use in curricula and learning practices. The latest phase has been characterized by the use of emerging technologies such as generative AI, ethical issues, and critical reading in the use of AI. Overlay and density visualizations reveal that core topics are still the focus of research, but there is some shift toward technology-based innovation and 21st-century necessary skills.

Nevertheless, the results of this review also underline some notable gaps in research. First, the research is limited to informal learning environments and primary schools. Secondly, it is not enough to focus on training teachers' competence as important players in the implementation of AI literacy. Third, the definitions, competency frameworks, and assessment tools for AI literacy are poorly standardized. Therefore, future research should engage in more inclusive learning models, teacher capacity building, and a comprehensive AI literacy framework with cognitive, ethical, and practical components.

The paper provides an in-depth mapping of the development of research on AI literacy and indicates the future research directions. The implications of the findings will likely have a profound impact on curriculum development, educational policy, and future research projects on how to promote the sustainable and successful adoption of AI literacy in the digital transformation age.

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