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From Digital Literacy to AI Literacy: Developing a Comprehensive Framework for the Age of Artificial Intelligence

Maria Ranieri[a], Gabriele Biagini[b], Stefano Cuomo[c]

[a]*University of Florence, Italy, maria.ranieri@unifi.it; https://orcid.org/0000-0002-8080-5436*
[b]*University of Florence, Italy, gabriele.biagini@unifi.it, https://orcid.org/0000-0002-6203-122X*
[c]*University of Florence, Italy, stefano.cuomo@unifi.it, https://orcid.org/0000-0003-3174-7337*

Abstract

As artificial intelligence (AI) increasingly permeates various sectors, existing digital literacy frameworks prove insufficient for addressing the unique challenges posed by autonomous, data-driven AI systems. This study aims to develop a comprehensive AI literacy framework that extends traditional digital literacy models to encompass the competencies required for effective and ethical engagement with AI technologies.
Through a multi-phase research process conducted between 2022 and 2025, we employed two scoping reviews and one systematic literature review. The first phase analysed 35 articles on AI literacy conceptualization, the second examined 12 studies on AI literacy assessment tools, and the third systematically reviewed 87 studies from an initial pool of 323 records across major databases including Web of Science, SCOPUS, ERIC, and IEEE Xplore.
Building on Calvani et al. (2009) digital literacy framework, we propose an AI literacy framework with four interconnected dimensions: cognitive (understanding AI concepts and mechanisms), operational (practical skills for AI interaction and application), critical (evaluating AI-generated content and societal impacts), and ethical (navigating moral implications and responsible AI use). The framework addresses key gaps in how AI literacy is conceptualized, moving beyond tool-based competencies to include understanding of autonomous systems.
The transition from digital to AI literacy represents a paradigm shift requiring new competencies for educational, professional, and societal contexts. The framework provides a foundation for curriculum development, assessment design, and policy formulation to ensure individuals can critically engage with AI technologies while addressing their ethical and social implications.

Keywords: *Artificial Intelligence, AI Literacy, Digital Literacy, Educational Framework, AI Ethics, Systematic Review*

Introduction

Since its inception in the mid-20th century, artificial intelligence (AI) has transitioned from a nascent concept to a pervasive and integral part of modern society. Originally coined in 1956 by John McCarthy, AI was defined as "the science and engineering of making intelligent machines" (McCarthy, 2007, p. 2). Over the decades, AI has undergone significant evolution, driven by interdisciplinary contributions from fields such as computer science, mathematics, neuroscience, cognitive science, and linguistics (Russell & Norvig, 2021; Wang, 2019). This collaborative development has resulted in the creation of complex AI systems capable of tasks such as sensory perception, machine learning, natural language processing, and reasoning, all of which are increasingly embedded in daily life (Zawacki-Richter et al., 2019). Today, AI is no longer confined to academic or research settings but is deeply intertwined with many facets of society, including education, healthcare, marketing, and entertainment (Author et al., 2023; Chen et al., 2020; Hwang et al., 2020). The World Economic Forum's Future of Jobs Report (2020) predicts that by 2025, AI will significantly reshape the global labor market, leading to both the displacement of traditional jobs and the creation of new ones. In this rapidly changing landscape, AI literacy is emerging as a critical skill set, akin to the fundamental importance of reading and writing in previous industrial revolutions (Kandlhofer et al., 2016).

AI's expansion into everyday applications has raised important questions about how individuals, both experts and non-experts, interact with these systems. As AI becomes ubiquitous, there is growing concern that most people use AI-driven technologies without fully understanding how these systems operate or the potential ethical challenges they pose. Issues such as algorithmic bias, data privacy, and AI-based surveillance have garnered increasing attention, with scholars warning of the need for informed decision-making regarding AI governance and usage (Burgsteiner et al., 2016; Ghallab, 2019). Indeed, the ability to critically evaluate and engage with AI systems, what is now being referred to as AI literacy, is fast becoming an essential competence for citizens navigating an increasingly automated world.

The concept of AI literacy builds upon but also extends beyond the traditional notions of digital literacy, which focus on the ability to navigate, interpret, and create digital content (Calvani et al., 2012; Gilster, 1997). AI literacy encompasses a broader set of competences that involve not only understanding AI as a technological tool but also grasping its underlying mechanisms and societal implications. According to Long & Magerko (2020), AI literacy involves three main areas: acquiring foundational knowledge of AI concepts and techniques, developing a critical understanding of how AI systems function and make decisions, and integrating AI competences into a process of lifelong learning that emphasizes ethical and responsible use. These skills are crucial for enabling individuals to collaborate effectively with AI technologies and to make informed choices about their deployment in various contexts (Miao et al., 2021).

As AI continues to evolve, its impact is expected to be profound not only in the workplace but also in terms of personal, social, and educational interactions. However, despite its growing influence, there is still a significant knowledge gap regarding AI among the general population. Studies have shown that while many people regularly interact with AI-driven tools, such as virtual assistants, recommendation systems, or autonomous vehicles, they often do so without a comprehensive understanding of how these technologies function or the broader implications of their use (Ng et al., 2021; Touretzky et al., 2019; Author et al., 2024b). This gap in understanding could exacerbate existing social inequalities, as those who are AI literate may have greater opportunities to benefit from these technologies, while those who lack such literacy could face marginalization or exclusion.

Furthermore, the rise of AI introduces complex ethical dilemmas. AI systems can perpetuate biases found in the data they are trained on, leading to discriminatory outcomes that disproportionately affect certain groups (Ghallab, 2019). Similarly, the widespread use of AI in surveillance systems raises concerns about privacy and civil liberties (Burgsteiner et al., 2016). These challenges highlight the importance of developing AI literacy as a means of empowering individuals to not only use AI technologies responsibly but also to participate in informed debates about their regulation and ethical use. Scholars such as Long & Magerko (2020) argue that fostering AI literacy is crucial for ensuring that individuals can critically assess the societal impacts of AI and advocate for policies that promote fairness, transparency, and accountability.

At the same time, AI literacy is becoming increasingly relevant in education. As AI-driven tools become more prevalent in classrooms, educators must be equipped with the knowledge and skills to integrate these technologies effectively into teaching and learning processes. This requires a shift in pedagogical approaches, from merely using digital tools to fostering an understanding of how AI systems function and how they can be leveraged to enhance educational outcomes (Steinbauer et al., 2021). In this sense, AI literacy is not just about technical competence but also about fostering a deeper understanding of the broader social, cultural, and ethical dimensions of AI.

In this paper, we propose a theoretical framework for AI literacy, building on existing models of digital literacy while acknowledging the unique challenges posed by AI. While digital literacy has traditionally focused on skills like media interpretation and online communication, AI literacy introduces new dimensions, including the ability to understand machine learning algorithms, engage with AI in collaborative tasks, and navigate the ethical complexities of AI deployment. This transition from digital literacy to AI literacy marks a critical shift in the broader conversation around technological literacy, as the skills required to engage with AI systems extend far beyond those traditionally associated with digital technologies.

Research Questions

This study aims to address the following research questions that guide our investigation into the evolving landscape of AI literacy:

RQ1: What are the key dimensions and competencies that distinguish AI literacy from traditional digital literacy frameworks?

RQ2: How can existing digital literacy models, particularly the framework by Calvani et al. (2009), be extended to encompass the unique challenges posed by AI technologies?

RQ3: What are the essential components of a comprehensive AI literacy framework that addresses both technical competencies and ethical considerations?
RQ4: What are the theoretical and practical implications of implementing AI literacy frameworks in educational settings?

1. Theoretical Background

1.1. The Evolution of Digital Literacy

The concept of digital literacy has evolved significantly over the past few decades, reflecting the growing importance of digital technologies in various aspects of life. Initially, digital literacy was largely defined by the ability to use computers and other digital devices for basic tasks, such as word processing, internet browsing, and email communication (Bawden, 2008). However, as digital technologies advanced and became more integrated into everyday activities, the definition of digital literacy expanded to encompass a broader set of skills, including the ability to critically evaluate digital information, create digital content, and navigate complex digital environments.

Paul Gilster is often credited with pioneering the concept of digital literacy in his seminal work Digital Literacy (1997), where he defines it as "the ability to understand and use information in multiple formats from a wide range of sources when it is presented via computers." Gilster's definition emphasizes not just the technical skills of operating digital devices, but also the cognitive and evaluative skills required to critically engage with digital media. Similarly, Livingstone (2004) emphasized the role of digital literacy in fostering critical thinking and media awareness, particularly in relation to the consumption and production of digital content.

As digital literacy became a key competence in education, various frameworks were developed to formalize the skills and knowledge required. Calvani et al. (2012) proposed a model of digital literacy that includes three key dimensions: the technical and operational ability to use digital tools, the cognitive ability to critically interpret and evaluate digital content, and the ethical ability to understand the social and cultural implications of digital technologies. This model reflects the increasing recognition that digital literacy is not just about technical competence but also about engaging with the broader societal impacts of digital technologies.

Beyond the work of Calvani and colleagues, the European policy context has produced two reference frameworks of particular relevance for situating the present discussion. The Digital Competence Framework for Citizens (DigComp), originally developed by Ferrari (2012, 2013) within the Joint Research Centre and subsequently refined through several iterations up to DigComp 2.2 (Vuorikari et al., 2022), articulates digital competence across five interrelated areas: information and data literacy, communication and collaboration, digital content creation, safety, and problem solving. Its educator-oriented counterpart, the European Framework for the Digital Competence of Educators (DigCompEdu; Redecker, 2017), translates these competences into the professional practice of teachers, identifying six areas of educators' digital competence and progression levels modelled after the Common European Framework of Reference for Languages. At the international level, the UNESCO ICT Competency Framework for Teachers (UNESCO, 2018), now in its third version, organises teachers' digital competences along three levels of progression—knowledge acquisition, knowledge deepening, and knowledge creation—across six aspects of professional practice, and explicitly addresses recent technological developments such as artificial intelligence and the Sustainable Development Goals. Together, these frameworks have shaped curriculum design, teacher education and certification across Europe and beyond, and constitute the institutional backdrop against which the present discussion of AI literacy needs to be situated.

Digital literacy is also closely linked to the concept of media literacy, which focuses on the critical consumption of media content across various platforms. Buckingham (2003) argued that media literacy is essential in the digital age, as it enables individuals to navigate the vast amount of information available online, recognize biases, and understand the ways in which media shapes public opinion and culture. The integration of media literacy into digital literacy frameworks underscores the importance of critical thinking and information evaluation in an increasingly media-saturated world.

Despite the increasing complexity of digital technologies, digital literacy remains a foundational skill in modern education systems. It equips individuals with the ability to engage with digital tools and information in a way that promotes critical thinking, creativity, and responsible participation in digital societies. However, as artificial intelligence (AI) becomes more prevalent, there is a growing recognition that digital literacy, as traditionally conceived, is no longer sufficient to prepare individuals for the challenges posed by AI-driven technologies.

1.2. Digital Literacy in the Age of AI

As the digital landscape evolves, the concept of digital literacy has been challenged by the emergence of artificial intelligence and the increasing automation of digital systems. While digital literacy frameworks have been effective in promoting critical engagement with digital content, they often fail to address the unique challenges posed by AI technologies, such as machine learning algorithms, automated decision-making, and data-driven systems. These technologies operate in ways that are fundamentally different from the tools traditionally associated with digital literacy.

One of the key limitations of digital literacy frameworks is their focus on human interaction with digital content, rather than the autonomous nature of AI systems. Tuomi (2020) argues that AI technologies differ from traditional digital tools

because they are designed to perform tasks that go beyond human control or direct input. For example, machine learning algorithms can analyze vast amounts of data, identify patterns, and make decisions without human intervention. This level of autonomy requires new forms of literacy that enable individuals to understand and critically assess how these systems function, how decisions are made, and what ethical implications arise.

Furthermore, the widespread use of AI-driven systems in areas such as education, healthcare, and governance has highlighted the need for a deeper understanding of how AI technologies impact society. AI systems are increasingly used to automate tasks that were previously performed by humans, raising concerns about job displacement, data privacy, and algorithmic bias. Eubanks (2018) highlights the dangers of algorithmic decision-making in public services, where AI systems have been shown to perpetuate biases against marginalized communities. Similarly, Noble (2018) emphasizes the role of AI in reinforcing existing social inequalities, particularly in relation to race and gender.

These challenges reveal a fundamental gap in traditional digital literacy frameworks, which do not account for the ways in which AI systems interact with and shape human behavior. As AI technologies become more sophisticated and embedded in daily life, there is a pressing need to expand the concept of literacy to include competences related to understanding and engaging with AI systems. This shift from digital literacy to AI literacy reflects the growing importance of equipping individuals with the skills needed to navigate an increasingly AI-driven world.

1.3. The Emergence of AI Literacy

AI literacy is a relatively new concept, but it is rapidly gaining traction as a necessary competence in the modern digital landscape. Scholars have begun to define AI literacy as the ability to understand AI technologies, engage with AI-driven systems, and critically evaluate their societal and ethical implications (Long & Magerko, 2020). Unlike digital literacy, which focuses on the ability to use and interpret digital content, AI literacy emphasizes the need to understand how AI systems function, how they make decisions, and what ethical considerations arise from their use.

One of the most comprehensive definitions of AI literacy comes from Miao et al. (2021), who outline three key dimensions of AI literacy: knowledge of AI concepts and technologies, understanding of how AI systems operate, and critical awareness of the ethical and societal impacts of AI. This framework reflects the interdisciplinary nature of AI literacy, as it draws on insights from computer science, ethics, cognitive science, and social theory to provide a holistic understanding of AI.

The growing importance of AI literacy is also reflected in educational initiatives aimed at preparing students for an AI-driven future. Touretzky et al. (2019) argue that AI literacy should be integrated into the curriculum at all levels of education, from primary school to university, to ensure that students are equipped with the skills needed to understand and work with AI technologies. This includes not only technical skills, such as programming and data analysis, but also critical thinking skills that enable students to assess the ethical implications of AI systems.

Moreover, AI literacy is increasingly recognized as a necessary competence for all individuals, not just AI experts. As AI technologies become more pervasive in everyday life, non-experts must also be able to engage with these systems in meaningful ways. Ng et al. (2021) emphasize that AI literacy should be accessible to all, regardless of technical expertise, as many individuals will interact with AI systems in their personal and professional lives. This democratization of AI literacy is seen as essential for promoting equity and ensuring that all individuals can benefit from the opportunities created by AI technologies.

Furthermore, as AI technologies become more integrated into society, the ethical and societal implications of these systems have become a central focus of AI literacy frameworks. One of the key challenges in promoting AI literacy is ensuring that individuals are not only equipped with the technical skills to engage with AI systems, but also with the critical awareness needed to navigate the ethical dilemmas posed by these technologies.

AI systems often operate as "black boxes," where the decision-making processes are not transparent or easily understood by users. This lack of transparency raises concerns about accountability and fairness, particularly in cases where AI systems are used to make decisions that affect people's lives, such as in criminal justice, healthcare, and hiring (Author et al., 2024; Pasquale, 2015). Promoting algorithmic transparency and ensuring that individuals understand how AI systems make decisions is a key component of AI literacy.

In addition to issues of transparency, AI literacy also involves understanding the biases that can be embedded in AI systems. Machine learning algorithms are trained on large datasets, and if these datasets contain biased or incomplete data, the AI systems can reproduce and even amplify these biases. O'Neil (2016) warns of the dangers of "weapons of math destruction," where biased algorithms lead to discriminatory outcomes in areas such as education, employment, and finance.

To address these challenges, AI literacy must include a focus on ethical decision-making and the social responsibilities of AI developers and users. Bostrom and Yudkowsky (2014) argue that ethical considerations should be central to the development and deployment of AI systems, particularly in relation to issues of bias, privacy, and surveillance. This ethical dimension of AI literacy is crucial for ensuring that AI technologies are used in ways that promote fairness, transparency, and accountability.

1.4. The Evolution from Digital Literacy to AI Literacy

As technology continues to evolve, the concept of digital literacy, once seen as the foundation for navigating the digital world, is being challenged by the rise of artificial intelligence (AI). Digital literacy has long been associated with the ability to access, evaluate, and produce information through digital platforms. This involves a broad set of skills, including the technical capacity to use digital tools, the cognitive ability to critically evaluate digital content, and the ethical understanding of how digital technologies impact society (Gilster, 1997; Calvani et al., 2012). These skills have become essential in a world where individuals constantly interact with digital media, social networks, and online resources.

However, the rapid proliferation of AI technologies requires a deeper and more specialized set of skills, known as AI literacy. While digital literacy focuses primarily on the interaction between humans and digital systems, AI literacy requires individuals to understand and interact with systems that operate autonomously, driven by algorithms and large datasets. This distinction marks a significant shift in the types of competencies required in a world where AI plays an increasingly central role.

Digital literacy equips individuals with the skills to consume and create digital content, but it does not necessarily include an understanding of the underlying mechanisms that drive AI systems. For example, a digitally literate person might be proficient in using social media platforms or creating multimedia content, but this does not imply that they understand how the recommendation algorithms of those platforms function, nor the data-driven processes that shape their interactions. As AI systems become more prevalent in various domains—ranging from personal assistants to complex decision-making systems in healthcare and finance—the ability to critically engage with these technologies becomes crucial.

In contrast, AI literacy involves not only the technical ability to use AI-driven systems but also a deeper understanding of how these systems work. This includes knowledge of machine learning processes, the ability to interpret the outputs of AI algorithms, and the competence to assess the limitations and biases inherent in AI models (Miao et al., 2021; Long & Magerko, 2020). AI literacy demands that individuals recognize the distinction between tools that simply respond to user inputs and those that autonomously adapt, predict, and make decisions based on vast amounts of data.

A key difference between the two concepts lies in the nature of the systems being used. Digital literacy pertains to systems that are largely deterministic: users input data, and the system reacts in predictable ways based on that input. Conversely, AI literacy deals with systems that are probabilistic in nature, relying on statistical models and algorithms that learn from data, often in ways that are opaque even to the developers who created them. This unpredictability and autonomy introduce a new layer of complexity that digital literacy frameworks were not designed to address.

Moreover, AI literacy introduces a critical awareness of the societal and ethical impacts of AI systems, which extend far beyond the scope of traditional digital literacy. For example, AI systems often rely on vast datasets that can inadvertently perpetuate societal biases, as has been widely documented in cases where machine learning algorithms reinforce racial or gender discrimination (Eubanks, 2018; Noble, 2018). Understanding these implications is a central aspect of AI literacy, as individuals must be equipped not only to use AI technologies but also to critically assess their fairness, transparency, and accountability (Author et al., 2025; Author et al., 2024a).

The distinction between digital literacy and AI literacy is not merely a matter of adding new technical skills to the digital literacy framework. Rather, it represents a paradigm shift in how we engage with technology. While digital literacy was largely concerned with human-driven processes mediated by digital tools, AI literacy deals with technologies that can act independently, learn from data, and make decisions that affect human lives in profound ways. This shift calls for a rethinking of educational frameworks and a more comprehensive approach to preparing individuals for the challenges posed by AI systems.

In summary, while digital literacy provides a crucial foundation for interacting with the digital world, it is no longer sufficient in the context of AI. AI literacy requires a more advanced set of competencies that encompass not only technical skills but also a deeper understanding of how AI systems function, how they

make decisions, and what ethical challenges they present. As AI continues to shape society in increasingly complex ways, fostering AI literacy will be essential for enabling individuals to navigate and critically engage with these transformative technologies.

2. Methodology

2.1. Research Design

This study employed a multi-phase systematic approach combining scoping reviews and a systematic literature review to develop and refine the AI literacy framework. The research was conducted over three phases between 2022 and 2025, following established guidelines for scoping reviews (Arksey & O'Malley, 2005) and systematic reviews (PRISMA guidelines; Page et al., 2021). This iterative approach allowed for progressive refinement of our understanding of AI literacy and its relationship to traditional digital literacy frameworks.

2.2. Phase 1: Initial Scoping Review (2022)

The first phase aimed to explore foundational themes of AI literacy and identify existing frameworks within the domain. We searched four major databases (SCOPUS, ERIC, IEEE Xplore, and Ebsco) for articles published between January 2015 and December 2022, using search strings that combined terms related to artificial intelligence literacy, frameworks, models, competencies, education, and learning.

Our inclusion criteria focused on peer-reviewed articles in English that addressed AI literacy conceptualization or frameworks within educational contexts. We excluded conference abstracts without full papers, articles focused solely on technical AI without literacy components, non-English publications, and grey literature. The initial search yielded 68 records. After removing 7 duplicates, 61 records remained. Through title and abstract screening and full-text assessment, 35 articles were included in the final analysis.

Two researchers independently extracted data using a standardized form that captured AI literacy definitions, framework components, educational applications, and theoretical foundations. We conducted thematic analysis using Braun and Clarke's (2006) six-phase approach, which allowed for the identification of recurring themes and patterns across the literature. The synthesis of these findings enabled the formulation of our initial conceptual framework of AI literacy, positioning it as a key competence for navigating AI technologies effectively and responsibly (Author et al., 2022).

2.3. Phase 2: Assessment Tools Scoping Review (2023)

Building on the findings of the 2022 review, we conducted a second scoping review focusing on assessment tools used to evaluate individuals' self-perception of their AI literacy. This phase employed databases including Web of Science, SCOPUS, ERIC, and IEEE Xplore, searching for articles published between January 2018 and June 2023. Our search strings specifically targeted studies on AI literacy assessment, evaluation, measurement tools, and instruments.

The selection criteria mirrored Phase 1 but with additional focus on studies presenting assessment instruments and validation studies of AI literacy tools. The initial search produced 88 records. After removing duplicates, 32 records remained for screening. Following title and abstract screening, 24 reports were assessed for eligibility, with 12 studies included in the final analysis. These studies examined 12 distinct assessment tools that reflected a multi-dimensional approach to AI literacy, encompassing affective, behavioral, cognitive, and ethical components. The findings informed the development of our AI literacy framework, designed to align with the conceptual understanding developed in 2022 (Author, 2024).

2.4. Phase 3: Systematic Literature Review (2024–2025)

The third phase, conducted between early 2024 and early 2025, consisted of a systematic literature review aimed at updating and refining the AI literacy framework in light of the most recent research developments. The literature search and screening were carried out during 2024, while data extraction, quality appraisal and synthesis were completed in January 2025, when the search was also updated to include publications up to that date. We searched Web of Science, SCOPUS, ERIC, and IEEE Xplore for articles published between January 2020 and January 2025, using comprehensive search strings that combined terms related to AI literacy, artificial intelligence literacy, AI competencies with education, frameworks, models, curricula, ethics, critical thinking, and social implications.

Following PRISMA guidelines, we identified 323 records, removed 67 duplicates, screened 256 records, assessed 124 full-text articles, and ultimately included 87 studies in our synthesis. Each study was assessed using the Mixed Methods Appraisal Tool (MMAT) by two independent reviewers, with disagreements resolved through discussion with a third reviewer. We employed a narrative synthesis approach, organizing findings according to AI literacy dimensions, educational contexts (K-12, higher education, professional), ethical and social considerations, and implementation strategies. This systematic review identified several central themes related to AI literacy, including the ethical and social implications of AI, the role of AI literacy in K-12 education, and the integration of AI in workplace settings (Author, 2025).

2.5. Framework Development Process

The AI literacy framework was developed iteratively through initial conceptualization based on Phase 1 findings, refinement incorporating assessment dimensions from Phase 2, and validation and expansion using Phase 3 systematic review results. We also conducted expert consultations with five AI education researchers and mapped our findings to existing digital literacy frameworks, particularly Calvani et al. (2009).

3. Results & Discussion

3.1. Overview of Findings

The multi-phase research process yielded progressive insights that shaped our AI literacy framework. Table 1 summarizes the key findings from each phase of our methodology, demonstrating how our understanding of AI literacy evolved through systematic investigation.

Table 1. Summary of Key Findings by Research Phase

Phase	Studies Analysed	Key Findings	Contribution to Framework
Phase 1 (2022)	35 articles	Identified three core themes: technical understanding, critical evaluation, ethical awareness	Initial conceptualization of multi-dimensional framework
Phase 2 (2023)	12 studies	Revealed four assessment dimensions: cognitive, operational, critical, ethical	Refined dimension definitions and assessment approaches
Phase 3 (2024–2025)	87 studies	Confirmed framework dimensions and added emphasis on societal impact and discrimination awareness	Validated and expanded framework with contemporary concerns

3.2. Transitioning from Digital Literacy to Artificial Intelligence Literacy

Our systematic analysis revealed a clear evolution from traditional digital literacy frameworks to the emerging AI literacy paradigm. Across the studies analysed in our three phases, we identified consistent themes that distinguish AI literacy from its digital predecessor, while also recognizing important continuities between the two concepts.

The journey from digital literacy to artificial intelligence literacy represents not a simple linear progression, but rather a rich tapestry of technological, social, and educational shifts. The foundational work of Calvani, Fini and Author (2009) provides a crucial starting point for understanding this evolution. Their framework for digital literacy encompassed three key dimensions that continue to resonate in the AI age, albeit with significant expansions and modifications.

The technological dimension in their framework focused on the technical-operational skills required to effectively use digital tools, emphasizing the importance of agility in adapting to rapidly evolving technologies and the ability to explore

and adopt new tools. This dimension promoted not merely knowledge of specific tools but also a flexible mindset to navigate the digital landscape. The cognitive dimension related to critical thinking and information evaluation, requiring individuals to not only process information but to discern its reliability, organize data systematically, and create abstract models from it. This cognitive aspect resonated with earlier definitions of digital literacy, such as that of Paul Gilster (1997), who emphasized the ability to critically engage with digital content and make informed judgments about the information encountered. Finally, the ethical dimension focused on the social and ethical responsibilities associated with digital environments, stressing the need to understand netiquette and privacy rights, to ensure respectful behavior online, and to navigate the ethical challenges posed by digital interactions.

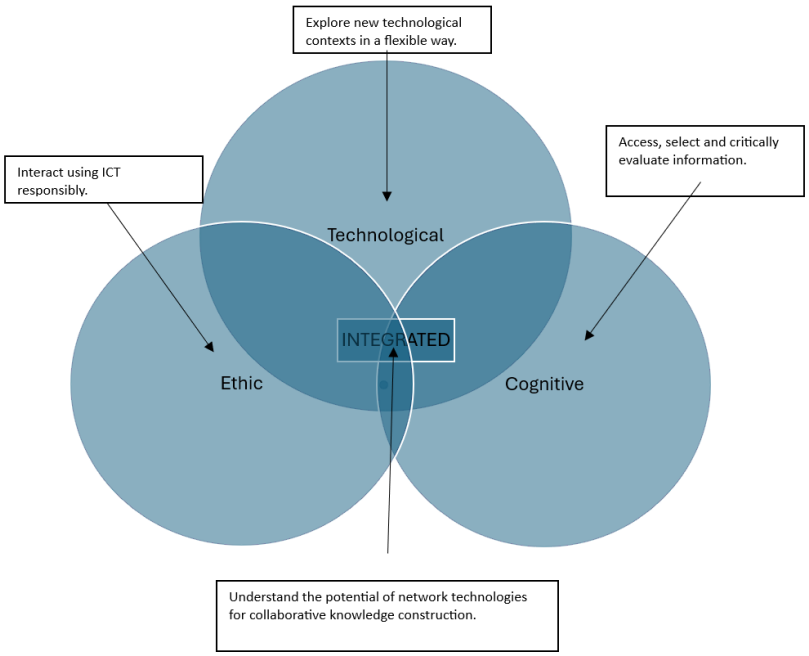

Fig. 1 Digital Competence Framework (Calvani, Fini & Ranieri, 2009)

While both digital and AI literacies share common ground in emphasizing ethical considerations, the nature and depth of these considerations differ significantly. Digital literacy focuses on responsible behavior within cyberspace, addressing issues such as online etiquette, privacy protection, and appropriate digital communication. In contrast, AI literacy delves deeper into the implications of AI-driven decisions, grappling with complex questions about algorithmic transparency, systemic fairness, and the protection of fundamental human rights in an age of automated decision-making. As Tuomi (2020) and Eubanks (2018) have demonstrated, these concerns extend far beyond individual behavior to encompass societal-level impacts.

The concept of functionality serves as another bridge between digital and AI literacy. Both frameworks reject the notion of passive technology consumption, instead encouraging individuals to understand, create, and critically assess tools, whether digital or AI-powered. However, the nature of this engagement differs substantially. While digital literacy emphasizes the reading, selection, and evaluation of data, AI literacy introduces individuals to the core principles of machine learning and the multifaceted functionalities of AI systems. This shift requires not just an understanding of how to use tools, but comprehension of how these tools learn, adapt, and make decisions autonomously.

The differences between digital and AI literacy become particularly pronounced when we examine the depth of understanding required. AI literacy demands comprehension of the intricate mechanisms that power AI tools, not simply their usage. The operational field also shows marked differences: while digital literacy is anchored in direct tools and applications that respond predictably to user inputs, AI literacy ventures into the intricate world of algorithms, requiring a grasp of how AI processes unfold through probabilistic reasoning and pattern recognition.

Perhaps most significantly, the societal ramifications of these literacies differ in both magnitude and immediacy. The societal implications embedded in digital literacy, while significant, pale in comparison to the immediate and far-reaching impacts of AI systems. AI literacy necessarily shifts focus toward understanding the broader, sometimes irreversible, impact of AI decisions in critical domains such as education, healthcare, criminal justice, and employment. This expanded scope reflects the reality that AI systems increasingly make or influence decisions that directly affect human lives and opportunities.

Several imperatives drive this essential shift from digital to AI literacy. The permeation of AI technologies throughout daily life—from recommendation systems to autonomous vehicles—calls for a deeper comprehension than what traditional digital literacy offers. AI systems now play instrumental roles in critical decision-making processes across sectors, necessitating detailed understanding to ensure these decisions are ethical, transparent, and just. As society evolves and becomes more intertwined with AI, this enhanced form of literacy guarantees that individuals are prepared not merely as consumers but as informed creators, critics, and overseers of AI technology.

Furthermore, as AI tools become increasingly democratized and accessible to non-technical users, there is an amplified need to ensure that individuals are not only utilizing these tools but also understanding and evaluating their broader implications. This democratization brings both opportunities and risks: while it enables wider access to powerful AI capabilities, it also increases the potential for misuse, manipulation, or unintended consequences if users lack adequate understanding of these systems.

In essence, the evolution from digital literacy to AI literacy represents more than a natural progression—it constitutes an essential adaptation to our changing technological landscape. As AI embeds itself more profoundly into societal structures, from educational systems to democratic processes, expanding our literacy frameworks becomes not just beneficial but imperative. This expansion ensures an informed, ethical, and equitable coexistence with AI, marking our transformative journey from mere digital users to informed inhabitants of an AI-augmented world.

3.3. The AI Literacy Framework

In response to the limitations of existing digital literacy models in addressing the unique challenges posed by artificial intelligence, our research has led to the development of a comprehensive AI literacy framework. This framework, synthesized from our multi-phase research process, consists of four interconnected dimensions that both build upon and extend beyond traditional digital literacy concepts.

The Cognitive Dimension focuses exclusively on knowledge and understanding of AI systems. This dimension encompasses foundational AI concepts including understanding what AI is, distinguishing between narrow and general AI, and grasping basic principles of machine learning. It requires comprehension of how AI systems process data, learn patterns, and make decisions, as well as recognition of various AI applications in daily life such as natural language processing, computer vision, and recommendation systems. Crucially, this dimension also includes data literacy—understanding the role of data in AI systems, including how data is collected, processed, and how biases can emerge from data selection and preparation.

The Operational Dimension encompasses the practical skills and competencies needed to interact with and utilize AI systems effectively. This includes the ability to use AI-powered applications and services effectively, apply AI tools to address real-world problems, and for more advanced learners, understand simple AI programming concepts. It also involves developing collaborative skills to work effectively alongside AI systems as co-creative partners and maintaining adaptive learning capabilities to continuously update skills as AI technologies evolve.

The Critical Dimension addresses the crucial ability to analyse and evaluate AI systems and their outputs. Following the recommendations from our systematic review and addressing contemporary concerns about algorithmic bias, this dimension focuses on assessing the quality, accuracy, and reliability of AI-generated content; identifying potential biases in AI systems and their outputs; analysing AI's effects on society including job displacement, privacy concerns, and social dynamics; understanding the limitations of AI "black boxes" and demanding explainability; and recognizing how AI can disproportionately affect certain groups through discriminatory outcomes.

The Ethical Dimension encompasses values and responsible use of AI technologies. This includes understanding data rights and consent in AI systems, recognizing and advocating for equitable AI systems, comprehending who is responsible for AI decisions and outcomes, maintaining appropriate human oversight and decision-making authority, and considering broader implications of AI deployment on communities and society at large.

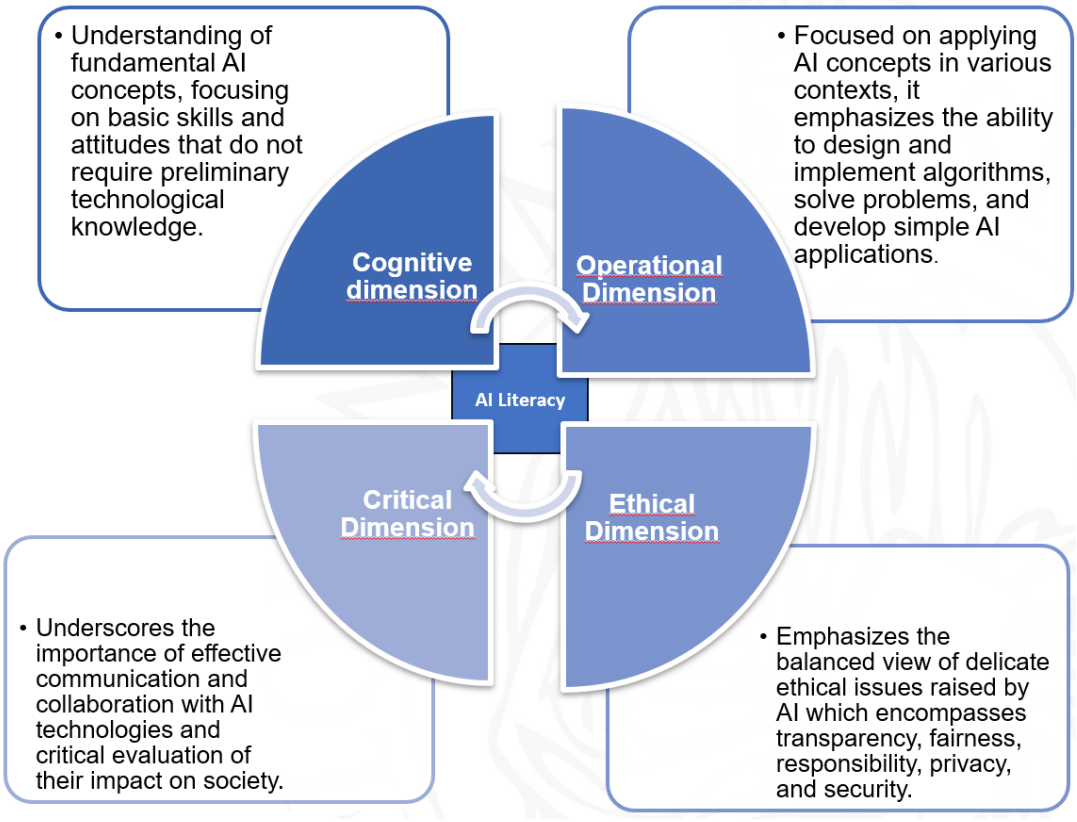

Fig. 2 The Proposed AI Literacy Framework

These four dimensions function not in isolation but as an integrated whole. Cognitive understanding provides the foundation for developing operational skills, which in turn enable more sophisticated critical evaluation. Critical analysis naturally leads to ethical considerations, while ethical awareness should inform all other dimensions. This interconnected nature reflects the complexity of AI literacy and the need for holistic approaches to its development.

The framework is designed to be scalable across different educational levels and contexts, from K-12 education to professional development programs. It can adapt to evolving technological advances, ensuring continued relevance as AI systems become more sophisticated. Importantly, it remains accessible to both technical and non-technical audiences, recognizing that AI literacy is essential for all members of society, not just technology specialists. Finally, it is actionable, translatable into concrete educational objectives and learning outcomes that educators can implement in various settings.

These findings set the stage for a broader reflection on their implications, which we outline in the following section.

4. Implications

4.1. Implications for Theory

This study contributes to the theoretical understanding of literacy in the digital age by demonstrating that AI literacy represents a qualitative shift in literacy theory, not merely an extension of digital literacy. Our framework challenges existing conceptualizations of technological literacy as primarily tool-based competencies. Instead, we argue that contemporary literacy must encompass understanding of autonomous systems that can learn and make decisions independently, often in ways that are opaque even to their creators. This shift from deterministic to probabilistic systems represents a fundamental change in the nature of human-technology interaction.

The interdisciplinary nature of our AI literacy framework also highlights the need for theoretical approaches that transcend traditional disciplinary boundaries. By integrating insights from education, computer science, ethics, and cognitive science, our framework suggests that future literacy theories must be inherently interdisciplinary. This integration is not merely additive but synergistic, as understanding AI literacy requires simultaneous consideration of technical mechanisms, cognitive processes, ethical implications, and social contexts.

Furthermore, our research introduces a temporal dimension to literacy theory that has been underexplored in previous frameworks. Unlike traditional literacy models that assume relatively stable competencies once acquired, AI literacy is

inherently dynamic, requiring continuous adaptation as AI technologies evolve. This dynamism challenges educational theorists to reconceptualize literacy not as a fixed set of skills but as an adaptive capability that must be continuously renewed and refined throughout one's lifetime.

4.2. Implications for Policy and Practice

The practical implications of our AI literacy framework extend across educational, professional, and societal domains. In educational policy, our findings suggest that AI literacy should be integrated across all educational levels, not as a separate subject but woven throughout existing disciplines. This integration requires careful curriculum design that balances technical understanding with critical and ethical considerations. Mathematics classes might explore algorithmic thinking, while social studies courses examine AI's impact on employment and democracy. Language arts could address the implications of AI-generated content for communication and creativity.

In this respect, the four-dimensional AI literacy framework proposed here is intended not as a substitute for established digital competence frameworks such as DigComp (Ferrari, 2012; Vuorikari et al., 2022), DigCompEdu (Redecker, 2017) or the UNESCO ICT Competency Framework for Teachers (UNESCO, 2018), but as a complementary lens that extends them to the specific challenges raised by autonomous, data-driven systems. Future work on European curricular and teacher-training policy should therefore explore how the cognitive, operational, critical and ethical descriptors articulated in this study can be mapped onto, and integrated within, these existing reference frameworks, so that AI literacy can be embedded in ongoing certification and professional development pathways rather than developed as a parallel and disconnected agenda.

Teacher preparation emerges as a critical policy priority. Our research indicates that successful AI literacy education depends heavily on educator confidence and competence. Policy frameworks must therefore address the urgent need for comprehensive AI literacy training for educators, including both pre-service preparation and in-service professional development. This training should equip teachers not only with technical knowledge but also with pedagogical strategies for addressing the ethical and social dimensions of AI.

In the workplace, our framework has implications for professional development and organizational policy. As AI systems become increasingly prevalent across industries, organizations must implement AI literacy programs to prepare workers for AI-augmented workplaces. These programs should address not only the operational skills needed to work with AI tools but also the critical thinking skills necessary to evaluate AI recommendations and the ethical judgment to identify when human intervention is necessary. Professional bodies across fields should develop AI literacy standards specific to their domains, recognizing that the implications of AI vary significantly across contexts.

The social equity implications of AI literacy demand particular attention from policymakers. Our research reveals the potential for AI literacy gaps to exacerbate existing inequalities, as those without adequate AI understanding may find themselves excluded from economic opportunities or vulnerable to AI-driven discrimination. Policies must therefore address potential AI literacy divides through inclusive program design, public awareness campaigns, and targeted support for underserved communities. This includes ensuring that AI literacy programs are accessible to diverse populations, including those with limited technical backgrounds, different language needs, and varying levels of digital access.

5. Limitations

While our study provides a comprehensive framework for AI literacy, several limitations should be acknowledged. Methodologically, our exclusion of non-English publications may have overlooked important perspectives from non-Western contexts where AI development and implementation may follow different patterns. The rapid evolution of AI technologies also means that some of our findings may quickly become outdated, particularly as new AI capabilities emerge and societal understanding of AI evolves. Additionally, our focus on peer-reviewed literature, while ensuring quality, may have missed innovative practices documented in grey literature or emerging in practice but not yet formally studied.

The framework itself, while comprehensive, was developed primarily from Western educational contexts and may require significant adaptation for other cultural settings where relationships with technology, authority, and knowledge differ. The empirical validation of the framework remains limited; while it is grounded in extensive literature review, it requires testing across diverse educational settings to confirm its applicability and effectiveness. The operationalization of the four dimensions for assessment purposes also remains complex, as the interconnected nature of the dimensions makes isolated measurement challenging.

Our study's scope, while broad, may not adequately address specialized AI literacy needs in specific professional domains where the stakes and applications of AI differ significantly. For instance, AI literacy for healthcare professionals dealing with diagnostic AI systems may require different emphases than AI literacy for educators using AI-powered learning platforms. Finally, the limited direct input from practitioners—educators, students, and AI professionals—in the framework development process represents a limitation that future research should address.

6. Recommendations for Future Research

Based on our findings and acknowledged limitations, we propose several directions for future research that can advance both theoretical understanding and practical implementation of AI literacy.

Empirical validation of the framework across different educational contexts represents a critical next step. Large-scale studies should examine how the four dimensions of AI literacy manifest in practice and how they can be effectively taught and assessed. Longitudinal research is particularly needed to understand how AI literacy develops over time and how the relationships between dimensions evolve as learners gain experience. The development and validation of assessment instruments for each dimension would provide educators with tools to measure progress and identify areas needing additional support.

Cultural and contextual adaptation of the framework deserves significant attention. Research should explore how AI literacy manifests in different cultural contexts, particularly in regions where AI development and deployment patterns differ from Western models. Studies examining AI literacy needs in Global South contexts, where AI applications may leapfrog traditional technological development patterns, could provide valuable insights. The intersection of AI literacy with existing digital divides also requires investigation to ensure that AI literacy initiatives do not inadvertently widen educational gaps.

Implementation studies focusing on effective pedagogical approaches for teaching AI literacy would provide practical guidance for educators. Research should investigate how AI literacy can be integrated into existing curricula without overwhelming already-packed educational programs. The professional development needs of educators represent another crucial area for investigation, including studies of effective training models and support systems for teachers developing AI literacy alongside their students.

As AI technologies continue to evolve rapidly, research must also examine how new developments impact literacy requirements. The emergence of generative AI and large language models, for example, introduces new challenges and opportunities for AI literacy education. Studies investigating the role of AI literacy in supporting effective human-AI collaboration could inform both educational and workplace applications. Finally, deeper investigation into the ethical and social dimensions of AI literacy, including how AI literacy influences civic engagement and democratic participation, would contribute to our understanding of AI's broader societal implications.

Conclusions

The rapid expansion of artificial intelligence across multiple sectors has fundamentally transformed how individuals interact with technology, making AI literacy an essential competency for navigating contemporary society. This paper has addressed the gap between traditional digital literacy and the competencies required for effective engagement with AI systems by proposing a comprehensive AI literacy framework that builds upon and extends existing digital literacy models.

Our multi-phase research process, spanning from 2022 to 2025 and analysing over 130 studies, revealed that while digital literacy provides a crucial foundation, it is insufficient for addressing the unique challenges posed by AI technologies. The autonomous nature of AI systems, their capacity for learning and adaptation, and their profound societal implications demand a new literacy paradigm that goes beyond traditional tool-based competencies.

The AI literacy framework we have developed encompasses four essential dimensions—cognitive, operational, critical, and ethical—that together provide a comprehensive approach to understanding and engaging with AI systems. These dimensions are not isolated competencies but interconnected aspects of a holistic literacy that enables individuals to not only use AI technologies but also understand their mechanisms, evaluate their outputs and impacts, and navigate their ethical implications. This framework reflects the interdisciplinary nature of AI literacy, drawing on insights from computer science, ethics, cognitive science, and education to prepare individuals for the challenges and opportunities of an AI-augmented world.

The transition from digital literacy to AI literacy represents more than an incremental evolution; it constitutes a paradigm shift in how we conceptualize technological literacy. While digital literacy focused primarily on human-driven processes mediated by digital tools, AI literacy must grapple with technologies that can act autonomously, learn from experience, and make decisions that directly affect human lives. This shift demands new educational approaches that integrate AI literacy across disciplines and levels, ensuring that all individuals—not just technical specialists—are prepared to engage critically with AI systems.

Looking ahead, the successful implementation of AI literacy education will require sustained effort from multiple stakeholders. Educational institutions must reimagine curricula to incorporate AI literacy across subjects, policymakers must address equity concerns to prevent new forms of digital divide, and society as a whole must engage in ongoing dialogue about the role of AI in our collective future. The framework we have presented provides a foundation for these efforts, but its realization will depend on continued research, experimentation, and adaptation as AI technologies and our understanding of them continue to evolve.

As AI becomes increasingly embedded in the fabric of society—influencing everything from personal recommendations to judicial decisions—the importance of AI literacy cannot be overstated. By developing comprehensive AI literacy, we empower individuals not merely as users of AI technologies but as informed critics, ethical decision-makers, and active participants in shaping how AI is developed and deployed. This empowerment is essential for ensuring that AI technologies contribute to a more equitable, transparent, and humane future, where the benefits of AI are accessible to all and its risks are understood and mitigated through collective wisdom and action.

In conclusion, the development of robust AI literacy represents one of the most pressing educational challenges of our time. The framework presented in this paper offers a path forward, but its success will ultimately depend on our collective commitment to preparing current and future generations for meaningful engagement with AI technologies. As we stand at this technological crossroads, the choices we make about AI literacy education will profoundly influence not only individual opportunities but also the nature of our shared technological future.

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