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K-12 AI curricula

A mapping of government-endorsed AI curricula

Education 2030

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Education 2030

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Objective and scope of the report

As AI technology represents a new subject area for K–12 schools worldwide, there is a lack of historical knowledge for governments, schools and teachers to draw from in defining AI competencies and designing AI curricula. This mapping exercise analyses existing AI curricula with a specific focus on the curriculum content and learning outcomes, and delineates development and validation mechanisms, curriculum alignment, the preparation of learning tools and required environments, the suggested pedagogies, and the training of teachers. Key considerations are drawn from the analysis to guide the future planning of enabling policies, the design of national curricula or institutional study programmes, and implementation strategies for AI competency development.

Scope of the mapping

UNESCO is investigating the current practices of developing and implementing AI curricula in primary and secondary school education from a global perspective. 'AI curricula' in this study refers to structured programmes of learning on AI-related topics that: 1) are endorsed by either national or regional governments; and 2) target learners in general school education from kindergarten to grade 12. This study does not cover AI curricula designed for specialized technical and vocational education and training (TVET) institutions, higher education institutions, or informal learning opportunities.

Introduction

A diverse range of AI technologies are currently in use internationally, and there is a growing recognition of the importance of AI in the context of labour and in terms of its impact on everyday life. There is 'wide consensus' that AI will 'affect occupations at all levels of pay and education' (Royal Society UK, 2018, cited in the Microsoft Computer Science Framework, 2021). A 2018 analysis by McKinsey concluded that by 2030, 70 per cent of global firms are expected to adopt at least one type of AI technology. However, AI adoption will widen existing gaps between countries (Bughin et al., 2018*a*). Currently, in the United States, machines perform as many as 30 per cent of workforce tasks (Kelly, 2020). Additionally, increasing mismatches between skills being taught in schools and TVET institutions and skills needed by the job market are anticipated in correlation with higher rates of automation and AI integration (Bughin et al., 2018*b*). The COVID-19 pandemic has only increased the pace of automation, which may result in as many as 1 in 16 workers[1] requiring retraining by 2030 and a further decline in the availability of middle- and low-skill jobs (Lund et al., 2021).

The impact of AI technology is not limited to the workforce. AI has profound implications for culture, diversity, education, scientific knowledge, and communication and information, especially insofar as they concern peace, sustainability, gender equality, and the specific challenges of Africa (COMEST, 2019). These are all areas of significant interest to both international and national bodies that focus on development and policy. Citizens are increasing their interactions with AI, knowingly or unknowingly. AI has been deployed to drive cars, automate customer service, identify targets for military bombs, screen applicants at national ports of entry, direct policing efforts, determine grades, select university entrants and scholarship recipients, and make decisions about personal finance (Engler, 2021; Frantzman and Atherton, 2019; Shiohira, 2021).

International policy guidance suggests that common areas should be pursued through different contextualized approaches such as promoting the inclusive and equitable use of AI in education; leveraging AI to enhance education and learning; fostering skills development for jobs and life with AI; and safeguarding education data so that its use is ethical, transparent and auditable (UNESCO, 2019*a*). However, currently relatively few initiatives focus on AI in K–12 contexts, leading to a recent recommendation that policy-makers should 'provide an enabling policy environment and curricular spaces for exploring AI' (Miao et al., 2021, p. 34).

As a leading part of the international community and conversation on technology in education, UNESCO has led a number of important developments in the AI in/for Education space.

In 2015, the *Qingdao Declaration* (UNESCO, 2015) included a point on exploring the potential of big data to enhance online learning, inform an understanding of student behaviour, and improve the design and delivery of online courses. The declaration urged that 'governments must develop policies and systems to ensure secure, appropriate and ethical use of data, including safeguarding the privacy and confidentiality of students' personally identifiable information'.

- The *Beijing Consensus on Artificial Intelligence and Education* (UNESCO, 2019*b*) includes a series of recommendations and considerations for AI in Education. Demonstrating a strong focus on equity and inclusion, one of the recommendations in the consensus is to ensure that AI promotes high-quality education and learning opportunities for all, irrespective of gender, disability, social or economic status, ethnic or cultural background, or geographic location.
- As part of the *UNESCO Strategy on Technological Innovation and Education (2022-2025),* in addition to an observatory and capacity building, the Organization seeks to develop standard-setting instruments and normative tools, including guidelines and frameworks, 'to strengthen the digital competencies (understanding, skills, and values) of teachers and learners and ensure a human-rights-based, safe, ethical, and meaningful use of

1 Eight countries were included in this analysis, namely China, France, Germany, India, Japan, Spain, the United Kingdom, and the United States, accounting for almost half the global population and 62 per cent of GDP.

technologies in a lifelong learning perspective' (UNESCO, 2021*a*). Transversal areas of action are the expansion of access to education, particularly for marginalized groups and individuals, and the quality of teaching and learning.

- UNESCO published *AI and Education: Guidance for policy-makers* in April 2021 with an aim to foster AI-readiness among policy-makers (Miao et al., 2021). This report provides an orientation for its target readers on AI, including opportunities, risks, key definitions, trends in AI, implications for teaching and learning, and how education can prepare students for the AI era. It concludes with recommendations for local policy planning.
- In October 2021, UNESCO launched AI and the Futures of Learning,[2] a project with three independent but complementary strands: (1) a report proposing recommendations on AI-enabled futures of learning; (2) guidance on ethical principles for the use of AI in education; and (3) a guiding framework on AI competencies for school students.

The everyday realities of the current uses of AI and its impact on the world of work spur a sense of urgency to create international consensus on its acceptable roles in society, the expected humanistic considerations in its development and deployment, and how to equip children with the competences they will need to successfully navigate the existing – not the future, but the existing – world. The *Beijing Consensus on Artificial Intelligence and Education* (UNESCO, 2019*b*) calls on all Member States to 'be cognizant of the emergence of a set of AI literacy skills required for effective human–machine collaboration, without losing sight of the need for foundational skills such as literacy and numeracy'. The Consensus endorses a 'humanistic approach' to 'preparing all people with the appropriate values and skills needed for effective human–machine collaboration in life, learning and work, and for sustainable development'. To support the implementation of the Beijing Consensus, on 7 and 8 December 2020 UNESCO hosted the International Forum on AI and the Futures of Education: Developing Competencies for the AI Era. Participants at this event considered the competencies that citizens require:

> The world's citizens need to understand what the impact of AI might be, what AI can do and what it cannot do, when AI is useful and when its use should be questioned, and how AI might be steered for the public good (Miao and Holmes, 2021, p. 6).

The Forum emphasized the centrality of human-oriented competencies, such as an understanding of the ethics of AI and its social impacts, and technology-oriented competencies, such as the skills and knowledge to use, interpret and develop AI. Subject-specific and interdisciplinary approaches to AI in education were recommended, including building on existing ICT curricula and integrating analyses of the opportunities and impacts of AI into humanities, science and art courses (Miao and Holmes, 2021).

This report contributes further to the understanding of AI in K–12 education, in particular the ways in which students are currently being prepared for life and work in the AI era, by providing an analysis of the global landscape of government-endorsed AI curricula for grade school education and their design, content and implementation. This report is intended to inform the creation of supportive tools and frameworks, with a view to enabling the development of a guiding framework on AI competencies. It also forms one part of the work laid out in the *UNESCO Strategy on Technological Innovation in Education (2022-2025)* (UNESCO, 2021*a*).

A primer on AI terms and technologies

This report engages a range of concepts and terms from both AI-specialist and education-specialist fields. Despite the ubiquitous presence of AI in fields such as marketing, finance, and increasingly education, some decision-makers and practitioners may be unfamiliar with some of the terms used in this analysis. Similarly, it is not guaranteed that all AI practitioners and decision-makers will be aware of prominent trends in pedagogy referenced in the curricula. Therefore, this section provides a brief primer on some of the technologies, terms and pedagogies discussed in this text, to equip readers with a general understanding of each main concept. First, five terms from the field of AI are explained in turn, and then the section on pedagogical concepts looks at several concepts including 'competence-based evaluation', 'constructivism', 'constructionism', and 'design thinking'.

2 See https://events.unesco.org/event?id=2883602288

Nearly all of these concepts and terms have generated at least some amount of academic debate, and have both proponents and detractors, but the purpose of this report is not to delve deeply into conflicting viewpoints. This should not be taken as an exhaustive exploration.

Artificial intelligence

The term 'artificial intelligence' was coined in 1956 when Marvin Minsky and John McCarthy hosted the Dartmouth Summer Research Project on Artificial Intelligence (COMEST, 2019; Haenlein and Kaplan, 2019). AI has gained popularity owing to the rise of big data and the exponential growth of computing power (Haenlein and Kaplan, 2019). The definition of AI has expanded and evolved over time (Miao et al., 2021), and now refers to machines that imitate some features of human intelligence, such as perception, learning, reasoning, problem-solving, language interaction and creative work (COMEST, 2019).

The analysis in this report divides AI into two categories, 'AI techniques' and 'AI technologies'. The former encompasses the methods used to build different types of AI, while the latter refers to the fields of study and products which are created by those techniques.

AI techniques

The AI techniques included in the curricula athat are analysed in this report are briefly described below:[3]

- **Classical AI** is rule-based and uses conditional if-then statements to generate outputs. Rule-based reasoning can be used in technologies such as chatbots (e.g. 'If the input contains the words "what", "price" and "?", then return the listed product price amount').
- **Machine learning (ML)** refers to any type of computer program that can 'learn' without explicit programming by accessing and processing large amounts of data. What is meant by 'learn' is that the program can produce new outputs without being explicitly 'told' what those outputs should be, as would be the case in classical AI. The remainder of this list is comprised of some of the many different sub-categories of ML.
- **Supervised learning** is a type of ML which is trained on known, labelled data to produce outputs. For example, a **classifier** is an algorithm that is designed to sort things into categories (e.g. 'spam' or 'not spam') using labelled data. **Decision trees** are a type of classification algorithm in which a series of 'nodes' (decision points, represented as questions) lead to 'branches', where the results of different response options are separated. For example, in the MIT DAILy Curriculum, which is discussed at length later in this report, students create a decision tree to classify different types of pasta. One node might ask, 'Is it longer than four inches?', with spaghetti, linguine, and other long pastas on one branch to the next node and macaroni, farfalle, and other short pastas on another branch.
- In **unsupervised learning**, machine learning generates outputs based on clustering similarities in groups of unknown and unlabelled data.
- **Reinforcement learning** is a type of ongoing ML which is trained to maximize a reward (for example, to return the maximum amount of currency on an investment).
- **Neural networks** are ML algorithms that are modelled on animal brains. They are comprised of input layers, hidden layers and output layers. In the hidden layers, data is processed in nodes based on its value and an assigned weight, and only data that passes a given threshold is allowed through. Filtered data makes its way through one or more hidden layers to the output layer. 'Learning' in neural networks occurs through 'back propagation', an algorithm which seeks to minimize error by adjusting the weights in the hidden layer(s) of different nodes based on the correctness and influence of each node's inputs.
- **Deep learning (DL)** refers to neural networks with multiple hidden layers. While ML in general relies on data that is structured (e.g. selected, labelled and organized into tables), DL can process unstructured data such as text and images. Neural networks and/or deep learning are used in image and speech recognition.
- **General adversarial networks (GANs)** are a type of machine learning which is designed to generate new content, for example images.[4] A GAN includes two deep neural networks. One of these generates content and the other evaluates it. GANs do not work particularly well with text – yet.

3 The explanations given here are derived from Miao et al. (2021), supplemented by examples and definitions from the curricula included in this report, in particular the MIT DAILy Curriculum, the AI4K12 Curriculum Framework, and the IBM Youth Challenge.

4 For example, GAN technology can be used to generate images of people that do not exist (see https://www.thispersondoesnotexist.com)

AI technologies

The AI technologies included in the curricula that are analysed in this report are briefly described below:

- **Chatbots** are computer programs designed to simulate oral and/or written conversation.[5]
- **Computer vision** is the field of AI that is concerned with deriving and using information gathered from images and visual inputs. Computer vision drives products such as automated highlight reels, self-driving cars, and quality-control tools (for the identification of defects) in manufacturing.[6]
- **Natural Language Processing (NLP)** is based on combining computer science with computational linguistics, an interdisciplinary field for studying human language, in order to create rule-based models of human speech or text that can be used by computers. This enables computers to process and appropriately respond to human language. This technology drives computer translation from one language to another and the ability of technologies such as satellite navigation or digital assistants to respond to verbal commands.
- **Sensors** are devices or systems that measure physical properties such as temperature or pressure and transmit this data to other electronics (such as a computer processor). Sensors are one method of gathering the data used in AI. They are a fundamental part of the Internet of Things (IoT), systems in which actions are undertaken without human intervention based on inputs from different sensors (Mahdavinejad et al., 2018). A simple example would be an IoT irrigation system that gathers information from sensors embedded in soil and activates a watering device accordingly.[7]

Ethical AI

As noted, AI has a wide range of applications and many demonstrable benefits. For instance, AI provided important insights and issued alerts early in the COVID-19 pandemic. However, the use of AI also raises a number of ethical considerations. Bias can be introduced into AI through the datasets used and the choices of developers, leading to discrimination. Due to elements such as the hidden layers of some types of AI, the processes and factors in AI decision-making cannot be seen, checked or redressed by humans, raising issues in terms of explainability and transparency. Other challenges include balancing the use of personal data with the individual right to privacy; the security of data and potential exposure to cyber-crime; and the reinforcement of prior beliefs by AI algorithms based on user interest, which can limit people's exposure to ideas and information and, some argue, infringe on an individual's right to freedom of expression (UNDESA et al., 2021).

The *First Draft of the Recommendation on the Ethics of Artificial Intelligence* (UNESCO, 2020) highlights some of the key ethical challenges of AI, noting impacts on decision-making, employment and labour, social interaction, health care, education, media, freedom of expression, access to information, privacy, democracy, discrimination, and weaponization. The Recommendation proposes that AI should be monitored by third parties to ensure it is trustworthy and works for the good of humanity, individuals, societies, and the natural environment and its ecosystems. It sets out ten principles for ethical AI:

1. **Proportionality and no do harm** suggests that AI should have legitimate objectives and aims that are appropriate to the context, and based on rigorous scientific foundations.
2. **Safety and security** suggests that AI should not cause damage and must protect against security risks throughout its life cycle.
3. **Fairness and non-discrimination** suggests that AI systems should avoid bias, and that access to AI and its benefits should be shared at national, local and international levels, and be equally distributed without preference for 'sex; gender; language; religion; political or other opinion; national, ethnic, indigenous or social origin; sexual orientation; gender identity; property; birth; disability; age; or other status'.
4. **Sustainability** suggests that the social, cultural, economic and environmental impact of AI technologies should be continuously assessed in the context of shifting goals.
5. **Privacy** suggests that data for AI is collected, used, shared, archived and deleted in ways that protect the individual agency of data subjects, and that 'legitimate aims' and a 'valid legal basis' are in place for processing personal data.

5 See, for example, https://towardsdatascience.com/building-a-chatbot-with-rasa-3f03ecc5b324
6 For more information, see https://www.ibm.com/topics/computer-vision
7 See for example https://www.digiteum.com/iot-solutions-agricultural-irrigation-system

6. **Human oversight and determination** suggests that humans or other legal entities bear responsibility for AI ethically and in law.
7. **Transparency and explainability** suggests that people should be aware of when decisions are based on AI algorithms, and that individuals and social entities should be able to request and receive explanations for those decisions, including insights into factors and decision trends. **Explanability** is detailed further: 'outcomes, and the sub-processes leading to outcomes, should be understandable and traceable, appropriate to the use context'.
8. **Responsibility and accountability** reinforces the principle of human oversight and determination, and suggests that impact assessment, monitoring, and due diligence mechanisms should be in place to ensure accountability for AI systems. *Auditability*[8] must be ensured.
9. **Awareness and literacy** refers to the responsibilities of governments as well as the public sector, academia and civil society to promote open and accessible education and other initiatives focused on the intersections of AI and human rights, in order to ensure that 'all members of society can take informed decisions about their use of AI systems and be protected from undue influence'.
10. **Multi-stakeholder and adaptive governance and collaboration** suggests that states should regulate data generated within and passing through their territories; that stakeholders from a broad range of civil organizations, and the public and private sector should be engaged throughout the AI life cycle; and that measures need to be adopted to allow for meaningful intervention by marginalized groups, communities and individuals.

AI literacy

The *synthesis report of the UNESCO International Forum on AI and the Futures of Education under the theme of Developing Competencies for the AI Era* (Miao and Holmes, 2020) noted that the world's citizens need to understand what the impact of AI might be, what AI can and cannot do, when AI is useful, when its use should be questioned, and how it might be steered for the public good. This requires everyone to achieve some level of competency with regard to AI, including knowledge, understanding, skills, and value orientation. Together, these might be called 'AI literacy'. AI literacy comprises both data literacy, or the ability to understand how AI collects, cleans, manipulates, and analyses data; and algorithm literacy, or the ability to understand how AI algorithms find patterns and connections in the data, which might be used for human-machine interactions. This is an attempt to frame the scope, structure, and main categories of the emerging field of AI literacy. This term has been used to guide the study presented in this report.

Pedagogical concepts and terminologies

'Competence-based education' (CBE) is a model often pursued in higher education and TVET, but it is increasingly being applied in various forms to K–12 education. CBE is intended to transition education from models of fixed time and flexible learning, to flexible time and fixed learning. In CBE models, students are expected to demonstrate applied knowledge, skills and values in context through assessments, and they are given as much additional support as needed until they meet the required benchmarks (NCLSorg, 2017).

At the heart of CBE is the concept of 'competence', a term which has evolved to describe 'the mobilization of knowledge, skills, attitudes and values to meet complex demands' (OECD, 2019, p. 5). The intended competencies of a curriculum are usually expressed through learning outcomes, or what a student is expected to know, understand and be able to do upon completion of a course of study (Biggs and Collis, 1982; Cedefop, 2017; Kinta, 2013). The terminology 'learning outcome' is a modification of the earlier term 'learning objective' which ensures that the focus of the statement is on students' actions or achievements rather than those of lecturers, and further are defined using measurable applications (Lopez et al., 2015; Sinha, 2020). The relationship between curricula, learning outcomes and competence is complex in actualization but theoretically quite direct: a curriculum describes a set of intended learning outcomes, and assessments of students demonstrate their attainment of these outcomes through the application of knowledge, skills and attitudes/values within the domain or subject of study and, ideally, in new domains – what Biggs and Collis's (1982) SOLO[9] taxonomy refers to as 'extended abstract' capacity.

8 While auditability is not explicitly defined in the Recommendation, this term refers to the ability of third parties to access, review, monitor and criticize algorithms (Jobin et al., 2019).
9 SOLO stands for 'structure of observed learning outcome'.

The frameworks and curricula examined for this report also reference constructivism, constructionism, computational thinking and design thinking.

'Constructivism(s)' is a broad series of concepts in academia that apply to the ways in which knowledge is created or constructed (and at times co-constructed) by individuals through interactions with each other and their physical, cultural and institutional or systemic environments (Taber, 2016). The types of constructivism often applied in education are built largely upon the work of Piaget (1972), who outlines a theory of types and forms of learning which are and are not accessible to children at various stages of development; for example, concrete application would precede abstraction.

A related concept is 'constructionism', the philosophy that students learn best through applying knowledge to projects which hold a personal interest for them (Papert and Harel, 1991). Constructionism is particularly applicable to digital curricula due to its origins in the domains of ICT and mathematics and its preoccupation with the ways in which meaning is generated through the process of engaging, manipulating and changing digital artefacts (Kynigos, 2015). Though constructivists and constructionists have a common base, constructionists challenge the hierarchies of knowledge that were set out by Piaget (1972), generating arguments that students can productively engage with more complex concepts at younger ages through the use of digital media and methods such as block-based programming (Papert, 1996).

Computational thinking, or the series of mental and physical processes undertaken to build a digital solution to a problem (identifying a problem, breaking it down into parts, building and assimilating solutions, and testing and refining them), is theorized to apply to an array of domains outside of computer science (Lodi and Martini, 2021). The four established 'parts' of computational thinking are sometimes cited as decomposition, abstraction, analysis and algorithms (Kush, 2019). Lee et al. (2011) studied a range of computational thinking initiatives in grades K–12 and determined that its processes could indeed be deployed by students of varying demographic backgrounds. They further proposed a 'use-modify-create' learning progression model for engaging with computational thinking, and noted that skilled teachers, developmental considerations and appropriate technology were critical support mechanisms.

One final tool which is presented in the context of some of the curricula included in this study is 'design thinking'. It is presented as 'an analytic and creative process that engages a person in opportunities to experiment, create and prototype models, gather feedback, and redesign' (Razzouk and Shute, 2012). Originally developed in fields such as archeology, marketing and economics (Buchanan, 1992), design thinking started emergning within industry in the early 1990s, where it was developed as a consumer-oriented methodology to design innovative products or business models, particularly those involving technology (Hobcraft, 2017). The process of design thinking includes empathizing (for example with consumers), defining a problem statement, generating ideas for solutions, and then prototyping and testing in an iterative design cycle until a desirable innovation is achieved (Hasso Plattner Institute of Design, 2010). In schools, design thinking can offer a clear procedure for responding to a need for digital as well as interdisciplinary activities and competences.

Existing frameworks of reference on AI curricula

There are a few recent initiatives to map or create AI curriculum frameworks for grades K–12. These include three that are detailed in this section: AI Literacy: Competencies and Design Considerations, the AI4K12: K-12 AI Guidelines,[10] and the Machine Learning Education Framework. This is not an exhaustive list, as a number of NGO, industry and academic organizations and/or individuals have developed AI curriculum frameworks to support their own programmes and undertakings. Some of these frameworks are in use by governments, such as the Microsoft Computer Science Framework, and are included in the learning outcomes mapping later in this report. The three frameworks covered in this section were developed with the primary purpose of informing the development of AI curricula by a range of partners and are not linked to specific products or courses.

10 See https://ai4k12.org

AI Literacy: Competencies and Design Considerations

Long and Magerko (2020) present a series of competencies and design considerations for AI literacy based on a scoping study of existing research, which sought to determine emerging themes in 1) what AI experts believe a non-technical audience should know, and 2) common perceptions and misconceptions among learners.

Their scoping study reveals 17 competencies and 13 design considerations. The descriptions indicate that for this proposal, competencies are universally at the lower levels of a knowledge taxonomy, largely confined to understanding, describing, and identifying. The competencies proposed by Long and Magerko are outlined in **Table 1**.

Table 1. AI Literacy Competency Framework

Competency	Description / learning outcomes
1. Recognizing AI	Distinguish between technological artefacts that use and do not use AI.
2. Understanding intelligence	Critically analyse and discuss features that make an entity 'intelligent'. Discuss differences between human, animal, and machine intelligence.
3. Interdisciplinarity	Recognize that there are many ways to think about and develop 'intelligent' machines. Identify a variety of technologies that use AI, including technology spanning cognitive systems, robotics and ML.
4. General vs narrow AI	Distinguish between general and narrow AI.
5. AI strengths and weaknesses	Identify problem types that AI does/does not excel at. Determine when it is appropriate to use AI and when to leverage human skills.
6. Imagine future AI	Imagine possible future applications of AI and consider the effects of such applications on the world.
7. Representations	Understand what a knowledge representation is and describe some examples of knowledge representations.
8. Decision-making	Recognize and describe examples of how computers reason and make decisions.
9. ML steps	Understand the steps involved in machine learning and the practices and challenges that each step entails.
10. Human role in AI	Recognize that humans play an important role in programming, choosing models, and fine-tuning AI systems.
11. Data literacy	Understand basic data literacy concepts.
12. Learning from data	Recognize that computers often learn from data (including one's own data).
13. Critically interpreting data	Understand that data requires interpretation. Describe how the training examples provided in an initial dataset can affect the results of an algorithm.
14. Action and reaction	Understand that some AI systems have the ability to physically act on the world. This action can be directed by higher-level reasoning (e.g. walking along a planned path) or reactive impulses (e.g. jumping backwards to avoid a sensed obstacle).
15. Sensors	Understand what sensors are and that computers perceive the world using sensors. Identify sensors on a variety of devices. Recognize that different sensors support different types of representation and reasoning about the world.
16. Ethics	Identify and describe different perspectives on the key ethical issues surrounding AI: privacy, employment, misinformation, 'singularity',[11] decision-making, diversity, bias, transparency and accountability.
17. Programmability	Understand that agents are programmable.

Source: Long and Magerko, 2020

The design considerations proposed by Long and Magerko (2020) focus on pedagogical and learning methods, but also on social and interpersonal elements. Overall, they emphasize experiential learning and relevant material, an appreciation for cognitive demands and child development theory, and the positioning of AI within learner contexts. The 15 specific design considerations that the researchers present are:

1. **Explainability**: Include graphical visualizations, simulations, explanations of agents' decision-making

11 Describes the point at which AI becomes more intelligent than humans, and can be accompanied by concerns that AI would intentionally harm humans.

processes, or interactive demonstrations in order to aid learners' understanding of AI.

2. **Embodied interactions**: Design interventions in which individuals can act as or follow the agent, as a way of making sense of the agent's reasoning process. This may involve embodied simulations of algorithms and/or hands-on physical experimentation with AI technology.
3. **Contextualizing data**: Encourage learners to investigate who created the dataset, how the data was collected, and what the limitations of the dataset are. This may involve choosing datasets that are relevant to learners' lives, are low-dimensional and are 'messy' (i.e. not cleaned or neatly categorizable).
4. **Promote transparency**: Promote transparency in all aspects of AI design (i.e. eliminating black-box functionality, sharing creator intentions and funding/data sources, etc.).
5. **Unveil gradually**: To prevent cognitive overload, give users the option to inspect and learn about different system components; explain only a few components at a time; or introduce scaffolding that fades as the user learns more about the system's operations.
6. **Opportunities to program**: Provide ways for individuals to program and/or teach AI agents. Keep coding prerequisites to a minimum by focusing on visual/auditory elements and/or incorporating strategies like Parsons problems and fill-in-the-blank code.
7. **Milestones**: Consider how perceptions of AI are affected by developmental milestones (e.g. theory of mind development), age, and prior experience with technology.
8. **Critical Thinking**: Encourage learners to be critical consumers of AI technologies by questioning the intelligence and trustworthiness of AI applications.
9. **Identities, values and backgrounds**: Consider how learners' identities, values, and backgrounds affect their interest in and preconceptions of AI. Learning interventions that incorporate personal identity or cultural values may encourage their interest and motivation.
10. **Support for parents**: When designing for families, help parents scaffold their children's AI learning experiences.
11. **Social interaction**: Design AI learning experiences that foster social interaction and collaboration.
12. **Leverage learners' interests**: Exploit current issues, everyday experiences, or common pastimes like games or music when designing AI literacy interventions.
13. **Acknowledge preconceptions**: Allow for the fact that learners may have politicized or sensationalized preconceptions of AI from popular media, and consider how to respect, address, and expand on these ideas in learning interventions.
14. **New perspectives**: Introduce perspectives that are not as well-represented in popular media (e.g. less-publicized AI subfields, balanced discussions on the dangers and benefits of AI).
15. **Low barrier to entry**: Consider how to communicate AI concepts to learners who do not have extensive backgrounds in mathematics or computer science (e.g. by reducing the prerequisite knowledge/skills, relating AI to prior knowledge, and addressing learners' insecurities about their ability).

AI4K12: Five Big Ideas and K–12 AI Curriculum Guidelines

The AI4K12 Initiative was launched by the Association for the Advancement of Artificial Intelligence (AAAI), the Computer Science Teachers Association (CSTA), and AI4All in 2018 as a joint working group that seeks to develop national guidelines for teaching K–12 students about AI (AAAI, 2018).

This group brought together academics, researchers and teachers to work towards a comprehensive AI framework based on 'five big ideas': 1) computers perceive the world using sensors; 2) agents maintain representations of the world and use them for reasoning; 3) computers can learn from data; 4) intelligent agents require many types of knowledge to interact naturally with humans; and, at the very centre, 5) AI can impact society in both positive and negative ways. The 'Five Big Ideas in Artificial Intelligence' poster resource has been translated into 15 languages to date,[12] and formed at least part of the basis for the development of curricula in multiple contexts, including several of the curricula researched for this study.

The working group was convened to unpack each of these ideas into a curriculum framework divided into four parts, for grades K–2; 3–5; 6–8; and 9–12. To date, curriculum guidelines for the first three 'big ideas' have been drafted and are currently available for public comment.[13]

12 See https://ai4k12.org/resources/big-ideas-poster
13 See https://ai4k12.org/gradeband-progression-charts

In the guidelines, each 'big idea' is subdivided into learning concepts, which are further split into concept components. For example, the learning concepts, concept components and associated learning outcomes for 'Big Idea 1: Perception' are summarized in **Table 2**.

Table 2. 'Big Idea 1: Perception' concepts and learning outcomes

Learning concepts	Concept components	Learning outcome progression
Sensing	Living things	K–2: Identify human senses and sensory organs. 3–5: Compare human and animal perception. 6–8: Give examples of how humans combine information from multiple modalities. 9–12: N/A
	Computer sensors	K–2: Locate and identify sensors (camera, microphone) on computers, phones, robots, and other devices. 3–5: Illustrate how computer sensing differs from human sensing. 6–8: Give examples of how intelligent agents combine information from multiple sensors. 9–12: Describe the limitations and advantages of various types of computer sensors.
	Digital encoding	K–2: N/A 3–5: Explain how images are represented digitally in a computer. 6–8: Explain how sounds are represented digitally in a computer. 9–12: Explain how radar, lidar, GPS, and accelerometer data are represented.
Processing	Sensing vs perception	K–2: Give examples of intelligent vs non-intelligent machines and discuss what makes a machine intelligent. 3–5: Use a software tool such as a speech transcription or visual object recognition demo to exhibit machine perception, and explain why this is perception rather than mere sensing. 6–8: Give examples of different types of computer perception that can extract meaning from sensory signals. 9–12: Explain perception algorithms and how they are used in real-world applications.
	Feature extraction	K–2: Give examples of the features that one would look for if one wanted to recognize a certain class of objects or entities (e.g. cats) in an image. 3–5: Illustrate how face detection works by extracting facial features. 6–8: Illustrate the concept of feature extraction from images by simulating an edge detector. 9–12: Explain how features are extracted from waveforms and images.
	Abstraction pipeline: language	K–2: Describe the different sounds that make up one's spoken language, and for every vowel sound, give a word containing that sound. 3–5: Illustrate how sequences of sounds can be recognized as candidate words, even if some sounds are unclear. 6–8: Illustrate how sequences of words can be recognized as phrases, even if some of the words are unclear. 9–12: Illustrate the abstraction hierarchy for speech understanding, from waveforms to sentences.
	Abstraction pipeline: vision	K–2: Demonstrate figure/ground segmentation by identifying the foreground figures and the background in an image. 3–5: Illustrate how the outlines of partially occluded (blocked) objects in an image differ from the full shapes of the objects. 6–8: Describe how edge detectors can be composed to form more complex feature detectors, e.g. for letters or shapes. 9–12: Demonstrate how perceptual reasoning at a higher level of abstraction draws upon earlier, lower levels of abstraction.
Domain knowledge	Types of domain knowledge	K–2: Describe some things an intelligent agent must 'know' to make sense of a question. 3–5: Demonstrate how a text-to-speech system can resolve ambiguity using context, and how the error rate increases with ungrammatical inputs. 6–8: Classify a given image and then describe the kinds of knowledge a computer would need in order to understand scenes of that type. 9–12: Analyse one or more online image datasets. Describe the information that the datasets provide and how this can be used to extract domain knowledge for a computer vision system.
	Inclusivity	K–2: Discuss why intelligent agents need to understand other languages. 3–5: Discuss how domain knowledge must be broad enough for all the groups an application is intended to serve. 6–8: Describe how a vision system might show cultural bias if it lacked knowledge of objects not found in the culture of those who created it. 9–12: Describe some of the technical difficulties in making computer perception systems function well for diverse groups.

Source: AI4K12 (2020)

Each big idea is broken down in a similar manner with a concrete learning outcome pathway from early primary school to high school. In addition to these outcomes, the curriculum guidelines offer examples of the 'enduring knowledge' that students are expected to retain, for example: 'Sounds are digitally encoded by sampling the waveform at discrete points (typically several thousand samples per second), yielding a series of numbers' or 'The spoken language hierarchy is: waveforms ➡ articulatory gestures➡ sounds ➡ morphemes ➡ words ➡ phrases ➡ sentences.' Sometimes the learning outcomes and enduring knowledge are further unpacked, as was this second example: 'To go from noisy, ambiguous signals to meaning requires recognizing structure and applying domain knowledge at multiple levels of abstraction. A classic example: the sentences "How to recognize speech" and "How to wreck a nice beach" are virtually identical at the waveform level.'

Occasionally, activities are suggested. For instance, to explain decision trees at the grade 3–5 level, 'the "guess the animal" game, troubleshooting problems, and the Pasta Land activity' are recommended.

The big ideas are mutually reinforcing. For example, 'Big Idea 3' leverages the knowledge from sensing components to facilitate a discussion of differences in how people and computers learn. Similarly, it builds on the knowledge of processing components to equip learners to label a dataset for machine learning, train classifiers and engage AI concepts such as decision trees, neural networks, supervised learning, unsupervised learning, and reinforcement learning.

The Machine Learning Education Framework

Although it never mentions competence-based education, the Machine Learning Education Framework (Lao, 2020) follows the well-known CBE framework of knowledge, skills and attitudes (which have in other contexts included items such as abilities and/or values) (Brewer and Comyn, 2015; CANTA, 2014; European Parliament and Council of the European Union, 2006). CBE has in the past been criticized by some for its lack of attention to the meaning of the task for students and a reductionist view of competence which, while firmly rooted in the context of performance, is less sensitive to individual factors like prior experience and the flexibility to tap into external resources, e.g. the knowledge of teammates (Rutayuga, 2014). However, the gradual integration of theories such as constructivism and experiential learning (Brunner, 1990; Kolb, 2015; Piaget, 1972; Williams, 2017) has resulted in a competence-based framework that focuses on 'head, heart and hands', in which the 'head' represents the cognitive domain (what you know about it), the 'heart' represents the affective domain (why it matters) and 'hands' represent the psychomotor domain (what you can do with it) (Gazibara, 2013; Singleton, 2015; Sipos et al., 2008). This integration has also expanded the concept of competence to include social and emotional skills (European Parliament and Council of the European Union, 2006; Mulder, 2007).

In addition, Lao (2020) draws on:

- theories of constructionism, or the idea that learning is enhanced when undertaken through the construction of an item that has personal meaning for the students;
- computational thinking, a proposed reframing of familiar competence concepts to apply concretely to the programming world: technical *concepts*, programming *practices,* and *perspectives* on an individual's relationships with technology;
- a model for understanding the learning outcomes for computational thinking lessons, divided into abstraction, or the ability to apply concepts to new use cases; automation, or utilizing a computer to increase efficiency in repeated tasks; and analysis, or reflection on a student's assumptions and methods of implementation (Lee et al., 2011).
- Use-Modify-Create (UMC), a tiered progression often employed in computational thinking lessons, in which students first engage with existing software, and then modify it to fit new needs, and finally create new software (Lee et al., 2011).

The Machine Learning Education Framework (outlined in **Table 3**) consists of six 'minimally required courses for ML-engaged citizens', and is targeted to a 'tinker/consumer' audience (Lao, 2020, p. 61). In her framework, Lao makes the argument that understanding bias and the social implications of AI are fundamental requirements for all skills.

Table 3. The Machine Learning Education Framework with learning outcomes and definitions

Knowledge	
1. General ML knowledge*	Know what machine learning is (and is not). Understand the entire pipeline of the creation of ML systems.
2. Knowledge of ML methods	Identify when to use a range of ML methods across the breadth of the field (e.g. k-nearest neighbours, CARTs or decision trees, neural networks, ensemble methods). Understand how different methods work.
3. Bias in ML systems*	Understand that systems can be biased, and the different levels and ways in which bias can be introduced.
4. Societal implications of AI*	Understand that ML systems can have widespread positive and negative impacts. Consider the ethical, cultural and social implications of what they do.
Skills	
1. ML problem scoping	Determine which problems can and should be solved by ML.
2. ML project planning	Plan a solution which 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	Students seek learning experiences outside the classroom.
Attitudes	
1. Interest	Students are engaged and motivated to study the topic.
2. Identity and community	Students contribute to and learn from a community of peers and/or broader online communities who are interested in ML.
3. Self-efficacy	Students are empowered to build new, meaningful things.
4. Persistence	Students continue and expand their engagement with ML.

**The starred items are the six required courses outlined in the framework.*

Source: Lao, 2020

Lao (2020) also presents a rubric for evaluating ML learning programmes against this framework, setting up the basis for a set of standards at the exit level which could be built upon. For example, the four 'top scores' in the rubric for the four learning outcomes under 'Knowledge' are:

1. **General knowledge**: Graduates of this course can give a precise definition of machine learning and provide a detailed description of the steps of the ML pipeline with technical and socio-ethical considerations for each step.
2. **Knowledge of ML methods**: Graduates of this course are able to accurately discern when to use a range of machine learning methods across the breadth of the field. They are able to describe core technical concepts of these methods and comfortably use/implement them in appropriate applications. (Lao then lists her views on appropriate methods for different educational levels:
   - **High school and above**: K-nearest neighbours, CART/DT, regression, convolutional neural networks; unsupervised methods such as k-means clustering, principal component analysis, GANs, and embeddings; RNNs/LSTMs; reinforcement learning; transfer learning; and ensemble methods.
   - **Primary and middle school**: Engage applications that allow students to complete specific tasks using ML, e.g. exploiting neural network and GAN applications to create art or music, or deploying reinforcement learning to play games, etc.)
3. **Bias**: Graduates of this course are able to describe how ML systems may come to be unpredictably biased against specific groups throughout each step of the ML pipeline. They can critically incorporate the practices of ethical thinking and design in their own work.
4. **Social implications**: Graduates of this course recognize that it is necessary for the creators of ML technologies to consider the societal implications of their work. They are able to apply ethical and cultural perspectives and concepts to the analysis of ML artefacts in comprehensive, interrelational and sensitive ways (i.e. considering privacy, security, the potential for abuse, and the balance of benefits and harm; and assessing ethnographic reception and disparate impacts using tools such as stakeholder analyses, ethical matrices and model cards).

Methodology

Data collection

Two surveys were distributed, the first to representatives of 193 UNESCO Member States and the second to over 10,000 private- and third-sector actors.[14] The surveys asked the respondents to report on AI curricula for students in K–12 general education. Appendix A provides the questions in the survey sent to the representatives of Member States. It was modified only very slightly for the private- and third-sector actors.

After the surveys were returned, the team emailed additional questions on learning outcomes, implementation and preparation to the respondents who had indicated that they did have AI curricula at some stage of development.

In addition, semi-structured key informant interviews were held with Member State representatives, non-profit leaders and developers, academics and industry professionals to gain further clarity on the curricula and their deployment in schools. Interviews probed the motivations for developing the AI curricula, and the reasons for their decisions around implementation methods and pedagogies.

Finally, a mapping exercise was undertaken for those curricula which had been drafted or published and were available for review. The exercise focused on the learning outcomes stated within each curriculum. Where possible, associated textbooks or materials were also reviewed to gain a further understanding of the content covered by the curriculum.

Criteria for selecting government-endorsed AI curricula

This study is focused on government-endorsed curricula within general K–12 education. The results include only the curricula that have been, or are in the process of being, approved by national or local governments. As stated earlier, 'AI curricula' in this study refers to structured programmes of learning that cover topics in the field of AI and engage with AI-related learning outcomes.

Of the 193 Member States contacted through the official UNESCO channels of correspondence, a total of 51 responded, indicating at least a general interest in the topic. Among them, 29 countries and one territory completed the full survey.

- Representatives from 10 countries reported no AI curricula in their country. These are: Bahrain, Canada, Colombia, Costa Rica, Estonia, Guinea, Macedonia, the Maldives, Singapore, and the Ukraine.
- Representatives from 20 countries and one territory responded that they were aware of at least one AI curriculum that was developed and endorsed by government or is under development. These are: Algeria, Armenia, Austria, Belgium, Canada (Yukon Territory), France, Germany, Jordan, Republic of Korea, Kuwait, Lao People's Democratic Republic, Peru, Portugal, Qatar, the Republic of Bulgaria, Saudi Arabia, Serbia, Slovenia, Syria, and the United Arab Emirates.

In addition, a total of 31 NGOs, academics and industry partners responded to the non-governmental survey and indicated that they had an AI curriculum.

All Member State representatives and organizations reported having an AI curriculum were contacted with follow-up questions via email and asked to provide any available curriculum documents.

During the course of these follow-up emails and the curriculum mapping exercises, it was found that some of the reported curricula did not to meet the stringent criteria set out for inclusion in this study. Curricula were excluded from further analysis if they did not have AI-specific learning outcomes, did not cover ordinary K–12 education (e.g. were focused on TVET), were not endorsed by the government at the national or regional level, and/or did not provide enough information to analyse.

14 These actors were sourced through a list of key organizations in the field of ICT in education accumulated by UNESCO over the course of organizing nine editions of the Mobile Learning Week from 2011 to 2020.

List of government-endorsed AI curricula

Curricula are categorized as 'governmental' if they were provided in response to the survey distributed to UNESCO Member States and were developed by or under the directive of governmental agencies. In order to be eligible for analysis, the survey and interview responses had to provide clear, consistent and meaningful information on the curriculum.

After applying the selection criteria to all of the data from the governmental and non-governmental surveys, it was found that:

- 11 Member States have developed, endorsed and implemented AI curricula.
- The Yukon Territory of Canada has developed and implemented a curriculum entitled Applied Design, Skills, and Technologies, which has been locally rather than nationally endorsed.

Table 4. K–12 AI curricula, endorsed and implemented by governments

Country/ region	Curriculum title	Curriculum developer[15]	Educational levels		
			Primary	Middle	High
Armenia	Curriculum of ICT	Government		X	X
Austria	Data Science and Artificial Intelligence	Federal Ministry of Education, Science and Research			X
Belgium	IT Repository	*Fédération Wallonie-Bruxelles* (French-speaking Community of Belgium)			X
China	AI curriculum embedded in the Information Science and Technology curriculum	The Ministry of Education of the People's Republic of China	X	X	X
India	Atal Tinker Labs AI modules	Atal Tinker Labs, Atal Innovation Mission, NITI Aayoag		X	X
Republic of Korea	'AI Mathematics' under the Mathematics Subject Group for high schools	Korea Foundation for the Advancement of Science and Creativity			X
Republic of Korea	'AI Basics' under Technology Home Economics Subject Group for high schools	Korea Foundation for the Advancement of Science and Creativity			X
Kuwait	Standards curriculum	Curricula technical guidance experts and teachers	X	X	
Portugal	Information and Communication Technologies	State school teachers of ICT and Mathematics	X	X	X
Qatar	Computing and Information Technology	Binary Logic, Ministry of Education and Higher Education	X	X	X
Qatar	Computing and Information Technology (High Tech Track)	Binary Logic, Ministry of Education and Higher Education			X
Serbia	Informatics and programming – Grade 8	Ministry of Education working group		X	
Serbia	Modern technologies in gymnasiums – Grade 3 and 4	Ministry of Education working group			X
United Arab Emirates	AI curriculum embedded under the Technology Subject Framework	Ministry of Education	X	X	X

Source: UNESCO (2021*b*)

In addition to the curricula being implemented, those that are in development and will likely be endorsed by the governmental agencies were also analysed. As shown in **Table 5**, these include an additional three AI curricula from Serbia and one each from four more countries (Germany, Jordan, the Republic of Bulgaria and Saudi Arabia).

15 This column shows the responses as they appeared in the completed surveys.

Table 5. Governmental K–12 AI curricula in development

Country/ region	Curriculum title	Curriculum developer	Educational levels		
			Primary	Middle	High
Germany	1. Identifying and Formulating Algorithms [*Algorithmen erkennen und formulieren*]	Standing Conference of the Ministers of Education and Cultural Affairs of the Länder	X	X	X
Jordan	2. Digital Skills	National Center for Curriculum Development		X	X
Bulgaria	3. Computer Modelling, Information Technology and Informatics	Expert groups (academia, teachers, education experts)	X	X	X
Saudi Arabia	4. Digital Skills	Binary Logic and Tatweer Co.	X	X	X
Serbia	5. Technique and Technology	Ministry of Education working group		X	
	6. AI in gymnasiums	Ministry of Education working group			X
	7. AI in all high schools	Ministry of Education working group			X

Source: UNESCO (2021*b*)

Non-governmental curricula were included in the study if they covered AI learning outcomes and were at some stage of implementation in cooperation with at least one local government. However, these curricula have not been confirmed as officially endorsed by governmental agencies, and are included only as non-governmental benchmarks.

Some of these developers have undertaken other work related to the listed curricula which was also examined for the curriculum mapping. These include a curriculum adaptation entitled 'IBM-CBSE AI Curriculum for Grade XI & XII' and the Microsoft series of textbooks called *Artificial Intelligence, Data Analytics* and *Machine Learning*, both designed for use in India; and the Microsoft Computer Science Curriculum Toolkit.

Table 6. Non-governmental AI curricula included in the study as benchmarks

Country/ region	Curriculum title(s)	Curriculum developer	Educational levels		
			Primary	Middle	High
International	1. IBM EdTech Youth Challenge	IBM		X	X
	2. AI Youth Skills	Microsoft		X	X
	3. Global AI Readiness Program (High Tech Track)	Intel		X	X
	4. Global AI Readiness Program (General Track)	Intel		X	X
United States	5. DAILy Curriculum	MIT		X	X

Source: UNESCO (2021*b*)

Limitations to the survey analysis

As noted earlier, this analysis does not capture all of the activities related to developing AI competencies for school children, and does not even encompass all of the available information on governmental AI curricula. A wide range of curricula are outside the scope of this study. For example, three curricula were submitted from Austria, but two operated in the TVET sector, which is not covered here. A number of for-profit providers supply training on their proprietary technology, and many AI-training programmes are offered by NGOs through non-formal learning channels like independent study; none of these were analysed.

Other limitations include the following:

- **Some government-endorsed AI curricula might have been missed.** The survey was sent out to all 193 Member States, but it is possible that some countries which do have AI curricula did not respond.
- **There are gaps in the data.** Some of the data sought, particularly around the number of schools and learners, were not available for many curricula, which either do not track these or are not authorized to release them.
- **The future relevance could be questionable.** The mapping is time-bound, as many curricula are still in development and may be further revised. This dataset only provides a snapshot of activities in the non-governmental and private sector, and may be of limited utility in the future.

Key findings of the analysis of government-endorsed AI curricula

The following five sections present the results of the analysis:

1. The section on **curriculum development and endorsement mechanisms** addresses the mandate, motivation and means of endorsement for the AI curricula.
2. The section on **curriculum integration and management** includes approaches to incorporating AI curricula into education systems, including time allocations in terms of percentages and total hours and the preparation of essential conditions for supporting AI curricula.
3. The section on **curriculum content** outlines the time allocations for topic areas in three main categories of content, namely AI foundations; ethics and social impact; and understanding, using and developing AI tools.
4. This section presents the **learning outcomes** of mapped AI curricula defined under the competence areas of knowledge, skills and values.
5. The section on **curriculum implementation** summarizes the main strategies for teacher training and support, preparation of the required learning tools and environments, and suggested pedagogies.

Curriculum development and endorsement

As listed above, 14 AI curricula were endorsed and mandated for use in schools by governmental agencies in 11 countries, while 7 curricula in 5 countries are still in development. Only Serbia has both endorsed curricula and curricula still in development. A further two curricula were endorsed at the local level: the Applied Design, Skills, and Technologies curriculum from the Yukon Territory in Canada, and the MIT DAILy Curriculum in the United States. In some parts of the analysis, the four private-sector, non-governmental AI curricula were also included as benchmarks.

AI curriculum development and endorsement mechanisms

- **Centralized government-led approach**

The majority of these curricula were developed by national public agencies and endorsed through a centralized government-led approach, at times with the participation of or in collaboration with key stakeholders. For example, in the Republic of Korea, development was undertaken by experts under a government directive; and in China, Kuwait, and the Republic of Bulgaria, development included teachers as well as academics and experts.

- **Government-commissioned private provision**

A second approach was government-commissioned private provision. In Saudi Arabia and Qatar, companies were commissioned by the government to develop the national curriculum. The Saudi Arabian representative commented that:

> " New technologies emerge every day, and application features are updated frequently. Therefore, we choose to work with a quality private company that has a strong reputation for ICT curriculum construction and incorporates the latest technologies and IT applications.

- **Government-directed decentralized approach**

The third approach to development and endorsement was a government-directed decentralized approach. In Belgium, a parliamentary mandate created standards which were then adopted by networks of schools. These networks determine aspects such as the technologies and pedagogies to be used. A similar approach is seen in Germany, where a national mandate and standards are further developed by local or provincial governments into a curriculum for implementation in schools.

- **Private-sector-driven non-governmental AI curricula**

Finally, some curricula are non-governmental and driven by private sector actors. They may be adopted as-is by schools or adapted by local experts when they develop curricula for governmental agencies. These curricula aim for a degree of flexibility so that they can be incorporated into various government frameworks and requirements, and further customization is also undertaken for specific country contexts. An important part of the development and endorsement of these curricula is validation, both nationally and internationally. Intel's representative remarked that:

> "We had the curriculum extensively validated by countries...We created a global pool of validator experts and gave them the content to modify and make recommendations. When we started implementing it in 2019 and 2020, we did an extensive evaluation.

But no evidence has shown that these private-sector-driven curricula have been endorsed as governmental AI curricula. In examples of this approach, industry or academic stakeholders including IBM, Intel, Microsoft and MIT have produced their own curricula and resources in consultation with experts and teachers.

Vision and motivations for developing AI curricula

The interview respondents indicated two significant rationales for the development of AI curricula: to improve capacity and respond to the skills needed by the labour market, and to ensure that students graduate with the skills necessary for everyday interactions in social and political life. The extent to which these considerations were emphasized differed widely, though. For example, one country indicated they were not at all concerned with labour market skills, while others cited this as the primary consideration.

The goal of developing skills for the labour market reflected an understanding of the shifting needs of the technology sector and the wider world of work. For most but not all countries, this was linked to a desire to develop an internationally competitive workforce. Corporate developers also mentioned this as a strong motivation for including the development of AI training courses for students in their corporate social responsibility activities.

The second rationale was associated with an understanding of AI as a driver of social as well as economic transformation, and a desire to foster general knowledge about AI and its functions and uses in society among students. Several survey respondents noted that AI is already embedded in a range of everyday interpersonal interactions, and felt citizens should recognize AI in their environments, understand its benefits and potential challenges, and be empowered to advocate for safe, beneficial and transparent AI technologies. This is exemplified in the following three comments, which were contributed by the representatives from Portugal, Austria and Jordan respectively:

> "We have a clear vision of the impact of technology in the future, and the need for a workforce and citizens who relate to technology in a healthy way on a daily basis. This includes the concepts, awareness, and skills to improve these areas, work with machines, and see robotics as complementary to society. This is the big picture.
>
> Artificial intelligence is seen as a transversal issue that has the potential to disruptively change key areas and concepts of life. Therefore, it is not only the expertise of specialists and developers that is of great importance in the consideration of AI in education, but also general knowledge about the basics for all people to enable them to lead a safe and self-determined life in a world shaped by AI.
>
> The plan is to develop a digital skills curriculum appropriate to global developments and the expected digital transformation, and also attain the worldwide digital competencies as relevant to our context.

Pilot testing and evaluation of AI curricula

The following governmental AI curricula have been implemented and evaluated: Computer Modelling, Information Technology and Informatics, Republic of Bulgaria; Information Science and Technology, China; MIT DAILy Curriculum; Serbia's Informatics and Programming, Modern Technologies, and Technique and Technology; and the Technology Subject Framework implemented in the UAE.

Additionally, the implementation of the following non-governmental AI curricula have been evaluated: IBM EdTech Youth Challenge; both versions of the Intel AI for Youth: Global AI Readiness Program; and Microsoft AI Youth Skills.

Some of the curricula were revised based on the evaluation, including China's, the UAE's, IBM's, Intel's (both versions), Microsoft's, and MIT's. A few are still being piloted and may be further revised, namely the one from Bulgaria, the MIT DAILy Curriculum, and Serbia's Technique and Technology.

Common evaluation methodologies included:

- **Expert reviews of the curriculum**. For example, in the UAE, the curriculum was shared with different social stakeholders including academics and AI specialists. Cross-disciplinary reviews were conducted by experts in psychology and education.
- **Research conducted by developers**. Methodologies included testing learners and carrying out interviews and surveys with teachers and representatives of regional and/or national administrative departments. Information was gathered on learning outcomes, the perceived usefulness of the curriculum, and challenges in implementation.
- **External evaluation**. Some governments commissioned external evaluations of the curriculum and/or its outcomes. For example, the Republic of Bulgaria commissioned a national external assessment which measured the digital competencies of learners.

Few of these reviews or evaluations are published. A key point surfaced by the interviews was that AI curricula should be coordinated with the mathematics curriculum and the classroom requirements. For example, a curriculum review in China determined that the level of requirements for the Information Science and Technology curriculum was above that of mathematics and science subjects, so the expectations had to be revised. The curriculum also had to cater for a wide range of contexts, and the unique opportunities and challenges of both urban and rural settings.

A pilot study of one part of the MIT DAILy Curriculum found that according to the teachers, the students seemed more engaged than usual, and 'what is and is not AI' was the key to students' understanding. Some teachers found the ethics modules odd and confusing, but others embraced them. The use of hardware was perceived to be the most difficult component of the pilot to manage and required strong teacher investment and attention, particularly when the equipment did not work properly, although this helped students to learn important skills like resiliency (Williams et al., 2021).

Example: Qatar curriculum development foundations and principles[16]

Qatar Vision 2030[17] acknowledges technology as a key factor for a modern knowledge-based economy, and the Qatar National Curriculum Framework (QNCF) defines IT as a major school subject in grades 1-12 which aims to 'support children's learning by offering beneficial opportunities in the areas of logic and mathematical thinking, language and communication, emergent literacy and creativity'.

To support these national policies, standards were created as a foundation of the national Computing and Information Technology curriculum through a collaboration between industry experts, the Qatar Ministry of Education and Higher Education's ICT experts team, and ICT supervisors at primary, preparatory and secondary schools. The standards were reviewed by the computer science experts and curriculum development experts of three Qatari higher education institutions. The curricula developed under the standards include a universal compulsory track for all grade levels and an elective 'high-tech' track for senior high schools. Both tracks include AI learning outcomes related to algorithms, programming, ethics and social impact, and understanding and using AI tools and technologies. Students in the high-tech track also engage in developing AI technologies.

The intention is to review the standards periodically to ensure that they capture current technologies and trends in computer science and IT. Ensuring the curriculum is not dependent on specific technologies, platforms or applications is another step toward guaranteeing the sustainability of the standards over time. The curriculum framework further suggests incorporating teacher feedback and international best practice reviews to make additional adjustments that bolster its effectiveness.

The development of Qatar's Computing and Information Technology curriculum standards was guided by five main principles:

1. Alignment to a national curriculum framework, including the 'competencies, values, aims, principles and cross-cutting issues', with competencies

16 Information in this section is sourced from the *Qatar Computing and Information Technology Curriculum 2018* produced by the country's Ministry of Education and Higher Education. It can be provided on request via email.
17 See https://www.gco.gov.qa/en/about-qatar/national-vision2030

explicitly linked to national standards. The curriculum covers knowledge, skills and attitudes with a focus on:

- Computer science principles and practices, namely programming, robotics and AI;
- Digital literacy, defined in the curriculum as the 'creative and productive use and application of computer systems', including aspects of ethics, intellectual property and e-safety;
- The promotion of soft skills, in this case as defined by the American Association of School Librarians: collaboration, communication, teamwork, critical thinking, problem-solving and decision-making.

2. 'Spiral' development, so that concepts reappear at different grade levels with increasing difficulty and greater depth with each iteration. At the same time, the skills development must be coherent and efficient, so that both needless repetition and academic gaps are eliminated.
3. Student-centred learning and hands-on project-based approaches. Computational thinking is a core element, and students are expected to leverage the process of abstraction, automation and analysis as a new approach to problem-solving, beginning with an understanding of the basic principles of computational thinking in grade 1.
4. Computing language, hardware and platform independence, meaning the curriculum does not rely on a particular provider, brand or programming language but seeks to cover a wide range of tools and technologies that students encounter in real life.

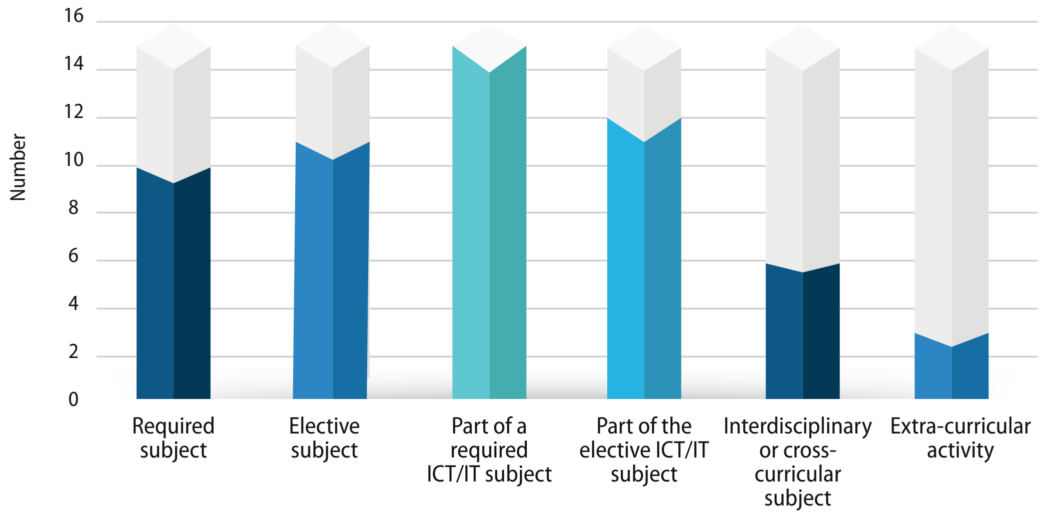
Curriculum integration and management

Curricula are integrated into existing education systems through a number of different models:

- **Discrete AI curricula** are developed in an independent subject category within the national or local curriculum framework. These curricula have their own time allocations, textbooks and resources, as in the case of China's Foundations of AI under Information Science and Technology for grades 10 to 12.
- **Embedded AI curricula** are developed and contained within other subject categories in the national or local curriculum framework. AI most commonly becomes a topic within ICT or computer science but may alternatively be part of language, mathematics, science or engineering (see **Figure 1**). In the Republic of Korea, two elective AI subjects have been developed, one falling within the mathematics subject group and the other in technology and home economics. Curricula can also be designed to be embedded flexibly into any subject depending on teacher capacity and interest. This is the case for the MIT DAILy Curriculum.
- **Interdisciplinary AI curricula** are implemented in systems with particular mandates for cross-subject work and associated time. These curricula target AI learning outcomes through project-based learning involving multiple subject areas. An example is seen in Portugal's curriculum frameworks, which feature 'autonomous curriculum domains', or projects that must engage two or three disciplines in an interdisciplinary approach. In the UAE, AI is integrated into a range of subjects including ICT, science, maths, language, social studies and moral education.
- **Multiple-modality AI curricula** have core requirements which are implemented during school time and supported by traditional resources such as facilitator guides and textbooks, but also leverage informal learning opportunities such as out-of-school resource networks and national or international competitions. An example of such a curriculum is the IBM-CBSE AI Curriculum for Grade XI & XII, which provides a gradual transition from guided to independent learning and links to competitions and industry mentorship.
- **Flexible AI curricula** can be implemented through one or more integration mechanisms at the discretion of regions, school networks or individual schools. Examples include the ATL AI modules curriculum in India, which can be embedded, interdisciplinary or delivered through out-of-school models such as extracurricular activities; and Digital Skills in Saudi Arabia, which can be implemented as either a discrete or embedded curriculum. For some curricula, the embedding mechanisms are at the discretion of regions, schools or networks. These include the French-speaking Belgium's IT Repository (2nd and 3rd degree technical transition), and Germany's *Algorithmen erkennen und formulieren* [Identifying and Formulating Algorithms] curriculum.

Curricula can also be compulsory, meaning all students must participate; or elective, meaning that students choose to participate. In some curricula, such as China's Information Science and Technology, certain modules are compulsory and others are elective.

Figure 1. Number of AI curricula by integration type (n = 27, multiple responses possible)



Source: UNESCO (2021*b*)

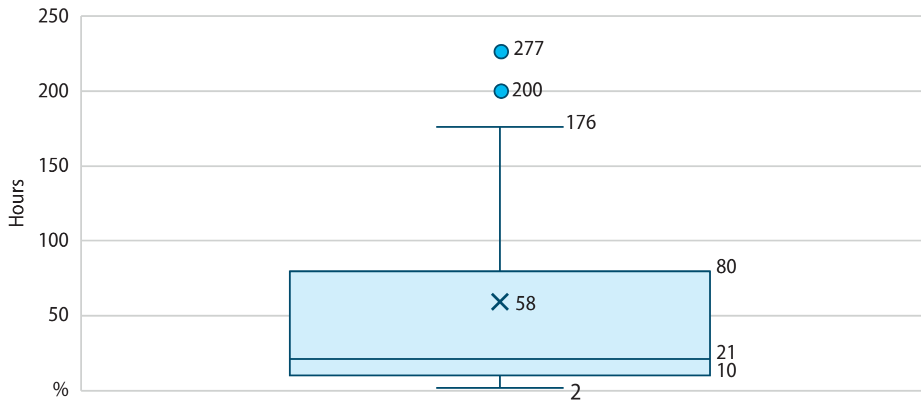
One important point raised was that AI curricula, and ICT curricula more broadly, should not be heavily reliant on one particular technology, as it is important to diversify the skills being developed across different platforms and providers. Some countries such as Austria and China emphasize an 'agnostic approach' to technology, which means that the curriculum is not linked to any particular brands, devices or programming languages. These curricula therefore aim to ensure (i) that teacher training is firmly rooted in theory, ensuring an understanding of underlying principles that can be applied across a range of technologies; and (ii) if particular hardware or software is used, teachers and learners are introduced to multiple choices and be engaged with different providers of AI tools.

Allocation of curriculum hours

Survey respondents were asked to provide the total number of learning hours for each of four grade levels: early primary, covering grades K-2; late primary, covering grade 3 to the end of primary school; middle school, covering grades 7 to 9 for most countries; and senior or high school, covering grades 10 to 12 for most countries.

The total time allocations for curricula ranged from two to 924 hours, spread over between one and twelve grade levels. A boxplot[18] of the time commitment per grade (see **Figure 2**) shows that the allocations vary widely.

Figure 2. Time allocation per year of AI curricula, n = 22



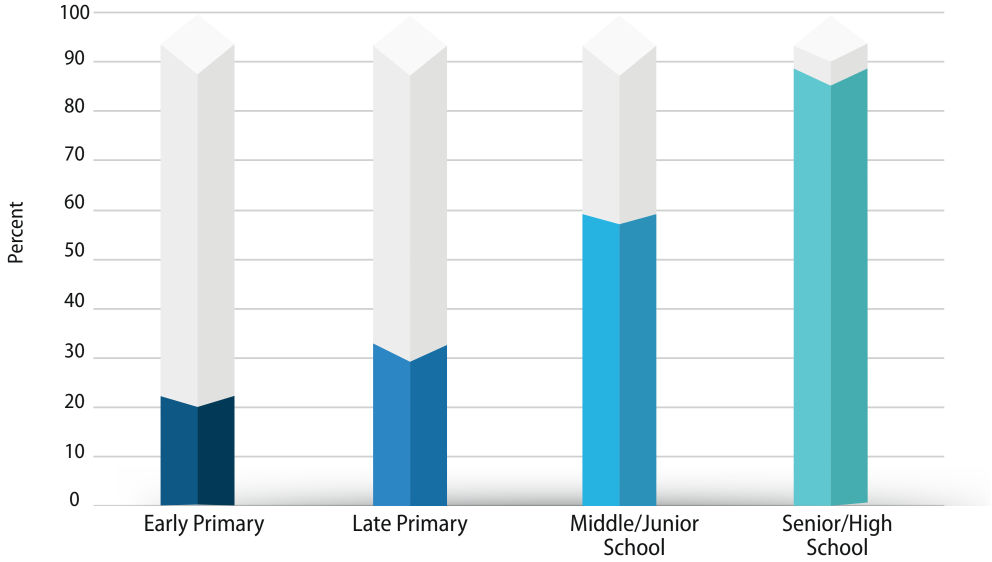
Source: UNESCO (2021*b*)

Two outliers, the Computing and Information Technology (High Tech Track) curriculum in Qatar and the IT Repository curriculum in Belgium average more than 200 hours per year. The average of 58 hours is more than twice as high as the median of 21 hours, revealing that there is a cluster of curricula which require relatively few hours of engagement with AI. In fact, five of the 22 curricula which provided time allocations require fewer than 5 hours of AI study per year, while five require 150 hours or more. Those demanding 150+ were either industry-developed curricula (two of the five) or high-technology elective tracks (also two of the five). Those requiring few hours of AI study were all embedded within other subjects.

Curricula were most likely to target senior or high school learners, and the proportion of curricula engaging each educational level increases steadily from early primary to the upper grades (see **Figure 3**).

18 Boxplots show the distribution of data including the minimum value, first quartile value, median value, third quartile value and maximum value. The mean value is displayed as an 'X', and outliers appear as dots above the boxplot.

Figure 3. Per cent of curricula engaging each grade level (n = 27)



Source: UNESCO (2021*b*)

The total hour commitment for curricula per grade level ranged from 1 to 680 hours. In grades K-2, AI was most likely to be integrated into other subjects and have no specific time allocation. Only Qatar's Computing and Information Technology dedicated a specific time allocation to K-2, 100 total hours. Across grades 3 to 6, an average of 156 hours was reported. The average time commitment as a whole for middle school (grades 7–9) was 109 hours, and for high schools (grades 10–12) the average was 153.5 hours. The average hours per grade were relatively static in K–9: 33.3 hours in grades K–2; 39 in grades 3–6; and 36.3 in grades 7–9. In high schools, the average time commitment per grade increases to 51.2 hours.

Essential conditions for supporting AI curricula

Survey respondents were asked how essential conditions were planned and prepared to support the design and implementation of the AI curriculum. The seven options that were presented in the questionnaire are outlined in **Table 7**. Multiple responses were possible, and a free-response option was also provided.

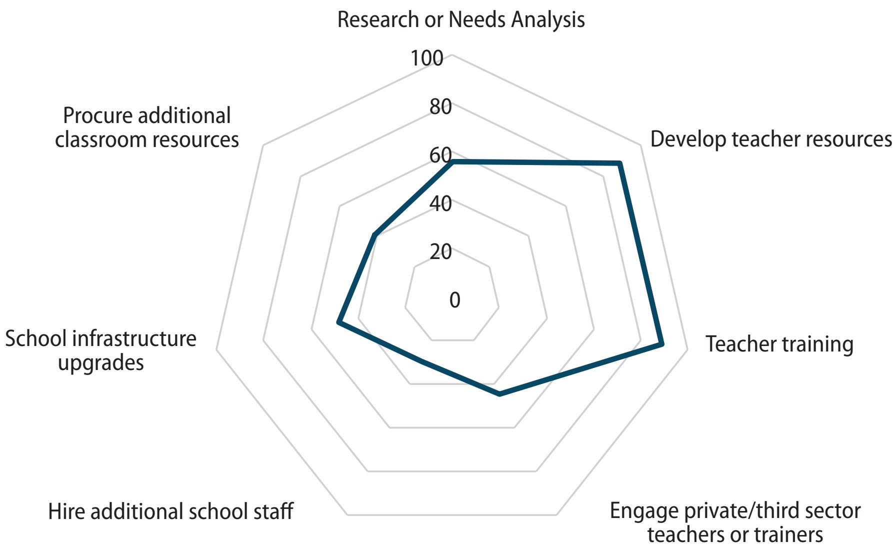
Table 7. Essential conditions for supporting AI curricula

Response options	Comment
Research or a needs analysis	Referred only to research or a needs analysis related to the implementation of the curriculum.
Development of resources for teachers	Textbooks and lesson plans were given as examples.
Teacher training	Respondents were asked about training specific to the AI curriculum and the resources facilitating it.
Hiring of additional staff/capacity	Referred to the recruitment of more paid teachers to implement the curriculum.
Engagement of the private or third sector	Rather or in addition to extra school staff, some countries engaged private or third-sector organizations as part-time trainers in or for schools.
Infrastructure upgrades at schools	Referred to the provision of hardware and/or internet connections for schools in relation to the AI curriculum. This includes items such as computer labs and servers.
Procurement of additional resources for schools or classrooms	Buying in classroom kits, coding resources, AI tools, etc.

Source: UNESCO (2021*b*)

The responses show that implementing an AI curriculum requires a range of adjustments to the resources and human capacity of education systems (see **Figure 4**). A majority of curricula were supported through the development of teachers' resources and training (89 per cent); 15 (56 per cent) through preliminary research or a needs analysis; 13 (48 per cent) through investment in school infrastructure upgrades; 12 (44 per cent) through engagement of the private or third sector; and 11 (41 per cent) through procuring additional resources for classrooms. The area emphasized the least was hiring additional school staff to implement the curriculum, but this was still a notable activity reported for 8 of the AI curricula included in this study (30 per cent).

Figure 4. Support for implementation undertaken



Source: UNESCO (2021*b*)

Example: The introduction of AI by the CBSE in India[19]

In 2019, India's Central Board of Secondary Education (CBSE) announced AI as an optional subject in the more than 22,000 schools under its jurisdiction, with a goal of ensuring that future citizens of India understand AI and are able to deploy it to address local and global problems. The curriculum focuses on 'learning through doing' and provides opportunities for students to learn AI by using it to build solutions to community challenges (CBSE, 2020).

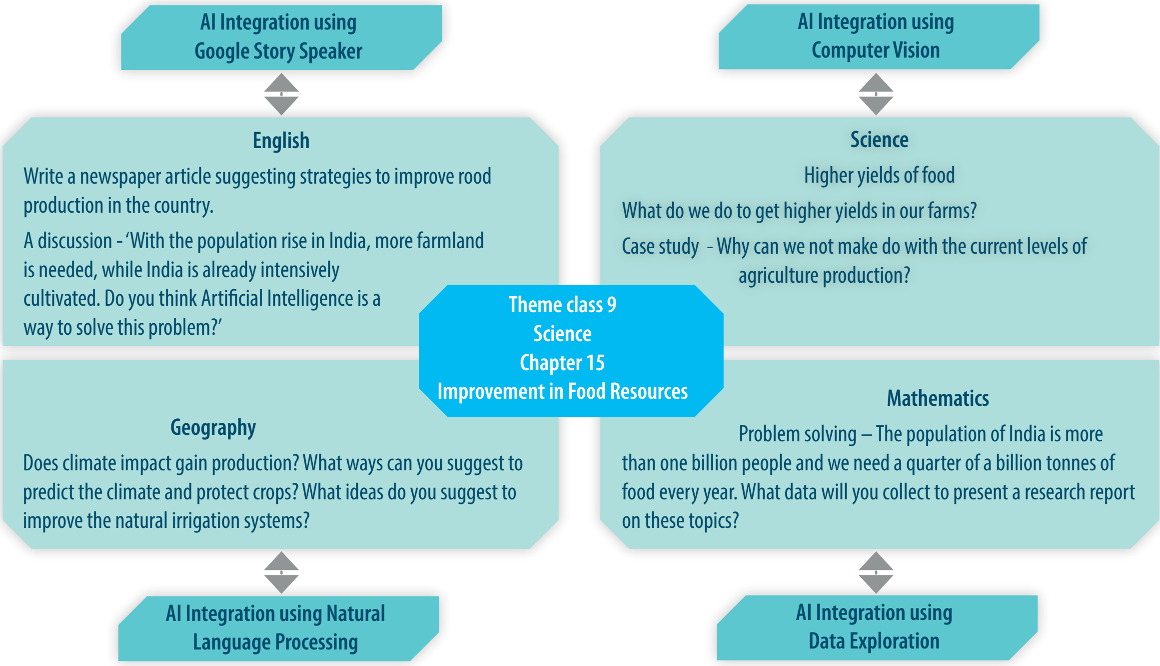
In support of the curriculum, the CBSE partnered with industry providers including IBM, Intel and Microsoft to develop training and support materials and content. NGOs also support the delivery of the curriculum.[20] To prepare for implementation, teacher and mentor training, and materials including facilitator guides, multi-disciplinary lesson plans and textbooks were created for grades 8–12. The CBSE also pursued a number of events with the overall aim of 'smoothing the integration of AI into schools'. These included competitions, virtual symposiums to give youth opportunities to explore AI technologies, and three-day 'AI-thon' camps where students execute a project design and prototype cycle using AI to solve an identified community challenge. More than 10,000 teachers and 120,000 students have been trained in AI through various partnership activities like these.

The AI curriculum is integrated as an elective or interdisciplinary subject in self-selected schools. The CBSE circulates an invitation to all schools to participate in this curriculum, and school administrators submit an application to the CBSE in response to the opportunity. Schools then select teachers for training, plan for AI to be included in the school timetable, and strategize around the interdisciplinary integration of AI based on common themes, such as 'improvement in food resources', the example in **Figure 5** (CBSE and Intel, 2019).

19 Sourced from: *CBSE Artificial Intelligence* (Ministry of Education, India, 2020); *Artificial Intelligence Curriculum, Class 9 Facilitator Handbook* (CBSE and Intel, 2019); and interviews with and presentations from representatives of IBM, Intel, the 1M1B Foundation and Microsoft. Note that this information may not represent the official views of the Government of India.

20 For example, 1M1B supports the implementation of the AI Youth Skills curriculum in partnership with CBSE and IBM. See https://www.youtube.com/watch?v=wKI5pghCIFY

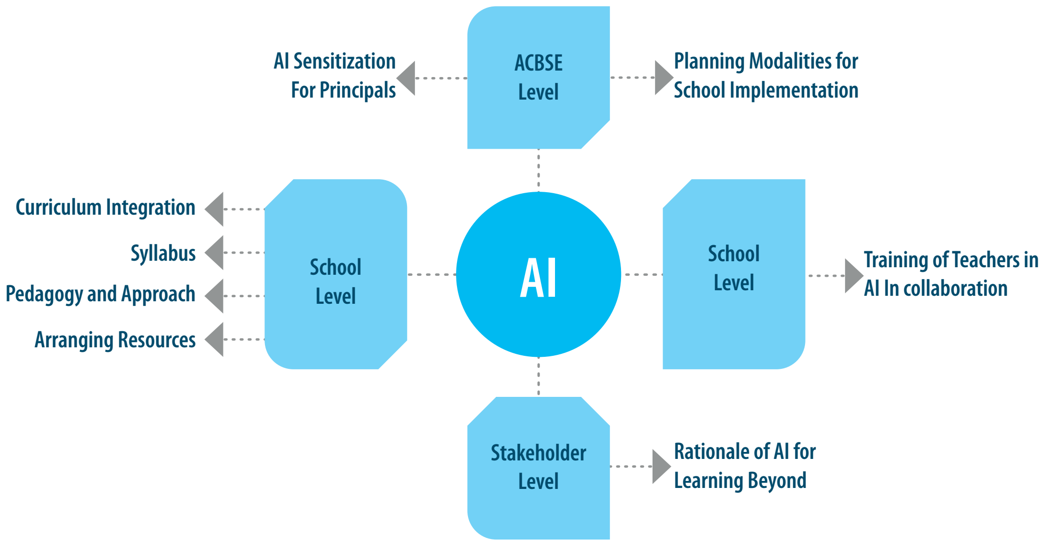
Figure 5. Thematic approach to the interdisciplinary integration of AI into the curriculum



Source: CBSE and Intel (2019)

At the school level, teacher training is facilitated by industry and/or implementation partners using bespoke courses and materials. Various providers such as IBM and Microsoft have developed textbooks in line with the CBSE curriculum aims. The curriculum integration, syllabus, pedagogy, approach, and procurement of necessary resources are also managed at the institutional level. Moreover, schools are expected to engage stakeholders, especially students and parents, to ensure they understand the rationale and aims behind the integration of AI into the curriculum. **Figure 6** outlines the relationship between the CBSE, schools and stakeholders.

Figure 6. AI implementation actors and procedures



Source: CBSE and Intel (2019)

AI curriculum content

Main categories of AI curriculum content

This analysis covers nine topic areas of AI curricula: algorithms and programming; data literacy; contextual problem-solving; the ethics of AI; the societal implications of AI; applications of AI to other domains; understanding and using AI techniques; understanding and using AI technologies; and developing AI.

As outlined in **Table 8**, these nine topic areas are grouped into three categories: AI foundations; ethics and social impact; and understanding, using and developing AI. The survey respondents were asked to provide information on the time and percentage allocation for these topic areas, which are shown in **Table 9**.

Table 8. AI curriculum areas

Category	Topic area	Competency and curriculum considerations
AI foundations	Algorithms and programming	Together with data literacy, algorithms and programming can be viewed as the basis of technical engagement with AI.
	Data literacy	A majority of AI applications run on 'big data'. Managing the data cycle from collection to cleaning, labelling, analysis and reporting forms one of the foundations for technical engagement with using and/or developing AI. An understanding of data and its functions can also help students understand the causes of some of the ethical and logistical challenges with AI and its role in society.
	Contextual problem-solving	AI is often framed as a potential solution to business-related or social challenges. Engaging at this level requires a framework for problem-solving in context, encompassing things like design thinking and project-based learning.
Ethics and social impact	The ethics of AI	Regardless of technical expertise, students in future societies will engage with AI in their personal and professional lives – many do so from a young age already. It will be important for every citizen to understand the ethical challenges of AI; what is meant by 'ethical AI'; concepts such as transparent, auditable, and fair use of AI; and the avenues for redress in case of unethical or illegal use of AI, e.g. that which contains harmful bias or violates privacy rights.
	The social or societal implications of AI	The social impacts of AI range from requiring adjustments to legal frameworks for liability, to inspiring transformations of the workforce. Survey respondents were asked about the extent to which their curricula targeted these issues. Trends such as workforce displacement, changes to legal frameworks, and the creation of new governance mechanisms were given as examples.
	Applications of AI to domains other than ICT	AI has a wide range of applications outside of computer science. The survey asked participants whether and to what extent AI applications in other domains were considered. Art, music, social studies, science and health were given as examples.
Understanding, using and developing AI	Understanding and using AI techniques	This area included (1) the extent to which theoretical understandings of AI processes were developed (e.g. defining or demonstrating patterns, or labelling parts of a machine learning model); and (2) the extent to which students used existing AI algorithms to produce outputs (e.g. training a classifier). Machine learning in general, supervised and unsupervised learning, reinforcement learning, deep learning, and neural networks were given as examples of AI techniques.
	Understanding and using AI technologies	AI technologies are often human-facing applications which may be offered 'as a service'. NLP and computer vision were given as examples. Respondents were asked about the extent to which learners used existing AI technologies to complete tasks or projects, and/or studied the processes of creating these technologies.
	Developing AI technologies	Developing AI technologies deals with the creation of new AI applications that may address a social challenge or provide a new type of service. It is a specialized field requiring knowledge of a range of complex techniques and skills in coding, mathematics (especially statistics), and data science.

Source: UNESCO (2021*b*)

Time allocations for AI curriculum categories

It must be noted that there is a degree of ambiguity as to what could be considered as part of the AI curriculum. Particularly for countries where AI is embedded in ICT curricula, respondents may not include data literacy, or algorithms and programming, as part of the AI component because they see it as being covered within the ICT curriculum. This also affects the responses in terms of the hour allocations, which for some curricula may not include all of the aspects related to AI. Therefore, the responses to this section should be interpreted as AI content in a curriculum or curriculum component according to the knowledge of the respondents.

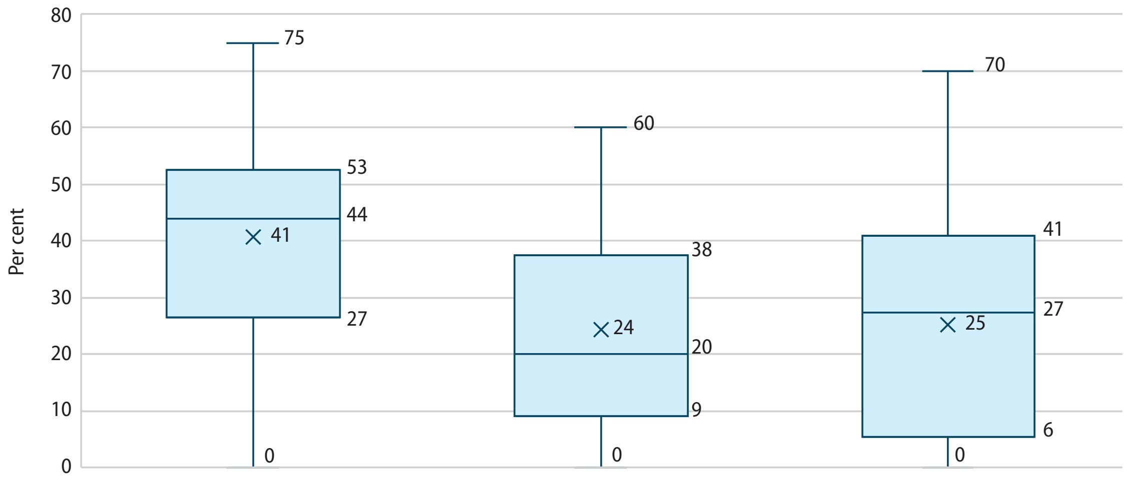
For government-led curricula, official representatives provided their estimations on the percentage of time allocations based on their knowledge of the curriculum and the education system. Some respondents were not able to estimate percentages due to the decentralization of decisions on time allocations or subject integration. Additionally, for some curricula, including those of IBM, Intel, Microsoft and MIT, the percentage allocations were calculated by the researchers from the curriculum content provided and are not estimates from respondents.

Finally, not all curriculum percentages added up to 100 per cent, and not all countries responded to the requests for clarification or submitted additional information on these challenges in follow-up surveys. Therefore, for some curricula, there is a percentage and/or time allocation which is 'unspecified'.

Coverage of AI curriculum categories

'AI foundations', which covers algorithms and programming, data literacy, and contextual problem-solving, formed the basis for most curricula, accounting for a combined average of 41 per cent of curriculum time. The remaining curriculum time is nearly evenly split between ethics and social impact (accounting for an average of 24 per cent of the hours), and understanding, using and developing AI (accounting for an average of 25 per cent). **Figure 7** provides a comparison of these three areas.

Figure 7. Boxplot of focus areas by per cent of curriculum hours (n = 21)[21]



Source: UNESCO (2021*b*)

When the total time commitment in hours rather than percentages is considered, it becomes clearer that by far the largest share is devoted to AI foundations. This area has more than treble the commitment of ethics and social impact and more than twice the commitment of understanding, using and developing AI (see **Table 9**).

Table 9. Curriculum engagement by topic area

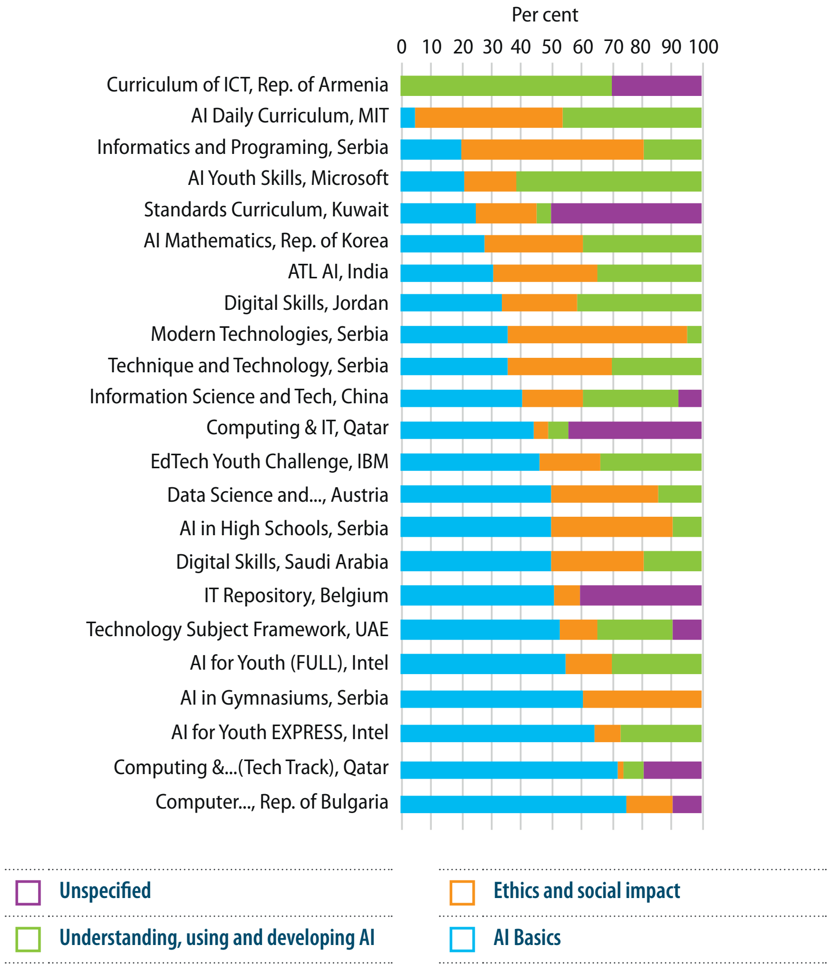
	AI foundations	Ethics and social impact	Understanding, using and developing AI
Number of curricula covering the topic area (n = 21)	20	20	18
Range of hours	0–432	0–185	0–465
Average hour commitment (all)	99.8	29.7	39.0
Average hour commitment (for those with allocations)	104.8	31.2	45.5
Median hour commitment (for those with allocations)	31.3	13.7	11.9

Source: UNESCO (2021*b*)

21 Percentage allocations for one curriculum from the Republic of Korea and the curriculum from the Yukon Territory of Canada were not reported.

As implied by the spread in **Figure 8** and the range in **Table 8**, the curricula have different focus profiles. AI foundations comprised from zero to 75 per cent of allocated curriculum time; ethics and social impact from zero to 60 per cent; and understanding, using and developing AI from zero to 70 per cent.

Figure 8. Allocation of curriculum time by topic area (n = 23)



Source: UNESCO (2021*b*)

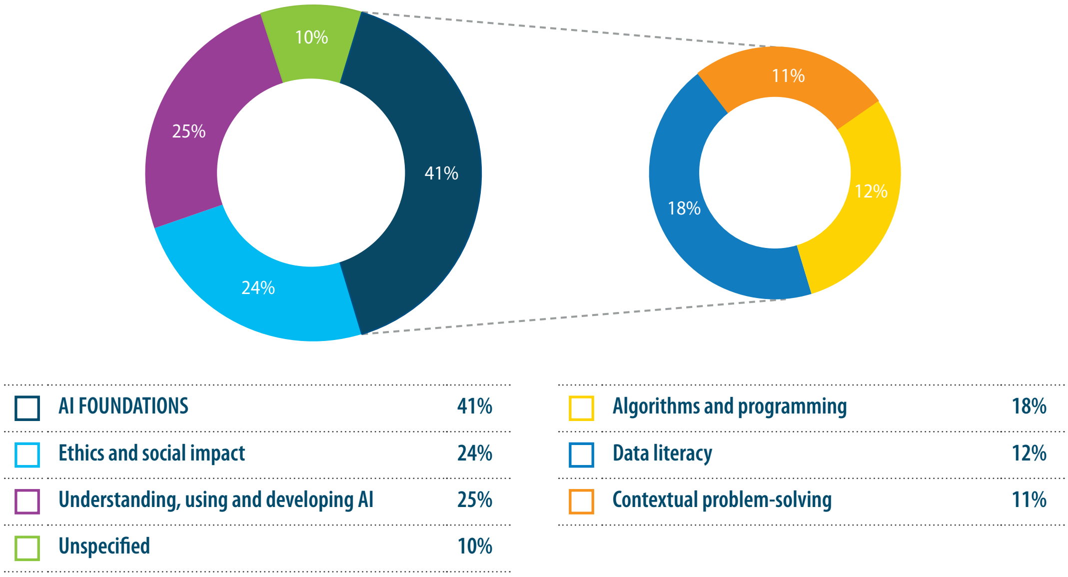
Given the hour and percentage allocations, we can conclude that curricula with a focus on ethics and social impact generally have shorter time commitments than curricula on AI foundations or understanding, using and developing AI. What follows is a closer examination of the sub-topics included in each area.

AI foundations

The AI foundations category includes data literacy, algorithms and programming, and contextual problem-solving. Overall, AI foundations accounted for 41 per cent of the total time allocation, with the largest share of this being allocated to algorithms and programming, followed by data literacy and contextual problem-solving in nearly equal measure.

Only one curriculum had no time for the AI foundations category: the Curriculum of ICT from the Republic of Armenia. It devoted a total of seven hours to engagement with AI as part of the required ICT subject covered in middle and high school. **Figure 9** provides a detailed view of the AI foundations components and their percentage allocations.

Figure 9. Percentage allocations for AI foundations (n = 21)



Source: UNESCO (2021*b*)

The topic area of algorithms and programming was covered by 21 out of 23 curricula, the exceptions being Armenia's Curriculum of ICT and the IBM EdTech Youth Challenge curriculum. A further six curricula allocate 10 per cent or less of AI teaching time to this area. On the other end of the spectrum, the Computer Modeling, Information Technology and Informatics curriculum from the Republic of Bulgaria devotes 65 per cent of teaching time to this topic. Overall, curricula were least likely to engage contextual problem-solving. However, curricula that do include contextual problem-solving invest an average of 42.5 hours to it. These curricula are outliers which invest heavily in contextual problem-solving as part of a project-based learning cycle. **Table 10** shows the number of curricula covering each of these topic areas, along with their ranges of hours and average time commitments.

Table 10. Curriculum engagement for the AI foundations category by topic area

	Algorithms and programming	Contextual problem-solving	Data literacy
Number covering the topic area (n = 21)	19	14	17
Range of hours	0 – 269	0 – 198	0 – 78
Average hour commitment (all)	50.0	28.3	21.5
Average hour commitment (for those with allocations)	55.3	42.5	26.5
Median hour commitment (for those with allocations)	10.8	18.6	25.5

Source: UNESCO (2021*b*)

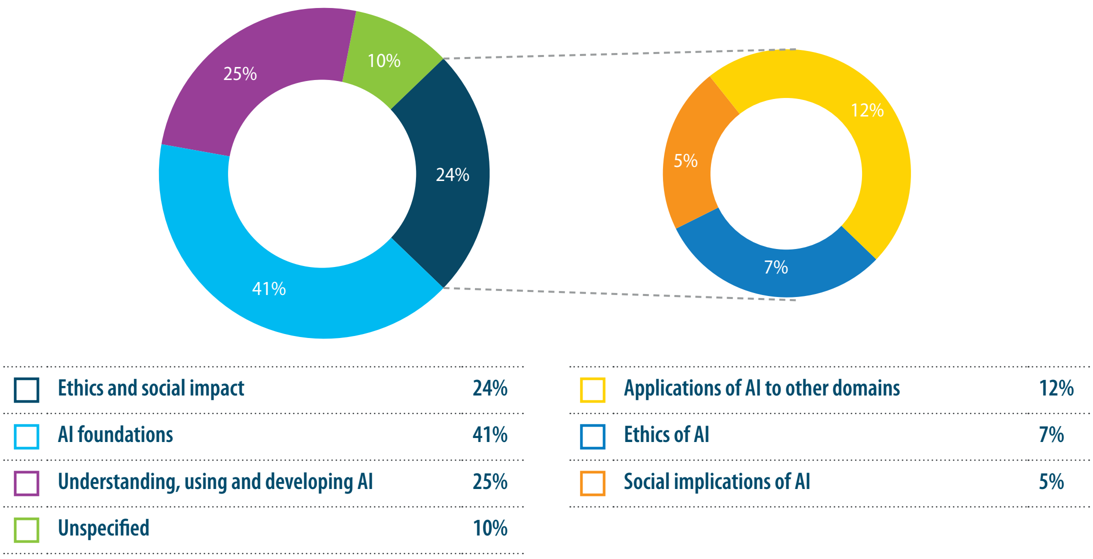
Ethics and social impact

The topics for the category of ethics and social impact include the ethics of AI, the social implications of AI, and applications of AI to other domains, the latter being particularly pertinent to the everyday interactions children and adults will have with AI.

Overall, this category represented 24 per cent of the content on average, but with a wide range of time investments, from zero hours in Armenia's Curriculum of ICT to 185 hours in Kuwait's Standards Curriculum. Percentage wise, Qatar's Computing and Information Technology (High Tech Track) committed less than 5 per cent, while on the other end of the spectrum Serbia's Informatics and Programming curriculum and Jordan's Digital Skills dedicated 60 per cent of their time to this topic area. However, in terms of hours, Qatar's curriculum commits 12 hours to this category, while Serbia's and Jordan's devote only 2 hours.

When the topic areas for this category are considered, it becomes clear that half of the time is for the applications of AI to other domains, with an overall average of 5 per cent spent on social implications, and 7 per cent on ethics (see **Figure 10**). It must be noted that in the two curricula from Qatar, the applications of AI to other domains is covered as part of mathematics, language and science, but a percentage commitment to this topic area was not specified.

Figure 10. Percentage allocations for ethics and social impact (n = 21)



Source: UNESCO (2021*b*)

Fewer hours were allocated on average to ethics and social impact than to AI foundations, and the percentage allocation of applications of AI to other domains is far higher than ethics or social implications. However, closer analysis shows that this discrepancy is due to a combination of fewer curricula engaging the latter two topics and curricula with higher overall hour commitments incorporating these two areas at very low percentages. As a result, when only curricula that target each topic area are considered, the average hour commitments of all three are nearly equal, and the median hour commitment is lowest for the application of AI to other domains (see **Table 11**).

Table 11. Curriculum engagement for the category ethics and social impact by topic area

	Applications of AI to other domains	Ethics of AI	Social implications of AI
Number covering the topic area (n = 21)	18	17	12
Range of hours	0–92	0–54	0–78
Average hour commitment (all)	11.9	10.8	8.1
Average hour commitment (for those with allocations)	14.1	13.3	14.2
Median hour commitment (for those with allocations)	5.2	6	7.3

Source: UNESCO (2021*b*)

The data provide a few important insights about the ways in which government-endorsed curricula are covering these topic areas.

- First, not all curricula engage the topic areas of this category, and only 12 include social implications.
- Second, the curriculum developers appear to believe the concepts and learning outcomes for all three topics can be achieved with a low number of hours.
- This category tends to be a small part of longer curricula, making up less than 10 per cent of the 144-hour Data Science and Artificial Intelligence from Austria, the two Computing and Information Science curricula from Qatar (both of which are 600 hours), and the 680-hour IT Repository in French-speaking Belgium.
- Finally, this category tends to draw a high percentage commitment from curricula with the smallest hour commitments. For the four curricula with the shortest

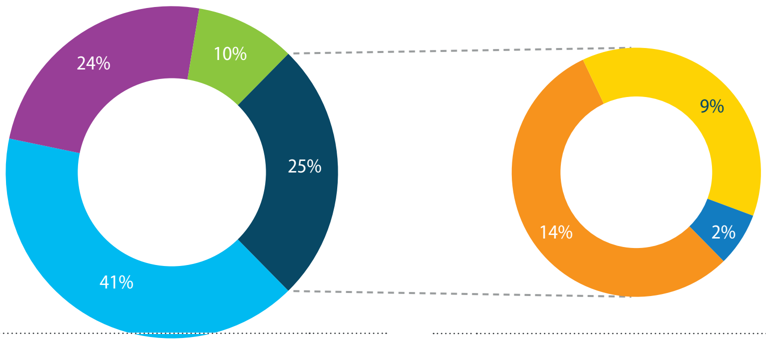
overall allocations, ethics and social impact make up an average of 45 per cent of the curriculum time, with the applications of AI to other domains accounting for 33 per cent of this, the ethics of AI accounting for 10 per cent, and social implications accounting for 1.5 per cent.

Understanding, using and developing AI

This category includes the topics of understanding and using AI techniques (such as machine learning, deep learning, decision trees and neural networks); understanding and using existing AI tools (such as computer vision, classifiers, NLP, and GAN generators); and developing AI technologies, which deals with the programming of AI and the creation of new tools or techniques.

Understanding, using and developing AI was represented in 25 per cent of the curricula. AI techniques accounted for more than half of this category, while developing AI was on average covered the least, with an average allocation of only 2 per cent (see **Figure 11**).

Figure 11. Percentage allocations for understanding, using and developing AI (n = 21)



UNDERSTANDING, USING, DEVELOPING AI	25%
AI foundations	41%
Ethics and social impact	24%
Unspecified	10%

Developing AI technologies	9%
AI techniques	2%
AI technologies	14%

Source: UNESCO (2021*b*)

Similar to the findings on contextual problem-solving and the social implications of AI, the low commitment to developing AI technologies emerges largely because few curricula engage this aspect at all. Only 6 of them included it, with allocations ranging from 2 to 14 per cent. Of these, only four indicated more than 10 hours of engagement in this area: China's Information Science and Technology curriculum, Intel's AI for Youth Global Development Skills (full version), Microsoft's AI Youth Skills, and Qatar's Computing and Information Technology (High Tech Track). Three of these four curricula require at least 150 hours of study per year. In interviews, some respondents from these countries indicated that they felt the role of primary education was to expose students to AI and its applications in work and everyday life, but that the development of AI was better suited to specialized tertiary study.

Respondents emphasized that the curricula on AI development must be adequately grounded in the relevant subject expertise. The most cited example was mathematics, where alignment is needed between maths principles and expectations around the use of coding and algorithms. Responses to this requirement vary. Portugal is an example of a country which has embedded large parts of its AI learning outcomes in 'computational thinking' within the subject of mathematics, while China has designed its ICT curriculum according to the year-by-year mathematics requirements. In devising a curriculum for high schools that would engage more heavily with AI development, MIT initially targeted science subjects, but found that science teachers are more interested in the applications of AI than its development. MIT are considering maths teachers as perhaps more grounded in the computational theory that underpins AI development.

Table 12 provides the averages, medians and ranges of hours dedicated to the topic areas for understanding, using and developing AI.

Table 12. Curriculum engagement for the category of understanding, using and developing AI, by topic area

	Developing AI technologies	Understanding/using AI techniques	Understanding/using existing AI technologies
Number covering the topic area (n = 21)	6	18	12
Range of hours	0–30	0–128	0–307.5
Average hour commitment (all)	3.3	14.6	21.1
Average hour commitment (for those with allocations)	11.7	17.0	36.9
Median hour commitment (for those with allocations)	11.3	5.5	11.1

Source: UNESCO (2021*b*)

Interestingly, there is a preference for AI techniques over AI technologies. This must be interpreted within the context of the fact that there are AI tools specifically designed to assist learners in unpacking and understanding AI techniques through active or experiential learning, such as Teachable Machine and MachineLearning4Kids. AI tools like these were cited as resources in Austria's Data Science and Artificial Intelligence curriculum, Armenia's Curriculum of ICT, Bulgaria's Computer Modeling, Information Technology and Informatics, the IBM EdTech Youth Challenge curriculum, the two Intel AI for Youth curricula, India's ATL AI modules, the MIT DAILy Curriculum, the Microsoft AI Youth Skills curriculum, Qatar's two Computing and Information Technology curricula, the UAE's Technology Subject Framework, and the Applied Design, Skills and Technologies curriculum from Canada's Yukon Territory.

Example: AI curriculum content in Austria

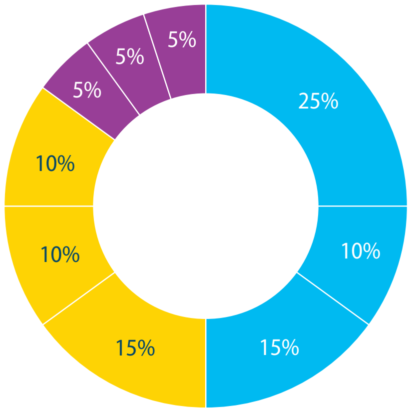
> Modern education and work processes are hardly conceivable without the use of digital technologies, just like participation in our society.
>
> – Digital Education Curriculum, Austria (Federal Ministry for Digital and Economic Affairs, Austria, 2018)

The Austrian Data Science and Artificial Intelligence curriculum includes digital basics such as using an operating system to store and print files, design presentations, and use spreadsheets and word-processing software. It also covers design and reflection on types and social issues in digital media, and safe digital media use.

Students in high school engage programming languages, algorithms and simulations. They learn the basic principles of data literacy, including collecting data, structuring a spreadsheet, and carrying out analyses and visualizations. They apply criteria to evaluate the credibility and reliability of data sources as well as digital content. Students are expected to know about careers in ICT, including AI, and the social applications of emerging technologies. They create digital media and learn about the cloud and how to connect and network computers. They also gain an understanding of the ethical dilemmas that are associated with the use of such technologies, and become active participants in social discourse on these issues. Finally, students are tasked with using technology to make public statements and understand how this reflects the democratic process.

The curriculum is offered in schools as a required subject for credit and includes 144 learning hours. Fifty per cent of the allocated time, or 72 hours, is spent on AI foundations: 25 per cent on algorithms and programming, 10 per cent on contextual problem-solving and 15 per cent on data literacy. Ethics and social impact takes up 35 per cent of the time, or 50 curriculum hours: 15 per cent on the application of AI to other domains, and 10 per cent each on ethics and the social implications. The remaining 15 per cent, is spent on understanding, using and developing AI, evenly split with 7 hours allocated to each of its sub-topics (understanding and using AI techniques, understanding and using AI technologies, and developing AI). **Figure 12** provides the percentage allocations by topic area for this Austrian curriculum.

Figure 12. Percentage allocations by topic area



Algorithms and programming	25%	Applications of AI to other domains	15%	AI techniques	5%
Contextual problem-solving	10%	Ethics of AI	10%	AI technologies	5%
Data literacy	15%	Social implications of AI	10%	Developing AI	5%

Source: Federal Ministry for Digital and Economic Affairs, Austria, 2018

Learning outcomes of AI curricula

Methodology for analysing learning outcomes

To construct this section, the learning outcomes of the curricula were extracted through an analysis of the frameworks and programmes of study. In line with the aims of this research, the curricula were not analysed comparatively, but examined in aggregate to map out the specifications across grade levels. The results show the types of engagements that were cited as curriculum objectives. It is important to note that this section makes no claim on what should or should not be included or covered in a K–12 AI curriculum, but merely represents what the current practices encompass.

In addition to the learning outcomes presented in this section, some curricula touch on some competences that are required for later work in the advanced study of technology, but which were not directly related to AI. These included gaining familiarity with computers and their operating systems; developing an awareness of the internet as a vehicle for information exchange; using software to work with text, sound, photos and drawings; creating and sharing media through ICT; practicing typing skills; using collaborative software; and understanding computer networking.

Framework for the categorization of learning outcomes

The presentation of this section corresponds to the major aspects of competence-based education. The OECD (2016) defines 'competence' as a combination of knowledge, skills, values and attitudes which is executed in order to address complex demands in a particular context. While it is important not to lose sight of the interrelations between the cognitive, psychomotor and affective domains, for ease of reference this report focuses on the learning outcomes of curricula in three parts: (i) knowledge, (ii) skills, and (iii) values and attitudes.

Knowledge deals with the cognitive demands, both general and domain-specific, deemed necessary to engage in competences. The knowledge outcomes commonly utilize verbs such as 'know', 'understand', 'reflect', and 'compare'. Skills refer to the psychomotor aspects, and outcomes related to skills commonly include verbs such as 'use', 'create', 'build', 'revise', and 'write'. For this classification, 'skills' also include the analysis and revision of technological artefacts and products. Values comprise the guiding principles that determine how one designates priorities when making a decision or taking action, and together with beliefs form the basis for attitudes and attributes and their influence on behaviour (IBE, 2013). Values and attributes can be implicit and unstated, stated explicitly within curricula, or embedded in learning outcomes via adjectives such as 'creative' or 'independent' or adjective-noun compounds such as 'critical thinking'.

The development of values is increasingly emphasized in international forums and literature. The purpose of this text is not to interrogate the viability or rationale of incorporating values into education, but rather to draw out the values and attitudes which are implicitly or explicitly interwoven into AI curricula. It is, however, important to note one key feature of values. Values are not immutable attributes. They can shift according to the context or situation (Haste, 2004, 2018). Therefore, the values presented in this section should be understood within the contexts of the fixed (although diverse) set of countries in this research.

This report presents the implicit and explicit values of the analysed curricula in four categories as presented by the OECD (2019): personal, dealing with how one defines and pursues personal goals; social, dealing with interpersonal relationships; societal, which deals with the shared priorities of cultures or societies and may be enshrined in law; and human, or values which reflect shared priorities that transcend national and cultural borders.

Knowledge and skills outcomes are presented under the categories and topic areas presented in the previous section (entitled 'AI curriculum content'). The categories are: AI foundations, including the topic areas of algorithms and programming, contextual problem-solving, and data literacy; understanding, using and developing AI, including the topic areas of AI techniques, existing AI technologies, and developing new AI technologies; and ethics and social impact, including the topic areas of applications of AI to other domains, the ethics of AI, and the social implications of AI.

Mapping of learning outcomes by AI categories

Knowledge

Table 13. Knowledge outcome mapping

Domain	Sub-domain	Learning outcomes	Grade levels engaged		
			Primary school	Middle school	High school
AI foundations					
Algorithms	Computational thinking	Understands abstraction	X		
		Understands decomposition	X		
		Explains the roles of decomposition, abstraction, pattern recognition and algorithms in computation		X	
		Discovers commonalities and rules (patterns) in instructions			X
	Algorithm definitions and applications	Understands what algorithms are and do	X	X	X
		Understands that learning algorithms are sets of instructions created by humans to modify an input to create an output		X	
		Identifies examples of types of algorithms (classifiers, generators, regression)		X	
		Recognizes and describes everyday applications of algorithms			X
		Recognizes the importance of algorithms in automated digital processes			X
	Algorithm components and processes	Understands the parts of an algorithm (input, steps to change input, output)		X	X
		Understands the process of training, testing and deploying algorithms		X	
		Compares and contrasts the searching and sorting of algorithms			X
		Analyses the flow of execution of a recursive algorithm			X
		Understands regression algorithms			X
		Compares how advanced data structures are used by algorithms			X
Programming	Programming languages	Develops knowledge of block-based and other programming tools		X	
		Knows different programming languages and production processes		X	X
	Representation and simulations	Understands rule-based reasoning		X	
		Develops an awareness of iterative processes in creating artefacts			X
		Develops knowledge of simulations/models/computational abstractions of real-world physical systems		X	
		Reflects on the limits and possibilities of simulations			X
Contextual problem-solving		Discusses and assesses the power and applicability of various AI approaches to practical problems		X	
Data literacy		Understands data trends	X		
		Understands the principles and processes of data collection and simple analysis	X		
		Understands how to collect, process, analyse, and report using data		X	X
		Understands the types of sources of information		X	X
		Describes the basic structure of a table in a spreadsheet		X	X
		Describes the characteristics of data and information			X
		Assesses the capabilities of big-data management (e.g. warehousing processes)			X
		Discusses the advantages and disadvantages of big-data cloud storage			X
		Compares structured and unstructured data			X
		Explores encoding techniques to represent data efficiently			X
		Develops an awareness of how the transformation and presentation of large datasets through visualization/modelling can be used for decision-making			X

Domain	Sub-domain	Learning outcomes	Grade levels engaged		
			Primary school	Middle school	High school
Understanding, using and developing AI					
AI techniques	AI definitions and components	Understands 'weak' and 'strong' AI	X		
		Describes basic terms related to AI		X	
		Understands what AI is (and what it is not)		X	X
		Understands the parts of AI (dataset, learning algorithm, prediction)		X	X
		Understands and uses basic and general terms related to AI and machine learning			X
		Describes the basic features of AI			X
		Understands that AI has underlying algorithms			X
		Understands convergence in AI			X
	Data use in AI	Explains how data is used to make predictions		X	X
		Describes the flow of data through a deep learning network for classification problems		X	X
	History of AI	Knows the history of AI and its development over time		X	X
		Understands different approaches to developing AI			X
	Understanding how AI works	Explains types of AI techniques and how they work (supervised, unsupervised, reinforcement, ML/DL)		X	X
		Understands how neural networks work and their parts (feed forward, evaluation of a prediction for accuracy, back propagation)		X	X
		Understands the concepts and challenges of artificial general intelligence		X	X
		Knows how GANs work and identifies their parts			X
		Explains heuristic searches and how they work			X
AI technologies	Computer and human perception	Compares computer and human perception	X		
		Understands computer recognition	X		
		Understands methods of measuring with sensors		X	
		Understands the role of sensors in data collection			X
		Understands the difference between AI and human intelligence			X
	Understanding AI technologies	Explores AI technology and tools (e.g. classifier)	X		
		Understands the processes of creating and using NLP		X	X
		Explores the principles of data for NLP processing			X
		Understands autonomous systems			X
		Understands recommender systems and the technology behind them			X
		Understands the process of creating and using computer vision			X
		Develops an understanding of advanced technologies (IoT, cloud computing)			X
		Compares and contrasts an IoT device operating system with a typical desktop OS			X
AI development	Design thinking	Understands design thinking		X	X
	Product development	Understands the product development cycle			X
Ethics and social impact					
Applications of AI to other domains		Identifies/explains AI use cases and applications in everyday life	X	X	X
		Describes how AI drives many software and physical systems			X
		Understands new advances and applications of AI			X
		Knows important areas of application in the AI and information technology professions			X

Domain	Sub-domain	Learning outcomes	Grade levels engaged		
			Primary school	Middle school	High school
Ethics of AI	Ethical terms, definitions and examples	Understands what ethical terms such as 'bias', 'fairness' and 'representation' mean in relation to AI		X	X
		Reflects on human rights and ethical issues in technology/AI use		X	X
		Describes the limitations of AI			X
		Understands the ethical considerations and dilemmas which may arise from AI			X
	Access	Understands issues of access to technology			X
	Bias	Explains how the biases of the programmers influence the fairness of the AI rules			X
		Understands the effects of information quality in decision-making			X
		Understands algorithmic bias and types/sources of bias		X	X
		Understands methods of mitigating/lessening bias in AI algorithms		X	
		Understands different types of bias (representation, selection, etc.)			X
		Analyses cases where AI has been clearly fair or unfair			X
	Intellectual property	Understands intellectual property rights	X		
		Defends a position on ownership of art generated or enhanced by AI		X	
		Understands/respects basic intellectual property laws		X	
	Privacy and security	Develops an awareness of cybersecurity	X		
		Develops deep knowledge of the concept of digital identity			X
		Understands how digital service providers inform users about how personal information is used			X
		Understands how personally identifiable information can be used and shared			X
	Transparency / explainability	Understands the mechanisms of image and data manipulation			X
		Understands the principle of explainable AI and its tenets			X
	Human agency	Understands that humans control AI and machine learning		X	X
		Understands usability, security, and accessibility of computer systems as key features of their design			X
		Understands how to ethically create and/or use AI			X
Social implications of AI	AI's advantages and disadvantages	Understands how AI can benefit humans	X	X	X
		Reflects on the advantages and disadvantages of new technologies	X	X	X
		Outlines the advantages and disadvantages of AI in different social, educational, and professional contexts			X
	AI in everyday life and work	Considers the role, importance and/or impact of new technologies on society (life, work and education)	X	X	X
		Explores emerging technologies that have the potential to disrupt the way people live, learn and work		X	X
		Develops an awareness of digital citizenship	X		
		Understands how AI is changing jobs (even outside STEM)		X	
		Understands the benefits of and demands for STEM jobs		X	
		Recognizes the interactions between nature, technology and society			X
	Environmental impacts	Understands the positive and negative environmental impacts of technology	X	X	X
		Knows the computational and environmental costs of generating AI		X	
		Understands how computational and environmental costs can be reduced (more efficient models, evaluation of costs and benefits)		X	
		Understands how computational and environmental costs lead to inequity in developing AI		X	
	Fakes and misinformation	Reflects on positive/negative aspects and social consequences of deepfakes		X	
		Reflects on the social implications of GAN technology (e.g. fake homework)		X	
		Knows the six key features of misinformation[22]		X	
		Understands how misinformation spreads		X	
	Gender	Develops an awareness of gendered consequences/opportunities in technology			X

Source: UNESCO (2021*b*)

22 Cited by the MIT DAILy Curriculum as: 'Invokes emotion; polarization; spreading conspiracy theories; deflecting blame; impersonating or fake accounts; and "trolling" people online'

Skills

Table 14. Skills outcome mapping

Topic area	Description of skills	Grade levels engaged		
		Primary school	Middle school	High school
AI foundations				
Algorithms	Recognizes patterns	X		
	Follows clear instructions for action (algorithms) and carries them out		X	X
	Formulates clear instructions for action (algorithms) verbally and in writing		X	X
	Creates an algorithm and the relevant flow chart iteratively		X	X
	Creates a predictive model			X
	Implements complex data structures and fundamental algorithms (e.g. for sorting and searching)			X
	Evaluates the efficiency of an algorithm in terms of time and space			X
	Optimizes computational procedures (to require fewer steps)			X
Programming	Programmatically controls a robot	X		
	Constructs simple code scripts using block-based programming	X		
	Creates a mobile application with a block-based programming language		X	
	Converts algorithms to code using a text-based programming tool		X	
	Codes in one or more programming languages		X	X
	Masters basic programming structures (e.g. branches, loops, procedures)		X	X
	Assesses user interfaces (usability, intuitiveness) and the technical processes behind them			X
	Uses, creates and reflects on coding (e.g. cipher, QR code)			X
	Creates code to manipulate local data files			X
	Creates software to control a robot or another computing device			X
	Uses modular programming methods in a variety of programming languages			X
	Develops an application using object-oriented programming			X
	Develops secure and user-friendly programs taking into consideration accessibility requirements			X
Contextual problem-solving	Creates simple programs or web applications with suitable tools to solve a specific problem or perform a specific task		X	X
	Designs, develops and employs strategies for solving real-life problems through decomposition and pattern identification			X
	Evaluates possible technological solutions and selects a suitable one, also taking into account proprietary and free software			X
Data literacy	Saves, changes and sorts simple databases	X		
	Creates visualizations of numerical and textual data	X		
	Searches for, selects and collects data from a range of sources using appropriate search strategies	X	X	X
	Organizes collected information (e.g. by using data labels and categorizing)	X	X	X
	Manipulates data, makes calculations, and creates simple charts with a spreadsheet	X	X	X
	Uses ICT tools to manage and maintain a relational database		X	X
	Works with relational databases to produce reports		X	X
	Evaluates the quality, authenticity, and accuracy of data		X	X
	Applies criteria to assess the credibility and reliability of data sources			X
	Implements automated data collection processes and manages data storage on a wide range of physical media and cloud platforms			X
	Parses IoT data streams and creates alerts for anomalous conditions such as extreme winds			X
	Transforms unstructured data into structured data			X
	Uses software tools or platforms to organize, calculate, present, and safeguard data			X
	Creates SQL scripts to manage normalized databases			X
	Uses ICT tools to transform data into information to support accurate decision-making			X
	Uses a range of models and charting methods to analyse, predict and communicate data stories			X

Topic area	Description of skills	Grade levels engaged		
		Primary school	Middle school	High school
Understanding, using and developing AI				
AI techniques	Classifies objects by characteristics	X		
	Constructs a decision tree (paper prototype)		X	
	Designs a workflow to train and test an AI algorithm		X	X
	Cleans and prepares textual data for analysis and ML			X
	Designs and tests supervised learning solutions for classification problems			X
	Uses open-source AI application frameworks to build simple intelligent systems			X
	Interprets the performance of a ML model (e.g. using a confusion matrix)			X
	Identifies whether various media products are GAN or not			X
	Creates GANs in different subject areas (music, art, biology)			X
	Creates a story and illustrations using GANs			X
AI technologies	Builds and tests a classifier using a teachable machine or similar AI tool		X	
	Builds a chatbot with support		X	
	Constructs and controls a simple robot that can use AI		X	
	Programs an autonomous robot		X	
	Sets a new goal for an existing AI algorithm		X	
	Uses existing AI technologies to develop new products			X
	Constructs and prepares a dataset for NLP processing			X
	Creates a chatbot with appropriate human/bot interfaces			X
AI development	Works as part of a team	X		
	Uses design thinking methodology to implement a project as part of a team		X	X
	Creates innovative solutions through AI tools			X
	Manages a technology-development project			X
	Verifies the correctness of the technological solutions applied			X
Ethics and social impact				
AI applications	Uses algorithms to produce art, music, etc.	X	X	X
Ethics of AI	Protects personal data and own/others' privacy	X	X	X
	Identifies instances of bias in AI algorithms		X	
	Identifies the stakeholders/beneficiaries of an AI algorithm		X	
	Builds an ethical matrix for an algorithm (stakeholders and their values)		X	
	Researches exposed private data on the internet		X	X
	Manages digital identities and reputations and demonstrates an understanding of digital footprints			X
	Queries messy data in a table, and find bias			X
	Undertakes self-advocacy and redress (e.g. if rights are violated)			X
	Designs an end-to-end ML process that maximizes transparency and ensures fairness			X
	Writes guidance for AI developers to ensure that AI is made ethically			X
Social implications of AI	Properly disposes of technology	X		
	Identifies deepfakes (independently and with AI)		X	
	Recognizes developments that pose a threat to equal opportunities in the use of IT and identifies options for action		X	X
	Compares, analyses and evaluates information and digital content critically (e.g. to recognize manipulation)		X	X
	Avoids health risks and threats to physical and mental well-being related to IT			X
	Helps shape social development by participating in public discourse			X

Source: UNESCO (2021*b*)

Values

Table 15. Values and attitudes outcome mapping

Value / attitude to be developed	Examples of related knowledge and skills outcomes	Grade levels engaged		
		Primary school	Middle school	High school
Personal				
Interest in ICT	Explores existing AI tools	X	X	X
	Creates innovative solutions through AI tools	X	X	X
Persistence / resilience	Solves problems using programming methodology Tests and redesigns artefacts and products	X	X	X
Personal empowerment	Creates a project using design thinking Researches exposed private data on the internet Identifies avenues of redress if personal rights are violated		X	X
Reflection	Reflects on how 'my personal future work' may be impacted by AI Describes the role and importance of AI and its applications Explores emerging technologies that have the potential to disrupt the way people live, learn and work		X	X
Critical thinking and reflection	Designs, develops and employs strategies for solving real-life problems using computational thinking Explains how the programmers' bias influences the fairness of AI rules Compares, analyses and critically evaluates information and digital content (e.g. to recognize manipulation)			X
Entrepreneurship	Uses design thinking methodology to produce a prototype Develops awareness of entrepreneurship principles/processes to implement innovative ideas			X
Social				
Collaboration / teamwork	Works as part of a team or group Implements a project as part of a team Collaborates online as a member of a team	X	X	X
Communication	Creates a story and illustrations using GANs Writes guidance for AI developers to ensure that AI is made ethically			X
Societal				
Respect for others	Engages respectfully with others Protects personal data and own/others' privacy	X	X	X
Personal responsibility	Disposes of technology properly Understands that humans control AI and ML	X	X	X
Integrity	Understands methods of mitigating/lessening bias in AI algorithms Designs an end-to-end ML process that maximizes transparency and ensures fairness		X	X
Tolerance	Shows tolerance for different ideas/positions		X	X
Human				
Respect for the environment / sustainable mindset	Understands the environmental impact of technology Recognizes the interactions between nature, technology and society Understands how computational and environmental costs can be reduced	X	X	X
Commitment to equity	Reflects on access to AI Understands how computational and environmental costs lead to inequity in developing AI		X	

Source: UNESCO (2021*b*)

Example: Progression of AI learning outcomes in the Republic of Korea[23]

The Republic of Korea's elementary and secondary AI curriculum standards were published in 2020, and a national curriculum for AI is under development. Local governments and schools can flexibly modify curricula to fit within the given hours and frameworks of the standards. In 2020, an AI school curriculum for high schools was implemented. As this curriculum is offered at the discretion of the principal, it has the potential to reach 2,367 high schools. The country has 500 'AI education leader' schools which are specifically focused on cultivating talent in the technology sector.

The curriculum builds on compulsory coding modules in elementary, middle and high schools, but requires no prior knowledge of AI.

The content standards for the Korean AI curriculum cover three domains:

1. Understanding AI, with sub-domains 'AI and society' and 'Intelligent agents'
2. Principles of AI and its application, with sub-domains 'Data', 'Recognition', 'Classification, exploration and reasoning', and 'Machine learning and deep learning'
3. The social impact of AI, with sub-domains 'AI influence' and 'AI ethics'.

Figure 13 outlines the curriculum progression for some of the learning goals in four key areas: understanding AI; data; machine learning (including classification); and social impact.

Figure 13. Curriculum Standards, Republic of Korea

Grade level	Understand AI	Data	Machine learning	Social impact
1 Primary school	AI Play Weak and strong AI Uses of AI	Data visualisations Text data Data trends	Computer and human perception Classification methods	AI that helps us Proper use of AI
2 Middle school	AI development process Turing test	The data cycle, data management	Introduction to ML	AI and my job Preventing misuse of AI
3 High school (basic)	Characteristics of AI AI and social change The role of intelligent agents (IA)	Data properties Structured and unstructured data	Sensors, CV, NLP, ML concepts	Data bias, fairness Solving social problems Ethical dilemmas
4 High school (advanced)	Domain applications of AI technology IA analysis AI convergence	Big data Data attribute analysis	Heuristic search Neural networks Reinforcement learning	Algorithm bias AI ethics for developers and adopters

Source: Interview and written submissions from Professor Ki-Sang Song

23 Information in this section is derived from verbal and written responses to interview questions provided by the respondents.

Curriculum implementation

Teacher training and support

Upskilling existing teaching staff

Most training strategies for government-endorsed curricula pursued the upskilling of existing staff. Some countries, e.g. China and Portugal, indicated that the preparation strategy leverages national training initiatives or projects for the teachers of subjects in which AI is embedded. In other areas such as Belgium, teacher-training programmes are decentralized and undertaken by education networks, and therefore may vary between regions, languages and types of schools (e.g. public or private).

Non-governmental actors tend to undertake other methods of teacher training. For the MIT DAILy Curriculum, teachers from three districts in the USA participated in training which included both general sessions and 30 hours of implementation practice at summer camps hosted by NGO partners. Industry partners engage in the delivery of training courses remotely or through blended-learning methodologies. For instance, a partnership between IBM and Macquarie University's School of Education created the 16-hour Artificial Intelligence (AI) Education for Teachers course hosted on Coursera. The course covers topics such as the history of AI, comparing AI and human intelligence, and ethical considerations in developing and using AI. Some providers offer certification. Intel does this for coaches and lead coaches, the latter of which are often positioned as trainers of trainers.

Integrating AI into initial teacher preparation

In Austria, the primary strategy for teacher training was to embed AI topics into initial teacher education at higher education institutions, which were expected to cover not only general AI topics but also the use of AI to support pedagogical processes and teaching and learning.

Supporting in-service teachers

In addition to the creation of standards, national and regional governments support the implementation of AI curricula through the development of resources. For example, in Serbia the implementation is bolstered by online tools including videos, presentations, and interactive tasks that were developed for the various AI curricula offered in the country. National or regional initiatives also produce resources such as textbooks and assessment guidelines to support the AI curriculum prior to implementation.

The MIT DAILy Curriculum provides materials to teachers including slide decks, talking points and full lesson plans that they can use or adapt. Industry partners such as IBM, Intel and Microsoft supply them with learning pathways and content through global, open online resources. These partners have also created context-specific teacher resources for implementing countries, including manuals, facilitator handbooks and AI textbooks.

Learning tools and environments

In addition to leveraging existing infrastructure initiatives to deliver hardware and internet connections, curricula engage a range of resources to support implementation in schools. In cases such as Belgium and China, the decision on tools and environments was not centralized and therefore specifics could not be given. On the other side of the continuum, in the case of Serbia, online tools including interactive tasks are being generated to strengthen the curriculum. Other curricula leverage existing environments and tools, engaging a range of free products. The representatives from Austria and the UAE made the following comments respectively:

> " We use Jupyter Notebook/Lab, Python, PyCharm, and Python libraries for AI (Scikit-learn, Keras, Tensorflow). We focus on natural language processing, image analysis, and big data analysis.
>
> We use different resources and platforms based on the students' grade levels. Online tools like Code.org, Microsoft and AI, MachineLearning4Kids, and IBM and AI Robotic Kits such as Magkinder Labeeb, Fateen, Maker, Maker with Robotics Car, and Raspberry-Pi are used in different AI projects. The tools are used to train different models, understand machine learning algorithms, and complete online tasks related to AI. Students at higher grades will be introduced to Python so that they can implement different ML algorithms.

The AI curricula did not all engage coding or programming, but many included these elements, often using introductory programming languages and tools such as PictoBlocks or Scratch. The introduction of the programming language Python was common, particularly in curricula targeting senior secondary schools, though some curricula also included HTML and Java.

A wide range of AI technologies such as Alexa, GAN image generators, Google Assistant, Pix2Pix, PoseNet, robotics kits, and simulation software were included in curricula, allowing students to explore the myriad ways in which AI can be used in different subject areas. Students who engaged in the creation of AI were most likely to do so through free software such as MachineLearning4Kids and Teachable Machine. These tools allow children to explore and build ML models to carry out tasks such as classifying objects. As students advance into higher grades, some curricula further engage ML libraries and tools like Scikit-learn.

Off-line environments were also leveraged by the MIT DAILy Curriculum. In addition to encouraging the exploration of online tools and resources, it included off-line games, e.g. a group activity where students act out the information flows in a GAN, and another in which they build a paper-based decision tree classification system for different types of pasta. In the case of China's Information Science and Technology, the curriculum is required to serve a range of schools and regions at varying levels of ICT access and integration, and therefore provides a series of learning outcomes without recommending specific technologies or tools for delivery, in order to accommodate both online and off-line options.

The following tools and instruments were suggested in the curricula based on the areas of AI on which the curricula focus:

- **Hardware and robotics**

The hardware needed for AI curricula includes computers, tablets, laptops, and internet/web access. Not all AI curricula include content on robots or robotics. When the learning on robots is required, curricula need to leverage kits such as Lego Mindstorm EV3,[24] Magkinder Labeeb,[25] and/or Maker Robotics.[26]

Devices like Raspberry Pi[27] are used by some curricula that require students to create programs and test them using low-cost devices.

- **Software**

The Ubuntu[28] open-source operating systems were used by some curricula as less expensive alternatives to other operating systems.

- **Programming languages**

Curricula often leveraged free programming languages such as:

— HTML[29]
— Javascript[30]
— Python[31]
— Micropython[32]
— NumPy[33]
— R[34]
— Scratch[35]

- **Tools for learning AI techniques**

A number of tools have been developed to facilitate understanding and allow the exploration of complex concepts and AI techniques, including the following which were specifically mentioned in the AI curricula in this study:

— MachineLearningForKids[36]
— Teachable Machine[37]
— TensorFlow[38]
— Keras[39]
— OpenVINO[40]
— Scikit-learn[41]

24 See https://www.lego.com/en-us/product/lego-mindstorms-ev3-31313
25 See https://shop.ibtikar.io/en/magkinder-labeeb-151-pcs-set
26 See http://site.makerrobotics.com.br
27 See https://www.raspberrypi.org or https://www.raspberrypi.com
28 See https://ubuntu.com/download
29 See https://www.w3schools.com/html
30 See https://www.w3schools.com/js
31 See https://www.python.org/psf
32 See https://micropython.org
33 See https://numpy.org
34 See https://www.r-project.org/about.html
35 See https://scratch.mit.edu
36 See https://machinelearningforkids.co.uk
37 See https://teachablemachine.withgoogle.com
38 See https://www.tensorflow.org
39 See https://keras.io
40 See https://docs.openvino.ai/
41 See https://scikit-learn.org/stable

- **Databases**

When the development of data-dependent AI tools is required in the curriculum, databases are needed so that students can test the programs and optimize the algorithms, for instance:

  - Coco, a large-scale object detection, segmentation, and captioning dataset[42]
  - ImageNet, an image database with over 14 million images[43]

- **Tools and resources for learning AI technologies**

When students are asked to apply the pedagogical methodology to technologies that follow the Use-Modify-Create model, examples of tools based on different categories of AI are needed. It is important to highlight the 'agnostic approach' to AI technologies, and explain to students that AI technology is not limited to a particular brand or tool.

  - GAN image generators, such as GANpaint[44]
  - NLP tools such as Google Assistant[45] and IBM Watson[46]

Both academic bodies and commercial companies have been offering online programming courses or spaces for learning AI. This report suggests that to prevent the AI curriculum from linking to particular brands or AI tools, the national or local curriculum authorities should curate and validate openly licensed or non-commercial learning tools, and create public online platforms or spaces to support the teaching and learning of AI.

Suggested pedagogies

Respondents to the survey were asked about the pedagogical recommendations included in the curriculum or its delivery. The options that they had to choose from are outlined in **Table 16**. Multiple selections were possible, and they also had the opportunity to provide free responses.

Table 16. Suggested pedagogical approaches and specifications

Pedagogical approach	Definition
Lecture or instruction	Refers to didactic, teacher-led classes. Information is delivered verbally, in print or through a combination of media, by a teacher, facilitator or expert.
Group work	Teaching and learning which requires students to collaborate to complete one or more tasks. Group work is intended to allow students to approach more complex tasks and practise skills such as teamwork.
Project-based learning	Learners leverage their skills and competencies to identify and/or respond to a real-world challenge over an extended period of time, facilitated by a teacher. Project-based learning is characterized by student autonomy, goal-setting, collaboration, and investigation of real-world contexts (Kokotsaki et al., 2016).
Activity-based learning	Learners progress at their own pace through activities facilitated by a teacher. Activity-based learning usually takes place in classrooms and is designed to foster independence, exploration and experimentation. It is often linked to presentations of work. Key features of activity-based learning are the active involvement of students and collaboration in the classroom (Anwar, 2019).

Source: UNESCO (2021*b*)

The results show that almost all of the curricula relied on lecture or instruction (89 per cent), with a strong dependence on group work and project-based learning as well. Project-based learning was a particularly prominent feature of many curricula, both national and industry. For example, as noted by the representative from Portugal, its national curriculum uses project-based learning through an interdisciplinary approach:

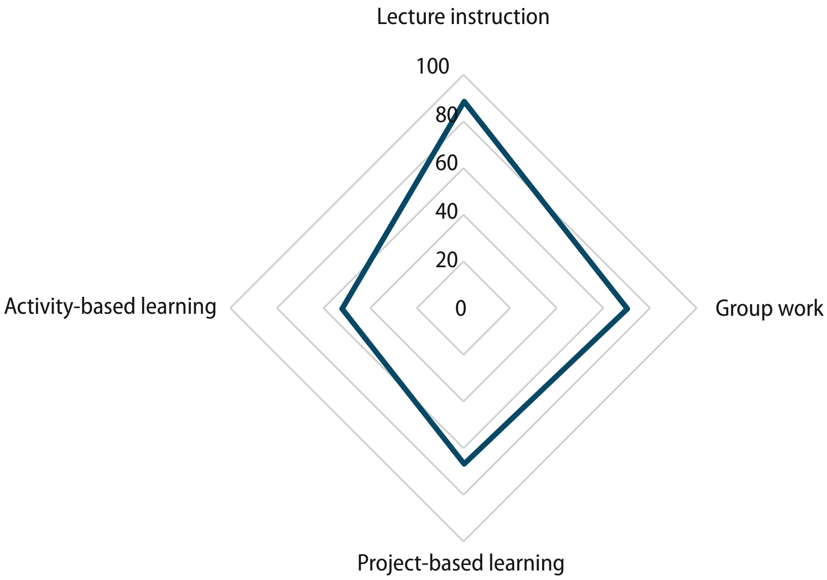
> " Our curriculum says we must use student-centered approaches to learning such a project-based learning. This is meant to be the main pedagogical methodology teachers can use. There is also a need to promote interdisciplinary approaches. Knowledge of one subject must be linked to the knowledge of others.

The types of projects engaged, however, as well as their time commitments, varied between curricula and approaches. Projects could be defined as time-limited activities such as using AI software to perform a translation task, using AI to generate art, or building or manipulating robots through robotics kits. For curricula such as the IBM EdTech Youth Challenge, Intel AI for Youth, Qatar's two Computing and Information Technology curricula, and Microsoft AI Youth Skills, this

42 See http://cocodataset.org/#explore
43 See https://image-net.org
44 See http://gandissect.res.ibm.com/ganpaint.html
45 See https://assistant.google.com
46 See https://www.ibm.com/academic/home

kind of work forms a core part of the engagements, with students undertaking the creation of an AI project through a guided cycle of design thinking. Activity-based learning, on the other hand, was suggested for 14 curricula (52 per cent) and therefore was less emphasized (see **Figure 14**).

Figure 14. Average pedagogical engagement profile (n = 27)



Source: UNESCO (2021*b*)

Additionally, blended and/or remote learning were suggested by all but three curricula (89 per cent), suggesting a heavy reliance on remote expertise for curriculum delivery. Assessment for learning, competency-based education, constructivism, constructionism, experiential learning and student-centered pedagogies were also endorsed or suggested as approaches.

Interestingly, most curricula allowing for remote learning were developed by the public sector or with government oversight. Only two curricula which use remote learning were generated by the private sector: the IBM EdTech Youth Challenge and Saudi Arabia's Digital Skills.

On a final note, the curricula included in the survey responses cover a wide range of AI applications, ethical issues, tools and techniques without depending heavily on mathematics or programming knowledge, and sometimes without relying explicitly on technology at all.

Example: Implementation of the Information Science and Technology Curriculum for Senior High Schools, China

The Ministry of Education of the People's Republic of China published the IT Curriculum for Senior High Schools in 2017. The curriculum is nationally mandated for implementation in 225,000 schools, and reaches over 180 million students. It is divided into 10 modules: 2 compulsory modules, 6 selective modules offered for credit, and 2 selective modules offered without credit. In total, the curriculum requires 54 hours of compulsory modules and 72 of selective modules, for a total of 126 hours. Aspects of AI are included in the compulsory modules, which are 'data and computing' and 'information systems and society'; the compulsorily selective modules, which means all students must choose one of these modules, include 'basics of artificial intelligence' and 'data management and analysis'; and the selective module 'algorithm preliminaries'.

The curriculum aims to guide students to understand what AI is, how it works, and the social issues surrounding its use. While the curriculum is nationally mandated, Provinces modify its implementation based on their population demographics, available resources and educational needs. China's representative explained this as follows:

> " We cannot do the same thing everywhere throughout China. There are different needs in different areas. In advanced cities, for example, they are familiar with the equipment, smartphones and many other things. Our challenge is to guide them to be ethical, respect others and do the right things for society. In other areas, students are less familiar with applications, so the challenge is to guide them to become familiar with devices and applications.

Before being released, the curriculum was reviewed by experts and piloted with students of different grade levels to determine the students' attitudes toward the curriculum content. The curriculum was then revised based on these reviews before being published.

China has undertaken a range of preparation including carrying out research, analysing needs, developing resources, training teachers, installing infrastructure, providing schools with necessary equipment and materials, and improving capacity by hiring additional staff and engaging the third sector and private companies as part-time trainers in schools. The curriculum utilizes a wide range of pedagogies including direct instruction, blended and remote learning, group work, project-based learning and activity-based learning.

To support the implementation, teachers of all subjects are trained through the National-Level Teacher Training Programme. Part of the programme is focused on Information Science and Technology, and includes AI. The National Ministry of Education has two sessions per year during the school holidays, and all teachers are required to join the programme once every three years. There is a concerted effort to ensure that students are familiar with a range of equipment and applications, so both schools and teachers control the types of technology utilized in the classroom. During the training, teachers are exposed to multiple brands of devices and different types of platforms and technologies, and the types of technologies to be used are not explicitly stated in the curriculum.

Key findings and recommendations

The nine key findings and thirteen recommendations presented in this section relate to four main stages of curriculum provision – development and endorsement, integration and management, content and learning outcomes, and implementation – and are categorized here accordingly.

Curriculum development and endorsement

Key finding 1 — Only a limited number of government-endorsed AI curricula have been developed and implemented

To date there are 14 AI curricula which have been developed and implemented by 11 governments. While countries are developing mandates for the inclusion of AI in curricula through policy documents, to date this has not translated into widespread integration of AI into K–12 curricula.

Recommendation 1.1: Further research is needed to determine the extent to which K–12 curriculum reform is mandated in national AI policy or strategy documents, and the extent to which these mandates have been actioned to develop a deeper understanding of the political mechanisms used and the enablers or inhibitors of AI curriculum development and implementation.

Key finding 2 — A strong governmental commitment and validation mechanism is necessary to manage competing interests in curriculum development

There is a wide range of stakeholders in the AI sector, and many of these are active in curriculum development or delivery. AI curriculum development teams included government officials, industry experts, academics, and in some cases, teachers. Without strong coordination and balanced input, conflicting goals may manifest within curricula. Conversely, strong coordination and validation mechanisms can unify the efforts of a range of public- and third-sector partners towards national goals for AI education.

Recommendation 2.1: There is a need for a balanced, multidisciplinary and collaborative approach to the production of AI curricula, undertaken with the overt management of government. Regardless of development status, each country has access to a range of industry, subject-specialist and education-practitioner expertise both within and across national borders, and must consider how this expertise can be best validated, de-commercialized, and curated for the good of students.

Recommendation 2.2: Include teachers in the development with the aim of ensuring that the curriculum is actionable in practice. Teachers can provide practical advice on the knowledge and competencies with which students enter different grade levels, the logistical challenges of integrating technology in different contexts, and the most appropriate methods to engage students. Teachers are also experts in explaining complex concepts to students, and can provide valuable inputs to not only curricula but also support and training materials.

Key finding 3 — An evidence base on the quality and effectiveness of AI curricula is needed.

Published studies on the evaluation of AI curricula remain scarce, and none have been found on the effects of such curricula on the development of AI competencies for students and the building of human resource capacity in AI areas. While some evaluations or pilots of AI curricula did include external feedback from teachers and learners, others relied only on reviews of the curriculum by experts.

Recommendation 3.1: Pilot studies should be carried out and must seek feedback from teachers and students as well as academic and/or industry experts. The implementation of AI curricula and their impact on students should be rigorously evaluated to inform the evidence base.

Curriculum integration and management

Key finding 4 — Resource development and teacher training are essential for curriculum integration

Nearly 90 per cent of curricula were supported by resource development and/or teacher training. However, just over half involved a needs analysis to inform resources or training programmes.

Recommendation 4.1: Engage in evidence-based resource development and teacher training by first gathering information on items such as the existing human capacity within the sector, and the training and support needed in order to integrate and implement an AI curriculum. Include teachers in resource development, and pilot-test the resources before they are released to teachers and students. Make adequate provision for AI concepts and pedagogy to be introduced to in-service teachers and integrated into initial teacher training at higher education institutions. Leverage AI events as opportunities for teacher training.

Key finding 5 — Government-endorsed AI curricula tend to be elective or integrated into existing subjects in schools

Most countries choose to implement AI within an existing subject or subjects, or as an elective or interdisciplinary subject. In all of these cases, it is necessary to determine what will be omitted from or condensed in the existing curricula to create space for substantial engagement with AI. Curriculum developers must also look at whether AI is to be a sub-topic with only a few hours of allocation, or a 'special topic' studied during out-of-school hours, e.g. on a personal interest basis.

Recommendation 5.1: Develop integration maps for a range of existing subjects or themes at different grade levels, which can support the implementation of AI learning outcomes across different topic areas without consuming large proportions of the teaching time of any one subject.

Recommendation 5.2: Consider multiple-modality AI curricula that include out-of-school components such as extracurricular opportunities for mentorship and participation in competitions.

Curriculum content and learning outcomes

Key finding 6 — The goals and learning outcomes of AI curricula should be focused on the main values and skills needed for work and life in the AI era

There is general consensus that AI curricula are important to ensure students have the necessary skills for work and life in the AI era. However, the development of these curricula has been undertaken with a continuum of goals and focus areas ranging from exposure to AI to expertise in building AI. The curricula produced to date demonstrate various understandings of the progression of task complexity and the types of learning outcomes that can or should be considered for students at different grade levels. The goals set for the AI curriculum affected the time commitment, curriculum content and embedding mechanisms of the curricula. The time allocated for understanding AI techniques, learning domain-specific AI technologies, and developing AI is limited and insufficient for fostering the creativity and skills that are needed to create innovative AI tools. Furthermore, without sufficient knowledge of AI techniques and tools, the stand-alone discussion on ethics is not enough to direct students towards an in-depth understanding and ability to apply the principles across the AI lifecycle.

Recommendation 6.1: AI curricula should explicitly align to international and national development goals and strategies. Special consideration should be given to developing skills for work and life in the AI era that can be further defined within particular contexts, providing more opportunities for generating innovative AI tools, and embedding ethics into the contexts of using AI to solve real-life problems.

Recommendation 6.2: Develop, adopt or adapt a coherent sequence of age-appropriate learning activities and outcomes in consultation with curriculum experts, computer scientists and education practitioners, taking into account the end goals of the curriculum, the motivations for its development, and national policy mandates. Interdependencies between different subject areas should be considered.

Key finding 7 — AI learning outcomes can be engaged through both off-line and online activities

The curricula included in this mapping exercise demonstrate that technological access is not a prerequisite for understanding AI and its impact within society, though it is often a requirement for those seeking to cover practical applications, data literacy components, and AI development. There are a range of free resources and AI learning tools and technologies available to teachers and students.

Recommendation 7.1: In low-resource contexts, curricula can focus on areas such as understanding AI, recognizing AI applications in everyday life, reflecting on social impacts, and engaging design thinking through paper prototypes or product redesign exercises.

Curriculum implementation

Key finding 8 — Project-based learning is commonly used as an appropriate pedagogical methodology for AI curricula

A third of the curricula in this study included project-based learning as a pedagogical strategy. The perceived benefits of this type of learning were linked to practical skills development and opportunities for problem-solving.

Recommendation 8.1: AI curriculum developers should consider leveraging innovative pedagogies to create interdisciplinary opportunities to solve real-life challenges faced by students and their communities, as a way to build skills in critical thinking, entrepreneurship, communication and teamwork.

Key finding 9 — AI curricula should not be linked to specific technologies or brands

While adequate learning environments need to be developed for the implementation of curricula, AI education should not be limited to particular brands or products. Students need to acquire basic knowledge, transferable skills, and value orientation on applying AI in different domains and contexts. Due to the pace of change and the development of new technologies and brands, curricula which are product-dependent may quickly lose relevance and students' brand-bound knowledge may not be transferred when they face new contexts or real-life problems.

Recommendation 9.1: Curriculum development should focus on learning outcomes and the application of AI principles and processes rather than the ability to use specific platforms, devices or products. Where possible, curricula should engage a wide range of different technologies.

Recommendation 9.2: Wherever necessary, invest in basic enabling infrastructure to engage a range of AI technologies and learning tools. Ensure that teacher training and other school support mechanisms such as quality assurance or performance reviews are adequately structured to guarantee that this infrastructure can be used for designated learning outcomes.

Concluding comment

The introduction of AI into life and work has already fundamentally changed the way people interact within their societies in both developed and developing nations. It is raising significant questions, e.g. about the expression and protection of human rights, legal liability in AI-related injury, and the philosophical orientation of AI development and use. AI will continue to change the nature of life and work, and therefore a basic understanding of it is now a critical component in the concept of an 'educated citizen', whether or not they will become AI specialists.

Given the importance of AI competencies, and the trajectory of the field of AI and its integration into other domains, it is perhaps surprising that so few countries have sought to formally integrate training in this area into K–12 education. Governments who have invested in this area have done so based on a recognition that AI skills are essential to both the current and future economy of their country and also to the full participation of citizens in social life. An understanding of what AI is, how it works and what it can do empowers students with the ability to better understand their world, advocate for their own and others' rights, and leverage technology and data for the public good.

Governments are called on to ensure that these opportunities are given to all of their citizens through the creation of AI curricula with well-sequenced learning outcomes, aligned to national policy goals and international standards of human rights and ethics. They are further encouraged to attach sufficient attention to building students' creativity in AI and understanding of ethics through deep engagement with the algorithms and data behind the AI tools. Governments should also apply the humanistic approach to the development and implementation of AI curricula to ensure the protection of people's fundamental rights, including data privacy, and the promotion of inclusion, equity, and gender equality. It is also critical to ensure the adequate provision of non-propriety resources and needs-based teacher training.

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Appendix

Survey sent to representatives of Member States

UNESCO mapping of government-approved AI curricula

The purpose of this survey is to gather some high-level information on government-approved **Artificial Intelligence (AI) curricula for K–12 or equivalent grade level**. This could be a discrete curriculum (e.g. for a core subject called AI or an elective), part of a curriculum (e.g. AI units or concepts within an ICT or other subject curriculum), an extracurricular subject, or distributed across multiple subjects. The information will be used as part of a mapping study of UNESCO to identify countries in which AI curricula are being developed and implemented, the grades these curricula cover, the positioning of these curricula as independent or within other subjects, and what is covered by these curricula.

Multiple responses to this survey are possible. If multiple AI curricula are developed or implemented by different developers in your context, or there are differences in the development, endorsement, evaluation or etc. of different grade levels you would like to draw out clearly, please respond separately for each case.

Your contribution is highly appreciated and will help enrich the global knowledge base on AI in education.

Your participation in this survey is taken as consent for the survey and also for the information gathered to be used in the mapping study and any subsequent publications of UNESCO.

General Information

1. What country, regional or international inter-governmental body(ies) are you representing in your responses to this survey? (free response, short answer)
2. Are you aware of the development or implementation of an AI curriculum for students in any grades K–12 in your country/context? [NB: The curriculum may be discrete (only about AI), embedded in another subject (such as ICT/IT subject), or cross-curricular (integrated across many subjects). The implementer of the curriculum may be the national government, private providers or NGOs.]
   - ○ No
   - ○ Yes, an AI curriculum (including one AI curriculum or multiple AI curricula) is developed and endorsed

If your country has government-approved AI curricula and if you are nominated as the focal point for the mapping study of UNESCO on AI curricula, UNESCO may follow up with you if we have additional questions.

3. Please provide your name
4. Please provide your email address
5. Please provide any alternative contact details

AI curriculum 1

[If multiple AI curricula are being developed and endorsed, please provide the information for each one separately by indicating the number of additional curricula at the end of this page and moving to the next page, or get in touch with UNESCO to map the AI curricula.]

6. What is the title of the AI curriculum? (free response)
7. Who is the developer of this curriculum? (free response, short answer)
8. Is the developer:
   - ○ Public sector (e.g. government)

- ○ Private sector (e.g. corporate/industry)
- ○ Third sector (e.g. NGO, civil society organization, public benefit organization, etc.)
- ○ Other (fill in)

9. How is the curriculum endorsed? If different grade levels of the curriculum are endorsed in different ways, please explain under 'other' (tick all that apply)
- ○ The national government has mandated or endorsed the use of this curriculum in schools.
- ○ Local government (e.g. districts or provinces) has mandated or endorsed the use of this curriculum in schools.
- ○ A school or schools have mandated or endorsed the use of this curriculum
- ○ The curriculum provides an industry certification.
- ○ None of the above
- ○ Other (free response)

10. How is the curriculum positioned in the governmental curriculum framework for schools? (tick all that apply)
- ○ In schools as a required subject for credit
- ○ In schools as an elective or optional subject for credit
- ○ In schools as part of the required ICT/IT subject for credit
- ○ In schools as part of the elective or optional ICT/IT subject for credit
- ○ As an interdisciplinary or cross-curricular subject in schools
- ○ As an extracurricular activity in schools
- ○ As an out-of-school activity (e.g. clubs, hackathons, at home)
- ○ Other (free response)

11. How many schools are **currently being reached** by this curriculum? If the curriculum is still in development, please enter a zero. (response restricted to numbers 0 or greater)

12. How many students are reached by this curriculum? If you do not know, please leave this question blank.
- ○ Male
- ○ Female
- ○ Overall (in case male/female is unknown)

13. What grades are covered by this curriculum? (select all that apply)
- ○ Early Primary: K– Grade 2
- ○ Late Primary: Grade 3 to the end of primary school
- ○ Middle or junior school
- ○ Senior or high school
- ○ Other (explain, free response)

14. What is the total number of learning hours assigned to the curriculum? If more than one option is available (if for example there is an optional extension), please provide all times with a brief label of what it describes. (free response)
- ○ Early Primary: K– Grade 2
- ○ Late Primary: Grade 3 to the end of primary school
- ○ Middle or junior school
- ○ Senior or high school

15. If you consider the AI curriculum, what percent of total teaching time would you estimate is allocated to each of the following (if no time is committed to the item, please leave blank):
- ○ Algorithms and programming
- ○ Applications of AI to domains *other* than ICT (e.g. Art, Music, Social Studies, Science, Health, etc.)

- ○ Contextual problem-solving
- ○ Data literacy (e.g. statistics, data collection, pre-processing, data modelling, analysis, interpretation, visualisation)
- ○ Ethics of AI / Ethical AI (e.g. bias, privacy, etc.)
- ○ The social or societal implications of AI (e.g. trends such as workforce displacement, changes to legal frameworks, the creation of governance mechanisms, etc.)
- ○ Understanding and using AI techniques (e.g. machine learning in general, unsupervised/supervised/reinforcement/deep learning, neural networks, etc.)
- ○ Understanding and using AI technologies (e.g. Natural Language Processing, Computer Vision, etc.) (if yes, please specify the AI technologies)
- ○ Developing AI technologies (e.g. Natural Language Processing, Computer Vision, etc.) (if yes, please specify the AI technologies)

16. What learning tools and environments are suggested by the curriculum? (free response)

17. What teacher preparation or mobilisation is taking/has taken place in order to effectively implement this curriculum? (Tick all that apply)

- ○ Research or a needs analysis related to the implementation of the curriculum
- ○ Development of resources for teachers (textbooks, lesson plans, etc.)
- ○ Teacher training on the curriculum and resources
- ○ Hiring of additional staff/capacity for schools to implement the curriculum
- ○ Engagement of the private or third sector for part-time trainers in schools
- ○ Infrastructure upgrades at schools o
- ○ Procurement of additional resources for schools/classrooms
- ○ Other (free response)

18. What suggested teaching methodologies or pedagogical approaches are emphasized in the curriculum and/or any associated training and resources? (tick all that apply)

- ○ Lecture or instruction
- ○ Blended learning (e.g. learning which takes place partly face-to-face, and partly remotely)
- ○ Remote learning
- ○ Group work
- ○ Project-based learning (e.g. learners leverage their skills and competencies to identify and/or respond to a real-world challenge over an extended period of time)
- ○ Activity-based learning (e.g. learners progress through activities facilitated by a teacher at their own pace)

19. Has the AI curriculum been evaluated?

- ○ No
- ○ Yes, please explain how the curriculum was evaluated

20. Has the AI curriculum been revised based on evaluation?

- ○ No
- ○ Yes, please explain how the curriculum was revised

21. Is the curriculum documentation, even in draft form, available for review by the mapping team?

- ○ No
- ○ Yes

22. [If more AI curricula, please select how many and move to the next page][47]

47 When adding more AI curricula, the questionnaire repeated questions six to 21 for up to 13 curricula.

United Nations
Educational, Scientific
and Cultural Organization

K-12 AI curricula

A mapping of government-endorsed AI curricula

Regulations on their own are insufficient to ensure AI as a common good for education and for humanity. All citizens need to be equipped with some level of AI literacy covering the values, knowledge and skills relating to AI. This report features key findings and recommendations of UNESCO's global survey on AI curricula for K-12. It reveals that only 11 countries have developed and endorsed K-12 AI curricula and another four countries have AI curricula in development. This is a strong call for Member States to develop AI curricula for K-12 students, and to build stronger mechanisms to validate non-governmental AI curricula offered to balance the private-driven approach. The report also reveals that the learning outcomes of AI curricula need to be more focused on fostering creativity in crafting AI technologies and on contextual ethics. Teacher training is key to ensure the implementation of AI curricula, and teachers need to be trained on designing and facilitating project-based learning which is the most commonly used pedagogical methodology in existing AI curricula. The report also advises an 'agnostic approach' towards AI brands and products when introducing domain-specific AI technologies.

Stay in touch

Unit for Technology and AI in Education
Future of Learning and Innovation Team
Education Sector
UNESCO
7, place de Fontenoy
75007 Paris, France

aied@unesco.org
@UNESCOICTs
@UNESCOICTinEducation
en.unesco.org/themes/ict-education

4 QUALITY EDUCATION

Sustainable Development Goals