

# TOWARDS AN INTEGRATED PEDAGOGICAL FRAMEWORK OF ASSESSMENT FOR ETHICAL AND CRITICAL ARTIFICIAL INTELLIGENCE LITERACY IN K-12 EDUCATION

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## **Abstract**

The rapid expansion of Artificial Intelligence (AI) in contemporary societies has brought renewed attention to the responsibility of educational systems to prepare learners to engage with AI in a critical, informed and ethically grounded manner. While a growing number of conceptual frameworks define the core dimensions of AI literacy, the assessment of these competences remains a significant gap in both research and educational practice. Current evaluation approaches are largely qualitative, fragmented and predominantly oriented toward technical understanding, thus failing to capture the complex interplay between conceptual knowledge, informed use of AI systems and ethical-critical reasoning highlighted in the literature. Empirical evidence suggests that existing AI literacy initiatives tend to privilege operational and process-oriented knowledge, whereas dimensions such as ethical judgement, learner agency and critical thinking are rarely assessed in a systematic way. Moreover, although AI literacy programs frequently adopt active and collaborative pedagogies, validated competence-based assessment tools aligned with these approaches are still largely absent.

To address this gap, this paper proposes a competence-based assessment framework for AI literacy grounded in the AI-related indicators of DigComp 2.2 and DigComp 3.0. The framework integrates knowledge, skills and attitudes and aligns them with the Engage-Investigate-Act structure of Challenge-Based Learning, a pedagogical model designed to elicit authentic, performance-based evidence. The resulting assessment grid articulates five competence areas and provides indicators, proficiency levels and examples of authentic evidence. The proposed framework offers teachers and curriculum designers a transparent and pedagogically coherent tool for assessing AI literacy and establishes a foundation for future empirical validation studies.

Keywords: AI literacy, Assessment, K-12 Education, Challenge-Based Learning, Ethics, Critical thinking.

## **1 INTRODUCTION**

Artificial Intelligence (AI) technologies increasingly permeate everyday life, reshaping how information is accessed, decisions are made and social interactions unfold. In this context, AI literacy has emerged as a central educational priority [1], to the point that it is often considered as fundamental as traditional literacy skills such as reading and writing [2]. Early educational initiatives related to AI were primarily situated within higher education and computer science curricula. More recent scholarship, however, has called for a broader educational perspective that integrates ethical, social and civic dimensions alongside technical knowledge, particularly within compulsory education [3].

A growing body of literature highlights the importance of introducing AI literacy from early childhood onwards [4,5], as well as strengthening it during middle and secondary education, when learners are developmentally able to engage with complex ethical and societal issues related to AI systems [6,7,8,9]. This shift reflects a broader reconceptualisation of AI literacy as a component of informed and responsible citizenship. From this perspective, critical use of AI systems, awareness of bias, transparency, accountability and respect for fundamental rights are understood as essential competences for participation in democratic societies [3,10,11].

This orientation is explicitly articulated in the European Digital Competence Framework for Citizens (DigComp 2.2), which emphasises that citizens require a basic understanding of AI systems in order to engage with them «confidently, critically and safely», while developing sensitivity to issues such as data protection, privacy, ethics and bias [12, p. 77]. Similarly, the OECD defines AI literacy as the combination of «technical knowledge, durable skills, and future-ready attitudes required to thrive in a world influenced by AI», explicitly including the capacity to critically evaluate benefits, risks and ethical implications [13, p. 6].

Despite this growing convergence around the multidimensional nature of AI literacy, the absence of a shared operational definition has led to a proliferation of frameworks and curricular proposals, often characterized by differing emphases and levels of granularity [14]. This conceptual fragmentation has had tangible consequences for educational practice, particularly in the domain of assessment. Recent systematic reviews consistently report that AI literacy evaluation relies predominantly on qualitative and self-reported measures, such as questionnaires and interviews, with limited use of structured, competence-based assessment tools [10,15,16]. Zhou et al. observe that interviews and classroom observations account for nearly half of the assessment methods employed in K–12 AI education, whereas assessment rubrics are used far less frequently [15].

Although some validated instruments have been developed, they tend to focus on specific dimensions of learning. Weber et al. [17], for instance, propose an objective, knowledge-based test aimed at measuring cognitive understanding of AI concepts. By contrast, Ng et al. [18] introduce a comprehensive self-report questionnaire capturing affective, behavioural, cognitive and ethical learning dimensions. While both approaches contribute valuable insights, neither fully addresses the need to assess observable competences, ethical reasoning and learner agency within authentic learning contexts [10,15].

Against this background, the present study addresses the following research question: How can a competence-based assessment tool be designed, in alignment with the DigComp framework, to evaluate AI literacy within collaborative, challenge-based learning contexts in K–12 education?

This paper contributes by proposing an integrated, competence-based assessment framework that operationalises AI literacy through observable performances within challenge-based learning environments.

## **1.1 Digital Competence Framework for Citizens**

The DigComp (Digital Competence Framework for Citizens) [12] is the European Union’s reference tool for defining and measuring citizens’ digital competences. DigComp 2.2, the fourth edition published in 2022, represents a significant update, emphasizing the integration of practical examples of knowledge, skills, and attitudes. This edition also introduced the first references to artificial intelligence, dedicating a specific annex to this topic. The framework is organized into five competence areas: 1) Information and Data Literacy; 2) Communication and Collaboration; 3) Digital Content Creation; 4) Safety; 5) Problem Solving. Each area is structured across eight levels of proficiency and includes examples of relevant knowledge, skills, and attitudes. The 2.2 version additionally includes a dedicated annex on AI. Specifically, the framework addresses artificial intelligence through five sections: 1) What do AI systems do and what do they not do?; 2) How do AI systems work?; 3) When interacting with AI systems; 4) The challenges and ethics of AI; 5) Attitudes regarding human agency and control. For each section, DigComp 2.2 considers three dimensions: 1) Knowledge – understanding what AI systems can and cannot do, and the benefits, limitations, and challenges associated with them; 2) Skills – the ability to use, interact with, and provide feedback on AI systems; 3) Attitudes – fostering critical thinking, ethical awareness in AI usage, and reflection on human agency and control. This tripartite structure already suggests the framework’s critical orientation: a closer look at the AI competences indicates that the document fosters a critical reading, including the more knowledge-related sections.

The latest edition published in 2025 - DigComp 3.0 [19] - aims to respond to the technological evolution that has occurred since 2022, particularly the widespread adoption of generative AI. The framework continues to regard competences as a combination of knowledge, skills, and attitudes, consistent with the previous version, although the names of the competence areas and their descriptors have been updated. In particular, the framework focuses on artificial intelligence (including generative AI) competence, cybersecurity competence; digital rights, choice and responsibilities; wellbeing in digital environments; and competence to tackle misinformation and disinformation. Notably, knowledge, skills, and attitudes related to AI are now included across all areas rather than in a separate annex, showing the pervasiveness of AI in everyday life.

## **1.2 Challenge Based Learning**

As previously mentioned, the literature identifies collaborative problem- and project-based learning as the most commonly used teaching methodologies for AI literacy programs within the K–12 educational system [3, 8, 16]. These approaches represent forms of active, student-centered learning to acquire competencies through trial and error and to engage in reflection – key component of metacognition. Specifically, problem-based learning uses a real-world problem as a guide and vehicle for the learning process, while project-based learning emphasizes the practical application of knowledge. In both cases,

the literature highlights the importance of cooperative learning [11, 14, 16], which allows students to work collaboratively, share knowledge, and engage in peer learning, reinforcing understanding and critical thinking. Building on these approaches, Challenge-Based Learning (CBL) is a multidisciplinary approach developed by Apple in collaboration with educators to identify key design principles for 21st-century high school learning environments. It is part of a larger project initiated in 2008, called Apple Classrooms of Tomorrow – Today (ACOT<sup>2</sup>) [20, 21] and represents a pedagogical approach aligned with the principles of active, student-centered learning. It represents a flexible pedagogical framework that can be integrated with other teaching approaches and emphasizes learner agency, promoting authentic learning experiences that connect academic content to real-world challenges while fostering critical thinking, collaborative attitudes, and problem-solving skills. In fact, it gives students opportunities to make a real impact and reflect on their educational experiences.

The Challenge Based Learning framework is built on a set of foundational ideas [21]:

- 1 *Everyone is a Learner: Teacher/Learner and Learner/ Teacher.* Learners share responsibility for shaping the learning process, while teachers guide the experience and learn alongside their students, promoting a collaborative environment in which knowledge is co-constructed.
- 2 *Moving Beyond the Four Walls of the Classroom.* CBL aims to involve all the community members in the process, moving the responsibility of education beyond the classroom.
- 3 *Learner Inspired, Learner Directed.* Learning is most meaningful when students are able to integrate new knowledge with their existing knowledge, establishing connections between the subject matter and real-world experiences.
- 4 *Challenges.* Challenges create conditions that engage and motivate learners, driving them to act.
- 5 *Content and 21st Century Skills.* Engaging with a real-world challenge enables students to develop, in a natural way, skills considered essential for the 21st century.
- 6 *Boundaries of Adventure.* Providing boundaries is important to guide the learning process, while ensuring students have freedom to explore and take responsibility for their own learning.
- 7 *Space and Freedom to Fail.* It is essential to provide learners with a safe space in which they can experiment, make mistakes, and think creatively.
- 8 *Slowing for Critical and Creative Thinking.* To promote reflective thinking and full participation, the teaching process is intentionally slowed down at times.
- 9 *Authentic and Powerful Use of Technology.* The framework encourages the use of technology, which can play a key role in research as well as in communication, organization, creation, and presentation of the project. It transforms the learning process into a more interactive, meaningful, and personalized experience.
- 10 *Focus on Process and Product.* CBL emphasizes the assessment of both the learning process and the final product, which should represent a concrete solution to the chosen challenge.
- 11 *Documentation.* At each stage of CBL, students document their learning process. These materials therefore serve as tools for assessment and also to foster metacognitive reflection.
- 12 *Reflection.* Throughout the entire learning process, students are encouraged to reflect on both the content and the learning process itself.

The Challenge Based Learning Framework is divided into three phases: (1) *Engage*, (2) *Investigate*, and (3) *Act*. Each step includes activity necessary to prepare students for subsequent phases.

The first phase – *Engage* – involves guiding students from an initial, abstract *Big Idea* to a concrete and actionable challenge. This process is carried out through *Essential Questions*, which allow learners to personalize the Big Idea, identifying what is most relevant and meaningful for their group.

The second phase – *Investigate* – forms the core of the framework and is structured around *Guiding Questions*, *Guiding Activities*, and *Analysis*, through which students acquire the essential knowledge needed to develop their project. In this phase, learners may utilize a wide range of resources, including expert interviews, podcasts, documentaries, scientific articles, and other relevant materials.

The third phase – *Act* – focuses on developing a tangible solution to the challenge initially chosen by the group. The solution emerges from the insights gained during the previous phase, and using the design cycle, learners prototype and refine their solution concepts.

From an assessment perspective, CBL emphasizes evaluating both the process and the final product produced by the group. The framework recommends focusing on three key areas: knowledge, content understanding, mastery of practical skills and the CBL process itself. To monitor student progress, two assessment strategies should be considered: formative, which takes place continuously throughout the learning process, and summative, that evaluates progress at specific points or at the conclusion of the learning experience. Both types of assessment can include tests, self-reported surveys, peer review, and teacher observations. Assessment should be carried out at both group and individual levels, and learners should receive feedback not only from the teacher but also through interactions with external stakeholders. Examples of questions that can be used during checkpoints include: 1) Where are you in the process?; 2) What new knowledge or skills have you acquired? 3) What has been your greatest success?; 4) What has been your greatest challenge?; 5) How is your group functioning as a team?; 6) What are your top priorities for the coming week? [21].

## **2 METHODOLOGY**

### **2.1 Research Design**

This study adopts a theoretical and design-oriented research approach aimed at the development of a competence-based assessment framework for AI literacy. Rather than testing hypotheses or collecting empirical data, the study focuses on the conceptual construction and pedagogical alignment of an assessment model, drawing on established policy frameworks and research literature [22,23]. Similar methodologies have been employed when the aim is to construct conceptual tools grounded in existing theory and policy, rather than to test hypotheses through empirical experimentation [15]. This type of approach is commonly adopted in educational research when the objective is to develop conceptual or analytical tools grounded in theory and policy rather than to evaluate interventions empirically [10,13,19].

#### *2.1.1 Data Sources and Analytical Procedure*

The analytical corpus comprised three authoritative sources: DigComp 2.2 [12], DigComp 3.0 [19] and the OECD AI Literacy Framework for primary and secondary education [13]. A structured document analysis was conducted to identify AI-related competences articulated in terms of knowledge, skills and attitudes. Particular attention was devoted to AI-explicit learning outcomes in DigComp 3.0, defined as outcomes that explicitly reference AI systems or their cognitive, ethical and societal implications [19].

Learning outcomes were inductively coded and clustered into macro-level competence areas following procedures commonly adopted in framework synthesis and review studies [10,15]. These categories were subsequently compared with the AI-related sections of DigComp 2.2 to ensure conceptual continuity and alignment across framework versions.

#### *2.1.2 Pedagogical Alignment with Challenge-Based Learning*

In a second analytical step, the identified competence areas were deductively aligned with the Engage–Investigate–Act structure of Challenge-Based Learning (CBL) [20,21]. This alignment was guided by the assumption that assessment should be coherent with pedagogy and should prioritise observable behaviours and authentic performances generated during learning activities [21,24]. CBL was selected due to its explicit focus on learner agency, ethical engagement and real-world problem solving, all of which are widely recognised as central dimensions of AI literacy [3,8,16].

## **3 RESULTS**

### **3.1 Identification of AI Literacy Competence Areas**

The document analysis led to the identification of five macro-level areas of AI literacy competence: 1) Understanding what AI systems can and cannot do; 2) Understanding how AI systems work; 3) Conscious and ethical interaction with AI tools; 4) Verification and critical evaluation of AI outputs; 5) Ethical awareness, societal impact and human agency.

These areas synthesise AI-explicit competences distributed across the five DigComp 3.0 competence areas [19] and are consistent with the tripartite structure of knowledge, skills and attitudes emphasised in DigComp 2.2 [12] and the OECD framework [13].

### 3.1.1 Structure of the Assessment Framework

For each competence area, the proposed assessment framework specifies:

- a) Competence descriptors articulated in terms of knowledge, skills and attitudes;
- b) Progressive proficiency levels aligned with digcomp 3.0 (basic, intermediate, advanced and highly advanced);
- c) Examples of authentic evidence generated through challenge-based learning activities.

## 3.2 A New Framework: Competence-Based Assessment for AI Literacy

The proposed framework operationalises AI literacy assessment by integrating DigComp-derived competence descriptors with principles of authentic and performance-based assessment [21]. It is designed to support both formative and summative assessment and to be applicable at individual and group levels, in line with recommendations for evaluating collaborative learning processes [16].

Table 1 presents the theoretical competence-based assessment grid for AI literacy, illustrating the alignment between DigComp 3.0 AI-explicit learning outcomes, the knowledge–skills–attitudes dimensions, and the Engage–Investigate–Act phases of Challenge-Based Learning.

*Table 1. Theoretical competence-based assessment grid for AI literacy.*

<b>Competence Area</b>	<b>DigComp 3.0 AI-explicit learning outcome (example)</b>	<b>K/S/A</b>	<b>CBL Phase</b>	<b>Examples of authentic assessment evidence</b>
Understanding AI capabilities and limitations	Recognise that it can be difficult to distinguish between information generated by humans and AI systems [19]	Knowledge	Engage	Scenario-based discussions distinguishing AI vs human-generated content; identification of plausible but inaccurate outputs
Understanding how AI systems work	Recognise that training data and algorithmic processes influence AI reliability and may function as a 'black box' [19]	Knowledge	Investigate	Concept maps on AI training processes; reflective notes on opacity and uncertainty
Conscious interaction with AI tools	Develop and refine prompts for AI systems to support digital interactions [19]	Skill	Act	Prompt iteration logs; comparison of outputs before and after refinement
Verification and critical evaluation	Critically assess the reliability of AI-generated information considering bias and interests [19]	Skill	Investigate	Bias identification tasks; evaluation rubrics applied to AI-generated content
Ethics, societal impact and human agency	Acknowledge the importance of human oversight and responsibility in AI use [12,19]	Attitude	Engage / Act	Ethical decision-making scenarios; reflective essays on agency and accountability

In this respect, the grid above illustrates the conceptual structure of the proposed assessment framework. Each competence area is explicitly connected to AI-explicit learning outcomes from DigComp 3.0, thereby ensuring policy alignment and conceptual coherence. The inclusion of the knowledge–skills–attitudes dimension reflects the tripartite structure shared by DigComp 2.2 and the OECD AI Literacy Framework, while the alignment with the Engage–Investigate–Act phases of Challenge-Based Learning clarifies how each competence can be assessed through observable learning processes and performances. Rather than prescribing specific tasks, the grid functions as a flexible interpretative tool that supports the design of assessment criteria coherent with active and collaborative pedagogies.

To operationalise this structure, Table 2 translates the theoretical framework into a practical assessment rubric for classroom implementation, making explicit how the proposed competences can be operationalised through observable indicators, level descriptors and assessment evidence.

Table 2. Practical assessment rubric for classroom implementation.

<b>Competence Area</b>	<b>Observable indicator</b>	<b>Level descriptor (example)</b>	<b>Assessment evidence</b>
AI capabilities and limitations	Distinguishes AI-generated from human-generated content	Basic: identifies AI output; Intermediate: explains plausibility vs accuracy; Advanced: justifies verification strategies	Annotated artefacts; short written justifications
How AI systems work	Explains the role of data and training	Basic: recognises data role; Intermediate: explains sources of bias; Advanced: reflects on opacity and limits	Concept maps; oral explanations
Interaction with AI tools	Designs and refines prompts	Basic: uses a single prompt; Intermediate: iterates prompts; Advanced: justifies prompt strategies ethically	Prompt logs; output comparison tables
Verification and evaluation	Evaluates reliability of AI outputs	Basic: checks accuracy; Intermediate: identifies bias; Advanced: triangulates sources	Evaluation grids; peer review notes
Ethics and human agency	Demonstrates responsible decision-making	Basic: recognises ethical issues; Intermediate: explains responsibility; Advanced: proposes mitigation strategies	Scenario-based tasks; reflective essays

Table 2 provides a classroom-oriented interpretation of the framework, supporting teachers in both formative and summative assessment during Challenge-Based Learning activities. The rubric guides the collection of diverse forms of evidence, including artefacts, reflections and peer interactions, while maintaining coherence with DigComp 3.0 proficiency levels. Importantly, the rubric is not intended as a standardised testing tool, but as a flexible instrument adaptable to different challenges, age groups and educational contexts (All indicators and descriptors are directly derived from the competence areas and dimensions presented in Table 1).

#### 4 DISCUSSION AND CONCLUSIONS

The framework proposed in this study directly addresses limitations identified in existing AI literacy assessment instruments. The knowledge-based test developed by Weber et al. provides a reliable and objective measure of cognitive understanding [17], yet it does not capture ethical reasoning, contextualised use or learner agency, dimensions increasingly recognised as integral to AI literacy [10,13]. Conversely, the questionnaire developed by Ng et al. offers a multidimensional perspective encompassing affective, behavioural, cognitive and ethical learning outcomes [18]. However, its reliance on self-reported data constrains its ability to assess observable competences enacted in authentic learning situations [15].

By integrating DigComp 3.0 competence descriptors with performance-based evidence generated through Challenge-Based Learning, the present framework seeks to bridge this gap. It complements existing instruments by linking policy-aligned competence definitions to pedagogical practices that foreground inquiry, collaboration and ethical engagement [3,8,16]. Embedding assessment within Challenge-Based Learning supports metacognitive reflection, learner agency and ethical judgement, all of which remain under-assessed in current AI literacy initiatives [10,15]. Moreover, explicit alignment with DigComp 3.0 enhances policy coherence and supports curriculum design at institutional and system levels.

From a pedagogical perspective, the framework conceptualises AI literacy as a situated and reflective competence, enacted through inquiry, decision-making and ethical judgement in real-world scenarios. The integration of assessment within Challenge-Based Learning processes enables both formative and summative evaluation of learning trajectories and outcomes, fostering metacognitive awareness and human agency in interactions with AI systems.

Although this study does not include empirical validation, its contribution lies in the systematic design and theoretical grounding of an assessment model that is coherent with European policy frameworks and contemporary research on AI literacy education. Future research should focus on validating the proposed framework across educational levels and contexts, examining its reliability, usability and impact on teaching practices and student learning. In particular, design-based research and mixed-methods studies could explore how the framework supports teachers in making assessment practices more transparent, equitable and aligned with the ethical and critical dimensions of AI literacy.

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