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Artificial intelligence literacy for technology education

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ABSTRACT

The interest in artificial intelligence (AI) in education has erupted during the last few years, primarily due to technological advances in AI. It is therefore argued that students should learn about AI, although it is debated exactly *how* it should be applied in education. AI literacy has been suggested as a way of defining competencies for students to acquire to meet a future everyday- and working life with AI. This study argues that researchers and educators need a framework for integrating AI literacy into technological literacy, where the latter is viewed as a multiliteracy. This study thus aims to critically analyse and discuss different components of AI literacy found in the literature in relation to technological literacy. The data consists of five AI literacy frameworks related to three traditions of technological knowledge: technical skills, technological scientific knowledge, and socio-ethical technical understanding. The results show that AI literacy for technology education emphasises technological scientific knowledge (e.g., knowledge about what AI is, how to recognise AI, and systems thinking) and socio-ethical technical understanding (e.g., AI ethics and the role of humans in AI). Technical skills such as programming competencies also appear but are less emphasised. Implications for technology education are also discussed, and a framework for AI literacy for technology education is suggested.

1. Introduction

Even though artificial intelligence (AI) is not a new phenomenon within computer science research (e.g., [1,2]), the interest in AI in education has exploded during the last few years [3]. Arguably, this development is mainly due to technological advances in AI. In the technology education field, technological development in society has challenged and led to an expansion of what should be included in the curriculum, for example, the recent introduction of programming for K-12 on a global level, which is also mirrored in technology education research. In a Swedish context, for example, research on programming within technology education was sparse during the first decades of the 2000s [4], but during the past five years programming content has become a natural part of technology education research both in Sweden (e.g., [5,6]) and internationally (e.g., [7–9]). Programming has thus been argued to be one of the so-called 21st-century skills [10].

However, as an answer to recent rapid technological development, scholars and policymakers have highlighted the importance of incorporating AI literacy into the K-12 curriculum [11–13]. AI is already an integral part of our daily lives. We use smart home appliances such as robot vacuum cleaners and smartphones. Based on our previous preferences, we receive suggestions for what we should watch next on Netflix or YouTube. We learn new languages using applications such as Duolingo and get advertisements on social media adjusted to what our profile tells us about who we are, where we are and what we are interested in. AI-driven applications affect our ways of living and interacting with technology and the people around us. The boundary between humans and machines is also increasingly blurred as interfaces change. We talk to Siri, ask Google to tell us about the weather, unlock the smartphone by showing our face to it and get instructions from the smartwatch that it is time to move. As technology becomes more integrated into our lives, it is also increasingly harder to notice. It is designed not to cause friction between the user and the device (e.g., [14,15]).

Recent research argues that all citizens should learn about AI [12,16, 17]. There are two main arguments for why. First, education about AI is needed to help students understand *what* AI is and *how* it works [12,18]. Second, young people should be inspired to future careers as designers of AI applications, software developers and AI researchers [18]. One aspect of knowledge about AI is distinguishing between technological artefacts that use and do not use AI [16,18], as well as critical and ethical perspectives. Identifying AI applications will be even more difficult as the technology develops towards a more integrated, friction-free user interface. This is related to the so-called *AI effect*, that once a new AI application has been integrated and accepted in a particular context, it is

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no longer regarded as AI and will therefore be more complicated to distinguish from non-AI (e.g., [19]). In addition, at the present rate, new AI innovations are launched almost every day in both current and new application areas.

In response, this study aims to critically analyse and discuss different components of AI literacy found in the literature in relation to technological literacy. First, we will present technological literacy as it is conceived in technology education and then conceptions of AI literacy. Second, we will compare components of these two types of literacy to elucidate aspects of AI literacy that have implications for technological literacy and technology education.

1.1. Technological literacy as multiliteracy

Although literacy originally had to do with reading and writing, the concept has come to be used to denote knowledge, skills, and competencies that a person would need in any given area to function as a citizen. Regarding, for example, science, it would be science or scientific literacy, and for computing, computer or computational literacy. The concept has garnered criticism, especially in science education, where multiple conflicting definitions abound (e.g., [20]). However, in technology education, there is a fair degree of consensus, not the least thanks to the work of the International Technology and Engineering Educators Association in the USA in the last couple of decades (see, [21,22]). A comprehensive and much-quoted summary of technological literacy is the following: "Technological literacy is the ability to use, manage, assess, and understand technology" ([21], p. 7).

Williams [23] argues that seeing technological literacy as the goal of technology education has appeal because of its multidimensionality. It can be related to having a technologically literate workforce, which would benefit the national economy. It could also relate to the individual's level of literacy and the personal satisfaction connected to that. Also, it relates to social responsibility and democracy in a technological society.

Technological literacy is generally constituted of three dimensions [23]. The first dimension concerns the ability to use technology. The second is the knowledge and understanding dimension. The third dimension concerns awareness or appreciation of the relationships between technology, society, and the environment. Today's students belong to a generation that has grown up familiar with communications technology. These so-called "Digital Natives" have a different relationship to digital technology than the generations before. Also, the introduction of social media, digital communication, information overflow, and accessibility put new demands on what constitutes technological literacy.

In this study, we are inspired by The New London Group [24,25], and in line with, for example, Kahn and Kellner [26] and Williams [23], we thus see technological literacy as a broad multiliteracy, an umbrella concept covering several other sub-literacies closely connected to the technological one. In this way, we address some of the criticisms against the literacy concept (e.g., many, often conflicting definitions; too general and sweeping competencies), at the same time as we maintain that the specific sub-literacies do not contradict the overall focus of the technological multiliteracy and also allow for technological change. The sub-literacies would include, for example, craft literacy, digital literacy, media literacy, design literacy, AI literacy, and computer literacy. The aim of such multiliteracy is both the understanding of technology itself and its embeddedness in a particular cultural, societal, and political context, which is essential for furthering democratic values in relation to present and future technologies [27].

Nordlöf et al. [28] propose an epistemological framework of technology education, which can be used as a tool for specifying and concretising the components of technological literacy. Their framework consists of three categories of technological knowledge: 1) *Technical skills* focus on how things work, not why they work, and are justified by experience; 2) *Technological scientific knowledge* concerns general scientific knowledge within a technological context. Within this category, it is essential to understand why things work and methods used come from technological and natural science traditions; 3) *Socio-ethical technical understanding* includes how technology relates to humans, society, and the environment. The relationship between technology and the human and natural worlds is highlighted within this category, and the methods have their foundation in the humanities and social sciences. Thereby, the framework, as a whole, puts the multidisciplinary nature of technology education and technological multiliteracy in the spotlight, something also reflected in the conception of technological literacy put forward by Williams [23,29].

1.2. Artificial intelligence

Alan Turing, a mathematician and computer scientist, was the first person to present a modern computational model for intelligent reasoning. His paper from 1950 opens with the sentence: "I propose to consider the question, 'Can machines think?'" ([30], p. 433). This question raised by Turing has continued to be central to artificial intelligence research since then [31].

The "perceptron" is the core concept of neural network algorithms and was first introduced by Frank Rosenblatt [32]. The word combines the two terms "perception" and "neuron". The concept denotes a binary classifier that can decide whether or not an input belongs to a specific class. Moreover, the concept of perceptron assigns a probabilistic model for information storage and organisation in the brain. Later, Minsky and Papert developed the concept further to today's machine learning and deep learning. Minsky and Papert's work "Perceptrons" has dramatically influenced AI education [32].

In his book "Mindstorms: Children, Computers, and Powerful Ideas", Papert discusses his ideas further [1]. Papert was influenced by Piaget. They are both convinced that students have to be active in constructing their knowledge, and they do so most efficiently when engaged in constructing things in the world. For that purpose, he and his colleagues developed computer environments that challenged students to solve mathematical problems. Papert wanted to apply ideas from AI to engage students to think about their thinking [33]. By learning about how machines work, students could learn more about how they learn:

> AI is concerned with extending the capacity of machines to perform functions that would be considered intelligent if performed by people. Its goal is to construct machines, and, in doing so, it can be thought of as a branch of advanced engineering. But in order to construct such machines, it is usually necessary to reflect not only on the nature of machines but on the nature of the intelligent functions to be performed. ([1], p. 176)

However, Papert's vision of using AI and machine learning to develop students' metacognition has not gained a strong impact in education. Instead, most of today's AI in education have different goals, focusing more on the machines as intelligent, in line with Turing, rather than on understanding human intelligence [33].

The critique from Papert is also evident regarding research on artificial intelligence in education. So far, the main focus is AI to help student learning [34,35]. However, researchers have also discussed what students need to know in a society influenced by artificial intelligence. The term AI literacy has been coined to capture what knowledge and skills students need to navigate in an AI-influenced society. However, no established curriculum for AI content knowledge is available [18].

1.2.1. Defining artificial intelligence

Research on artificial intelligence in educational settings seldom defines the term. According to the Merriam-Webster Dictionary, artificial intelligence is the capability of a machine to imitate intelligent human behaviour. The definition of an 'artificially created' and 'intelligent' machine is well dispersed in human culture. The term can be traced back to 1955, when it was coined by John McCarthy and colleagues [36].

Several policy organisations have tried to define the term. Amongst those are UNESCO and OECD. The definitions of AI have expanded and evolved [37]. In the definition by UNESCO, AI refers to machines that imitate some aspects of "human intelligence, such as perception, learning, reasoning, problem-solving, language interaction and creative work" ([13], p. 9). Currently, no AI system can be considered generally 'intelligent' in the sense that it can perform well in different contexts (so-called strong AI), which is an ability of human intelligence [38]. Weak AI, that is, the ability of AI to perform a more narrow set of intelligent tasks, has been much more successful, for instance, recently in new generative AI applications based on large language models.

OECD defines an AI system as "a machine-based system that can, for a given set of human-defined objectives, make predictions, recommendations or decisions influencing real or virtual environments" ([39], p. 23).

Even though this definition works in everyday life, it could be challenged from a scientific and technical perspective. Margaret Boden argues that AI has two aims. One is *technological*, meaning computers are used to get useful things done. The other is *scientific*, implying that AI concepts and models are employed to answer questions about human beings and other living things ([40], p. 2).

Technologies might be model-driven. For example, scientists develop a scientific model which technology can advance based on such models. However, when it comes to the human mind, there is still an unreachable dream to fetch all those complex processes into a model-based cognitive machine [38]. Instead, current AI is based on a data-driven approach aided by statistical models of probability. Moreover, at its core, AI is machine learning. However, even if AI has different goals, many AI researchers do not care about how the human mind works. Rather than a scientific understanding, they seek technological efficiency [40].

AI is a diverse field. There is no core technique unifying the field, and the practitioners work in different areas, having diverse goals and methods [40]. This could explain the lack of coherent definitions and straightforward descriptions of what AI is. However, three areas central to AI in society generally, and in education specifically, are worth mentioning: AI techniques, AI technologies and AI ethics.

1.2.2. AI techniques, technologies, and ethics

AI could be interpreted as an umbrella concept covering technical, technological, and ethical aspects [13].

AI techniques describe how the computer works. The overall technique is based on the input of data. Examples of techniques are "classical AI" ,[1] which is rule-based, using conditional if-then statements to generate output [13]. Classical AI can model learning, planning and reasoning, especially when combined with statistics [40].

Another example is "machine learning", which refers to a computer program that can 'learn' without explicit programming by accessing a significant amount of data [13]. Hence, data is crucial for the program to 'learn'.

Different kinds of machine learning, such as neural networks, consist of machine learning algorithms. Artificial neural networks (ANNs) comprise many interconnected units where each unit can only compute one thing. Moreover, ANNs can learn, and the principle of learning is "fire together, wire together". The so-called Hebbian[2] learning strengthens often-used connections, making it more likely in the future [40].

Previous studies have identified several ethical challenges associated with the development and use of AI. These challenges exist from both the perspective of the developers and the users. One such challenge arises when AI is used to personalise communication content on a large scale, such as commercial or user-generated messages, which can raise ethical concerns. To tackle these challenges, Hermann [41] suggests promoting AI literacy to empower users of AI-driven mass personalisation. Additionally, explicability is considered the most important ethical principle, as black-box AI, where the decision-making process is not transparent, can hinder individuals' ability to make ethical judgments. Four potential ethical and societal risks have been highlighted when AI applications are used in education [42]. First, privacy is an issue when students and teachers use face recognition or recommender systems. Second, bias and discrimination could be a risk pertaining to gender or cultural or ethical background [43]. Third, surveillance via student activity in personalised learning systems could be a potential risk. Fourth, students' autonomy and agency could be jeopardised through predictive systems.

2. Method and materials

In this study, we have chosen to analyse five frameworks for AI literacy and AI curricula from the literature. The frameworks have been chosen because they have been significant within research on AI in education. The frameworks will then be related to technological literacy in order to present a model for AI literacy in technology education as a subset of technological multiliteracy:

- The AI4K12 Initiative and The Big Ideas in AI [17,44].
- The Machine Learning Education Framework [45].
- Competencies and design considerations for AI literacy [16].
- The Holistic Approach to the Design of AI Education for K-12 schools [18].
- UNESCO's map of domains and subdomains for AI education [13].

The frameworks build on different empirical and philosophical foundations. The Big Ideas in AI is based on work done by experts in AI education. The Machine Learning Education Framework is constructed as a curriculum for people interested in AI. Competencies and design considerations for AI literacy are based on an extensive literature review. The Holistic Approach to the Design of AI Education has its empirical foundation in interviews with teachers teaching AI at different levels in school. The UNESCO map builds on the three first frameworks and applies those to AI curricula from different countries around the globe. They then suggest a new framework, presented as UNESCO's map.

Our above selection of literature was carried out as a type of *narrative review*, which aims to identify central literature for the topic at hand without following a pre-determined protocol [46]. The previously described frameworks for technological literacy and technology education informed the analysis inspired by qualitative content analysis. Qualitative content analysis is a method for systematic description and analysis of written, verbal or visual information [47], which was loosely employed when analysing and categorising the AI frameworks concerning technological literacy according to the phases of preparation, organising and reporting. Our approach was deductive as the objective was to, in Elo and Kyngäs' [47] words, "test a previous theory in a different situation" (p. 107).

3. AI literacy and technological literacy

The following section presents the five AI literacy frameworks and relates them to technological literacy. After that, based on the analyses, a new framework for AI literacy, adjusted for technology education, will be presented.

3.1. The AI4K12 initiative and the big ideas in AI

The first national guidelines in the US were introduced by the

[1] Sometimes classical AI is referred to as Good-Old-Fashioned AI (GOFAI) (Boden, M. A. [40]. *AI: Its nature and future*. Oxford University Press.

[2] The rule was stated by the neuropsychologist Donald Hebb in the 1940s. (ibid.)

AI4K12 Initiative [44]. Later, the framework was further developed based on knowledge from best practice [17]. The organisational framework of the guidelines is based on the Five Big Ideas in AI (Table 1). The Five Big Ideas have worked as a foundation to suggest guidelines for kindergarten to year 12.

Different learning concepts have been defined regarding concept components within each of the Big Ideas. For example, three learning concepts have been outlined for the Big Idea *Perception*: sensing, processing, and domain knowledge. The components of living things, computer sensors and digital encoding have defined sensing. A learning outcome progression has been suggested for each of those conceptual components. Regarding the learning concept of sensing and the learning component of living things, a progression from identifying human senses for kindergartners to giving examples of how humans combine information from multiple modalities in year eight is proposed [13].

As seen in Table 1, the input aspect is explicated within this framework. Computers need to perceive information, and sensors are how to do so. The information from the sensors also needs to be processed in order to be usable. The information, or data, is used by the computer to learn. Hence, within this framework, AI is part of an integrated technological system in which hardware and software are necessary aspects. This is an example of systems thinking, an important aspect of technological literacy [48]. Moreover, the societal impact of AI is raised within this framework. The issues such as bias and transparency are important aspects of critical thinking. The societal impact also enhances the relationship between humans and technology.

Based on the three-part heuristic framework for technology education [28], the categories of technical skills and technological scientific knowledge can be said to be closely intertwined with the Big Ideas in AI. However, in Big Idea 3, learning is divided into four insights about machine learning: 1) the definition of machine learning, 2) how machine learning algorithms work, 3) the role of training data, and 4) the learning phase vs. application phase [17]. All those four insights align more with technological scientific knowledge than technical skills. The insights presuppose knowledge reflected and grounded in technological knowledge about how the system works and what role data plays in machine learning, not just carrying out the actual coding (technical skills).

Moreover, the socio-ethical technical understanding [28] is also represented in this framework regarding AI's positive and negative impact on society. Herein, ethical considerations are also integrated.

3.2. The machine learning education framework

In a framework presented by Lao [45], a gradual integration of theories such as constructivism and experiential learning has resulted in a competence-based framework focused on 'head, heart and hands' [13]. The head represents the cognitive domain (what you know), the heart represents the affective domain (why it matters), and the hands represent the psychomotor domain (what you can do with it). The Machine Learning Education Framework proposes a framework for courses designed for ML-engaged citizens [45]. The framework is based on knowledge (head), skills (hand) and attitudes (heart) (Table 2).

Within technological literacy, the three aspects of knowledge, skills and attitudes are highly relevant. They could be compared to the three-part heuristic framework for technology education [28]. The first category of the Machine Learning Education Framework, Knowledge, has two aspects that could be incorporated into the category of technological scientific knowledge: General ML knowledge and Knowledge of ML methods. However, the second two aspects, Bias in ML systems and Societal implications of AI, fit better into the category of socio-ethical technical understanding.

Regarding skills, the two frameworks are concerned with practical aspects such as project planning and creating. However, the Machine Learning Education Framework emphasises that cognitive aspects are related to the practical work. It is not only a matter of doing what works, based on experience, as in the heuristic framework for technology education. Instead, the cognitive aspects are highlighted in terms of 'explicit and implicit design intentions', 'critically analyse', and 'plan a solution sensitive to both technical and contextual considerations'.

The aspect of Attitudes does not correspond to an exact equivalent in the three-part heuristic framework for technology education [28]. These aspects are more on a meta-level, with components such as interest and self-efficacy. Even though such components are important, at least from the perspective of attracting future workforce within AI technology, it is not possible to fully relate to the epistemological framework presented by Nordlöf and colleagues.

3.3. Competencies and design considerations for AI literacy

Long and Magerko [16] present a series of competencies and design considerations for AI literacy (Table 3). Their framework is based on a scoping literature review. Seventeen competencies and 15 design considerations emerged from their review.

The first three overarching themes are: What is AI? What can AI do? and How does AI work? and they are more or less connected to Technological scientific knowledge from the three-part heuristic framework for technology education [28].

However, there are also competencies, such as no. 10, which highlights the role of humans in AI. This competency explicates that it is important to recognise the role of humans in choosing models, programming, and fine-tuning the AI system. Also, no. 16, ethics, raises issues such as ethical decision-making, bias, and transparency [16]. Furthermore, no. 6 of the design considerations, opportunities to program, and no. 8, critical thinking, emphasise the role of humans in AI. Technology is not detached from human influence; therefore, humans also have a responsibility, both as developers and as users of AI. Those competencies align with socio-ethical technical understanding and how AI will affect humans and society.

Within this framework suggested by Long and Magerko [16], there is not much emphasis on practical technical skills. Not even in the design consideration, the aspect of practical work or technical skill is evident. However, one aspect that is illuminated is the systems approach. Within design consideration, no. 5 unveils gradually; this is mentioned from a cognitive load perspective. Long and Magerko [16] suggest that teaching should focus on one or a few system components simultaneously to prevent cognitive overload. Understanding how digital and physical components interact is an important aspect of AI literacy.

3.4. The holistic approach to the design of AI education for K-12 schools

Another conceptual framework for AI Education curriculum in K-12

Table 1
The Big Ideas in AI [17].

	Big Idea	Description
1.	**Perception:** Computers perceive the world using sensors	Sensors provide computers with information that can be used for extracting meaning.
2.	**Representation and reasoning:** Agents maintain representations of the world and use them for reasoning	Representation drives reasoning, and reasoners operate on representations.
3.	**Learning:** Computers can learn from data	A machine learning algorithm constructs a reasoner by adjusting the internal representations of a reasoning model, such as a decision tree or a neural network.
4.	**Natural Interaction:** Intelligent agents require many kinds of knowledge in order to interact naturally with humans	Knowledge about language, "common sense", cultural knowledge, and knowledge about human emotions.
5.	**Societal impact:** AI can impact society in both positive and negative ways	Relevant issues include fairness, bias, transparency of automated decision-making systems, etc.

Table 2
The Machine Learning Education Framework with learning outcomes and definitions [45]. Table based on [13].

Knowledge		
1.	General ML knowledge	Know what machine learning is and is not. Understand the entire ML system.
2.	Knowledge of ML methods	Identify when to use ML methods and understand how different methods work.
3.	Bias in ML systems	Understand that systems can be biased and the different levels and ways bias can be introduced.
4.	Societal implications of AI	Understand that ML systems can have widespread positive and negative impacts. Consider ethical, cultural, and societal implications.
Skills		
1.	ML problem scoping	Determine which problems can and should be solved by ML.
2.	ML project planning	Plan a solution that is sensitive to both technical and contextual considerations.
3.	Creating ML artefacts	Use tools to create appropriate artefacts.
4.	Analysis of ML design interactions and results	Describe the explicit and implicit design intentions of an ML system. Critically analyse the intentions against how the system can and should be used.
5.	ML advocacy	Critically discuss ML policies, products, and education.
6.	Independent out-of-class learning	Seek learning experiences outside the classroom.
Attitudes		
1	Interest	Engagement and motivation for the topic.
2.	Identity and community	Contributing to and learning from a community of peers.
3.	Self-efficacy	Empowered to build new, meaningful things.
4.	Persistence	Continuing and expanding engagement with ML.

Table 3
Competencies and design considerations for AI literacy [16].

Overarching theme	Competency	Design consideration
What is AI?	1. Recognizing AI 2. Understanding intelligence 3. Interdisciplinary 4. General vs. narrow AI	
What can AI do?	5. AI's strengths and weaknesses 6. Imagine future AI	
How does AI work?	7. Representations 8. Decision-making 9. ML steps 10. Human Role in AI 11. Data literacy 12. Learning from data 13. Critically interpreting data 14. Action and reaction 15. Sensors	1. Explainability 2. Embodied interactions 3. Contextualizing data
How should AI be used?	16. Ethics	
How do people perceive AI?	17. Programmability	4. Promote transparency 5. Unveil gradually 6. Opportunities to program 7. Milestones 8. Critical thinking 9. Identity, values and backgrounds 10. Support for parents 11. Social interaction 12. Leverage learners' interest 13. Acknowledging preconceptions 14. New perspectives 15. Low barrier entry

is suggested by Chiu [18]. The Holistic Approach to the Design of AI Education for K-12 schools is designed based on interviews with 24 teachers and analysis of their teaching material. The findings reveal six critical components for AI education, organised into two themes. “Content and product” consists of the critical components: AI knowledge, AI processes, and the impact of AI, and “Process and praxis” contains student relevance, teacher-student communication, and flexibility (Table 4).

The epistemological aspects of AI literacy are found within the theme of Content and product. The first subtheme, knowledge in AI, includes

Table 4
The holistic approach to the design of AI education for K-12 schools [18].

Theme	Subtheme	Contained in subtheme
Curriculum as content and product	Knowledge in AI	Definition of AI Development of AI
	Process in AI	Perception Technical skills
	Impact of AI	Social impact AI ethics and human bias
Curriculum as process and praxis	Student relevance	Authenticity Local understanding with a global perspective
	Teacher-student communication	Consistent terminology Graphical representations
	Flexibility	School environment Student needs

knowledge about AI and how it could be defined and developed. Hence, the first subtheme could be included in Technological scientific knowledge from the three-part heuristic framework for technology education [28]. The second subtheme, process in AI, connects to technical skills by its foci on practical aspects. The third subtheme, impact of AI, aligns with socio-ethical technical understanding from Nordlöf et al. [28]. Impact of AI concerns the social impact, AI ethics and the role of humans.

3.5. UNESCO's map of domains and subdomains for AI education

UNESCO has mapped governmental initiatives for AI curricula around the globe. Their report is based on 11 countries' curricula [13]. Table 5 summarises the main domains and subdomains for curriculum areas emerging from their analyses.

The first two areas cover both content and practical aspects of AI literacy. Within UNESCO's framework, content and practice are intertwined and cannot easily be separated. Instead, practical skills such as development, design thinking, programming, and problem-solving are closely connected to more theoretical knowledge such as defining AI, understanding technologies, and programming languages. Hence, technical skills and technological scientific knowledge could not easily be distinguished regarding specific activities related to AI.

The third area is closely connected to socio-ethical technical understanding [28] since it focuses on ethics and social implications of AI both for everyday life and work and the environment. Here, personal aspects, such as integrity and human agency, and societal aspects, such as AI in everyday life, are included. Moreover, there is also a content

Table 5
UNESCO's map of domains and subdomains for AI education [13].

Area	Domain	Sub-domain
AI foundations	Algorithms	Computational thinking Algorithm definitions and applications Algorithm components and processes
	Programming	Programming languages Representations and simulations
	Contextual problem-solving	
	Data literacy	
Understanding, using, and developing AI	AI techniques	AI definitions and components Data use in AI History of AI Understanding how AI works
	AI technologies	Computer and human perception Understanding of AI technologies
	AI development	Design thinking Product development
Ethics and social impact	Applications of AI to other domains	
	Ethics of AI	Ethical terms, definitions, and examples Access Bias Intellectual property Privacy and security Transparency/explainability Human agency
	Social implications of AI	AI's advantages and disadvantages AI in everyday life and work Environmental impacts Fakes and misinformation Gender

aspect within this area that could be connected to technological scientific knowledge, namely ethical terms, definitions, and examples. This sub-domain calls for content knowledge where technological aspects are connected to ethical ones.

4. Merging the frameworks: AI literacy for technology education

In order to suggest a framework for AI literacy adjusted for technology education, the three-part heuristic framework for technology [28] was used as a baseline. However, in this new framework for AI literacy, a clear connection is seen to conceptual, procedural, and contextual technological knowledge [49,50] (Table 6).

The analytical question "What?" identifies technological scientific knowledge due to its orientation towards the content. This category is represented by conceptual technological knowledge, including definitions and theoretical knowledge. Technological scientific knowledge is in the Framework for AI literacy, based on technological scientific knowledge and computer science knowledge. The knowledge from AI literacy that is sorted into this category are the following: defining AI [13,18,45], recognising AI [16], understanding AI [13,16,17,45], and understanding the role of data in AI [13,16,17]. Moreover, knowledge that implies a particular way of thinking is sorted into this category, specifically, systems thinking [16,17,45], computational thinking [13,16], and design thinking [13,16]. For example, Long and Magerko [16] describe robotics as one branch of AI that includes many aspects, such as design thinking, mathematics, and computational thinking. Robotics can be used to teach how data from sensors can be used to localise and

Table 6
A framework of AI literacy for technology education.

	Technological scientific knowledge	Technical skills	Socio-ethical technical understanding
Epistemological stance	Conceptual knowledge	Procedural knowledge	Contextual knowledge
Description of the category	Conceptual aspects Definitions Understanding why things work or not	Skill or ability to make things work Problem-solving Coding	Critical thinking, relating technology to society/the human world, and the environment
Source of knowledge	Technology, engineering, science, and computer science	Experience, trial and error, practical work, practice, rules of thumb in computing and technology	Humanities and social sciences, philosophy
Analytical question	What?	How?	Why? Consequences?
Examples from AI literacy	Defining AI Recognising AI Understanding AI Role of data in AI Computational thinking Design thinking Systems thinking	Programming Data literacy, e.g., data use Product development	Human role in AI AI ethics AI's impact on society and the environment Privacy, integrity, and cyber security Bias

guide robot movement and also how to construct algorithms necessary to plan robot action. The question "What?" could be used analytically and could also help teachers when planning technology education about AI [13,18].

Technical skills and practical work with AI are identified as procedural, technological knowledge within the Framework of AI literacy. This category describes how one makes things work. In this context, it is also to design and make programs work and solve problems using AI. An important aspect is to know when a problem can be solved using AI and when it cannot, but also when AI should be used [45]. To develop AI artefacts and applications, some basic knowledge of programming concepts is needed, for example, data and conditionals (if-then). The technical skills are trained through practical work where learners can practice. In this context, practical work does not necessarily imply building physical models and working with robotics. It could also be to code using block-based or text-based programming interfaces. We suggest that the analytical question "How?" helps to illuminate what AI-related technical skills are at hand in the technology classroom.

It could be worth mentioning that the distinction between Technological scientific knowledge and Technical skills is made only to emphasise the differences between the two epistemological stances. Hence, this is an analytical distinction. In an actual teaching situation, it is not always possible to distinguish the conceptual knowledge from the procedural knowledge. Examples from the different frameworks indicate that working with AI in the technology classroom is a matter of constant interplay between conceptual and procedural knowledge, where they presuppose each other. However, a progression could be discussed between the two. Several frameworks suggest progression where Technological scientific knowledge precedes Technical skills [17,18]. For example, defining what AI is and understanding the basic concepts of how AI machines use data to develop their abilities is often seen as a prerequisite for continuing to other, more practical aspects of AI. However, we propose that the relationship between Technological scientific knowledge and Technical skills within the Framework of AI literacy should be further investigated in naturalistic educational settings.

If a constant interplay between Technological scientific knowledge and Technical skills could be interpreted from the different frameworks, there is no such clear connection to the Socio-ethical technical understanding. However, one implication is that the learner must have a basic knowledge of what AI is to be able to think critically about it. Nevertheless, this issue is of great importance and apparent in all five frameworks of AI. In this epistemological stance, it is imperative to relate AI technology to society and the human world. Therefore, the Socio-ethical technical understanding of the Framework of AI literacy is contextual knowledge. We argue that this is a philosophical stance, and the learners practice moral thinking and ethical reasoning. Once more, the interconnection between the three different epistemological stances are highlighted.

Two different perspectives of ethics on an individual level could be interpreted from the frameworks. The first is the user perspective: how can AI be used, and in what situations? How can it influence our decision-making, and what information can we trust? Questions about equality and gender are also raised here [13]. The second perspective is that of the AI developer: how can we avoid bias [13,18,45]? Transparency is another issue raised by several frameworks [13,17]. Ethics on a societal level is also mentioned in some of the frameworks [13,18,45]. Issues such as privacy, integrity, and security (of data) are some examples that are raised. It could also be worth mentioning that some frameworks only mention ethics without specifying it further [16]. The analytical question that guides explicating the socio-ethical technical understanding is "What are the consequences?" of AI. This question is also suggested to guide teachers' work with teaching AI literacy in technology classrooms.

5. Discussion and implications of AI literacy for technology education

The framework of AI literacy for technology education (Table 6) is suggested to be of importance for further research within this area. AI literacy is here to stay, calling for knowledge, skills and ethical reasoning concerning this content.

The AI literacy for technology education framework is based on policy documents, empirical research in terms of interviews with teachers, experts in the field of AI literacy, and a literature review [13, 16–18,44,45]. In merging those materials, we argue that this framework stands on solid ground. However, research is now needed to inform the usability of it, both as an analytical tool and as a planning tool for technology teachers. The analytical questions ought to be tested empirically.

When programming was introduced as new content globally, the researchers in technology education were slow to react. However, AI has now become discussed within the context of technology education research [32]. As suggested in this paper, we also need a unified framework adjusted to the context of technology education.

So far, much of the research concerns how AI can be used for learning and teaching [34,35]. The entrance of generative AI has already impacted school education in at least four domains: teaching, learning, assessment, and administration [51]. For example, Steele [52] argues that generative AI (such as ChatGPT) can empower students. AI can also be used for teachers to plan their teaching, for example, field trips [53]. However, from a technology education perspective, studies must also focus on students' learning about AI as knowledge components and as part of technological literacy, according to the specified epistemological stances and content in Table 6. In this study, technological literacy is considered a multiliteracy [27]. We argue that AI literacy should also be considered part of that technological multiliteracy. The three dimensions of technological literacy [23]: the ability to use technology, knowledge and understanding of technology, and awareness and appreciation of the relationships between technology, society, and environment could all be exemplified by different AI literacy components (Table 6).

This study also shows clear connections to and between the epistemological views of technology education as presented by [28]. In this sense, this framework functioned well as an analytical tool for more clearly defining AI literacy for technology education. From Table 6, it could be concluded that AI literacy for students connected to technological scientific knowledge (e.g., knowledge about AI and how AI works as part of a technological system) and the socio-ethical technical understanding are emphasised. We term these epistemological stances as conceptual and contextual knowledge, respectively. Defining, recognising, and understanding AI, how AI impacts humans and how humans impact AI are important aspects of AI literacy and technology literacy. However, the aspect of technical skills and procedural knowledge is not very explicit in this framework. It could be argued that technical skills are more critical in higher education for those aiming to work as AI developers and that it is primarily technological scientific knowledge and socio-ethical technical understanding that are important at the primary and secondary levels. On the other hand, it is also epistemologically challenging to define "pure" technical skills concerning AI; most capabilities require cognitive input since AI is quite different from traditional craft skills, such as problem-solving.

The framework of AI literacy for technology education (Table 6) may be used by researchers, policymakers, school leaders, and teachers. Researchers could use it similarly to how it has been designed and used in this article, namely as an analytical tool in researching AI in technology education. Regarding policymakers, we suggest that the framework could be used for curriculum design. In many countries, there is ongoing intense work on AI (technology) curriculum development, and the framework could guide and facilitate that type of work. School leaders could use the framework to identify AI in technology education on a school level and look for ways to integrate it in the overall planning of teaching at the school. Teachers, finally, could use the framework of AI literacy for technology education to plan and evaluate their own teaching, for example, by posing the analytical questions or making sure the epistemological stances are covered, to facilitate teaching and assessment. Empirical research is however suggested to get more evidence on the practical usefulness of the framework, in research as well as in the various levels of schooling.

Research on the use of AI in education has also highlighted several challenges for future education. For example, the risk of students' learning inaccurate information is substantial, and assessing students' knowledge and skills is challenging, given the (lack of) quality of data on the Internet. It is not the first time a new technology has entered the education system; for example, intense debates followed the introduction of the calculator and the computer. However, introducing AI challenges our deepest beliefs about what education should be. The philosopher Langdon Winner, already in 1980, stated that technology is a non-separable part of human lives [54]. According to Winner, technologies do not only aid human activity. It shapes our ways of living, giving us meaning and direction. Because of this strong intertwinement between humans and technology, it is necessary to stay critical towards technology. However, in this context, being critical is not equivalent to being anti-technology [55]. It is important to ask, "[Where] have modern technologies added *fundamentally new* activities to the range of things human beings do? Where and how have innovations in science and technology begun to alter the very *conditions of life* itself?" ([56], p. 13). Winner takes the example of computer programming and asks if it is "only a powerful recombination of forms of life known for ages – doing mathematics, listing, sorting, planning, organizing, etc. – or is it something unprecedented?" (p. 13). It seems as if we, as human beings, have now approached the next level in the intertwined relationship between humans and technology. It is hard not to imagine a future that will radically change following the evolution of AI. Therefore, today's students must develop AI literacy as part of a broad technological multiliteracy.

Declaration of generative AI and AI-assisted technologies in the writing process

While preparing this work, the authors used Grammarly to improve the text's spelling and grammar. After using this tool, the authors reviewed and edited the content as needed and take full responsibility for the content of the publication.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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