AI in STEAM Education to develop a critical understanding of AI and prepare learners on AI literacy

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WP2

Report on AI Tools, AI curricula and Data on AI utilization in STEM

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Declaration

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1. Introduction:

The rapid advancement and growing ubiquity of Artificial Intelligence (AI) technologies are reshaping the digital landscape of European societies, with profound implications for education systems. In response, the European Commission has called for coordinated efforts to strengthen digital competencies, AI literacy, and critical engagement with emerging technologies, as outlined in the Digital Education Action Plan 2021–2027 (European Commission, 2020). In parallel, the proposed Artificial Intelligence Act (European Commission, 2021) aims to establish a legal framework for trustworthy and human-centric AI, emphasizing the importance of transparency, accountability, and safety—principles that are equally essential for educational contexts.

This first report for AI2Schools provides a comparative and research-informed analysis of AI integration in school curricula and STEM education across four partner countries: Germany, Greece, Italy, and Poland. It addresses how AI is currently embedded in national curricula, identifies learning objectives and pedagogical strategies, and examines the use of specific AI tools in classroom practice. In doing so, it reflects the strategic priorities outlined in the European Framework for the Digital Competence of Educators (DigCompEdu) (Redecker, 2017), particularly in the areas of digital pedagogy, learner empowerment, and innovative teaching approaches.

Complementing the curricular analysis, the report includes a systematic review of recent scientific literature (2022–2025) on the use and impact of AI in STEM education. This review maps the landscape of AI applications in teaching and learning, identifies challenges and barriers to implementation, and highlights best practices and opportunities for enhancing digital and scientific competencies through AI-supported instruction.

Through this dual focus on national policy and international research, the report aims to support evidence-based policy development, curriculum innovation, and professional development strategies. The overarching goal is to contribute to the responsible and inclusive integration of AI in European education systems—ensuring that learners are equipped not only with technical skills, but also with the critical, ethical, and collaborative capacities needed to thrive in a digitally mediated and AI-augmented society.

2. Methods:

2.1 Analysis of Curricula in partner countries

All partners analyzed the curricula in their respective countries. This approach was found to be advantageous due to the fact that the curricula are typically only available in the national language. The following key questions were provided to the partners for analysis:

1. How is AI integrated into the school curriculum?
2. What are the learning objectives or/and the learning outcomes
3. How is AI introduced in the classroom?
4. What AI tools are utilized (or suggested to be utilized)?
5. What are the basic skills and competences that students will acquire?

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6. Whether and how AI is combined with STEM subjects?

For comparison, we also looked at a recently published UNESCO recommendation (2023) with the same guiding questions in order to compare the country-specific approaches and recommendations with those of an organization that takes a broader geographical perspective.

2.2 Scientific Literature on AI implementation

In a second step, we conducted a systematic review of scientific articles published in the period from 2022 to 2025 that relate to AI in the context of school education. For this purpose, the GoogleScholar database was searched using the following search string:
“AI” or “AI Tools” and “STEM” or “STEAM” or “STEM education” OR “Science education” NOT “Engineering education” AND “K12” OR “Secondary School”.

The search period was chosen to coincide with the year of release of OpenAI's chatGPT model 3.5, i.e. starting in 2022, as this allowed for a qualitative leap in the large language models. For other areas of AI use, there were also already meaningful systematic reviews from 2020 and 2022 that we were able to use for our analysis.

The search resulted in 81 papers. These articles were then screened manually using differentiated criteria:

1. AI in STEM Focus: Does the study primarily focus on artificial intelligence applications in STEM education WITH a clear description of the AI implementation?
2. Educational Setting: Is the study conducted in a formal educational setting (K-12, higher education, or professional training)?
3. STEM Subject Matter: Does the study specifically address one or more STEM (Science, Technology, Engineering, Mathematics) subjects?
4. Research Type: Is the study either empirical research OR a theoretical framework with substantial academic content (not an opinion piece or editorial)?
5. Learning Components: Does the study include clear description of learning objectives, outcomes, OR pedagogical approaches?
6. Implementation Details: Does the study describe specific AI-powered educational tools, platforms, OR implementation models?
7. Methodological Completeness: Is this a complete study with full methodological details (not a preliminary study or conference abstract)?
8. Tools used: Are there AI tools presented? Is there a description of the purpose the AI tool is used for?
9. Category of AI Use - Tutoring: Is their information on the objectives of AI in STEM education?
10. Category of AI use - assessment: Is there information on the objectives of AI in STEM education? Is AI used for any kind of assessment or test?
11. Category of AI use- counseling, student support: Is there any information on the objectives of AI in STEM education? Is AI used for counseling students or support for students?
12. Category of AI use - collaboration: Is there information on the objectives of AI in STEM education? Is AI used for collaboration among students ?
13. AI related competences: Is there information what competences can be learned about AI?
14. Micro-level - learning and practicing: Is there information about the use of AI for self-learning, practicing, homework, testing, self-evaluation, communicating, collaboration?

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15. Education level: Do the studies focus on secondary level or k-12-level?

The resulting 41 papers were included into the analysis following the questions for the curriculum analysis.

3. Results

3.1 Analysis of the relevant curricula in the project countries

3.1.1 German curriculum analysis

The German general school system is characterised by a distinction between schools that lead up to the intermediate school leaving certificate (secondary school) and whose attendance is compulsory for all children. Furthermore, there are schools that offer programmes which ultimately lead to the higher education entrance qualification (Gymnasium, Abitur). Approximately 55 percent of all pupils attend these kinds of grammar schools. There are different curricula for secondary schools and grammar schools, which are considered separately below.

How is AI integrated into the school curriculum?

In the German school curriculum, the integration of AI is recommended to be approached in a structured and cautious manner, with a specific emphasis on adapting the introduction of AI technologies to the developmental stages of students. For early stages of education, such as primary and early secondary education, the recommendations are cautious, suggesting limited or no direct integration of sophisticated AI technologies, with a focus on foundational literacy and numeracy. In the later stages of secondary education, the integration of Large Language Models (LLMs) is encouraged, primarily to support tasks such as text creation and revision, always balanced with traditional literacy tasks performed without AI assistance (SWK, 2024).

The standing conference of ministers of education (Kultusministerkonferenz (KMK)) also underscores the imperative of incorporating competencies essential for digitally enabled participation into educational curricula commencing from the primary school level. This integration is cross-disciplinary, embedded within all subjects rather than treated as a separate curricular element. This strategy emphasises individual learning processes supported by digital tools and environments, contributing to the development of autonomy and self-regulated learning (KMK, 2017).

Secondary school

The educational standards explicitly integrate competencies related to digital literacy, including AI, across the disciplines of Mathematics, Biology, Chemistry, and Physics. The KMK's updated standards from 2024 emphasise the integration of digital technologies and AI as an integral component within subject-specific curricula. Rather than creating separate courses on AI, the standards promote a cross-disciplinary approach, embedding digital competencies within existing curricular frameworks. AI and digital tools are utilised to facilitate learning processes, support experimental investigations, model scientific phenomena, and engage students in explorative and self-regulated learning.

Grammar school

The educational standards for the Allgemeine Hochschulreife emphasise the integration of digital tools, including AI, as a cross-disciplinary skill embedded within the natural sciences

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(Physics, Chemistry, Biology). While AI integration is not delineated as a discrete subject in its own right, it is woven into the fabric of learning activities, scientific inquiry processes and research projects through the medium of digitally supported competencies. Digital literacy, understood as the competent and responsible use of digital tools, including AI-driven applications, is regarded as essential for students to participate actively and autonomously in a digitally-oriented society.

What are the learning objectives and/or outcomes?

The learning objectives delineated by the KMK and SWK (standing scientific commission (Ständige Wissenschaftliche Kommission)) are mainly concerned with cultivating digital competence, critical thinking, and autonomy in learners. It is expected that learners will experience digital technologies, including AI, in a critical and reflective manner to enhance their educational experience and personal development. The students should acquire competencies in evaluating AI-generated information critically, discerning its reliability, ethical implications, and limitations. The overarching objective is to empower students to become digitally literate citizens capable of navigating a technology-rich environment in a responsible manner (KMK 2017, 2024).

The SWK (2024) further emphasises developing competencies related to technology reflection, source evaluation, content knowledge, prompt tuning, and self-regulation. These skills are designed to equip students with the necessary tools to interact with generative AI models in educational settings in a competent and reflective manner.

Secondary school
The overarching learning objectives across Mathematics and Natural Sciences include fostering competencies that allow students to solve problems, engage in scientific inquiry, and critically assess scientific data and phenomena using digital and AI-driven tools. Students are expected to develop digital literacy, critical thinking, problem-solving abilities, and competencies to responsibly and ethically use AI. They should learn to evaluate AI-generated information critically, integrate it meaningfully into problem-solving processes, and become capable of autonomous, informed decision-making regarding technology use.

Grammar school
The core objectives outlined include the development of deep subject knowledge alongside critical digital literacy, scientific inquiry competencies, and the capability for autonomous, reflective participation in digital environments. It is expected that students will apply their knowledge in problem-solving contexts, critically assess scientific findings, reflect on the ethical implications of scientific and technological developments, and responsibly utilise digital technologies and AI tools in scientific exploration and communication.

Description of the methodology for introducing AI

The introduction methodology as recommended by German education papers involves a phased and experimental approach. Initially, this approach involves systematic testing phases accompanied by open error cultures, active collaboration between practice and research, and significant investment in professional development for teachers. Educational institutions are encouraged to integrate AI tools such as Large Language Models within dedicated and secure learning platforms. Furthermore, authorities advocate for the integration of AI tools in a manner that complements traditional methods, ensuring that learners continue to engage critically with educational content both independently and assisted by AI (KMK, 2024, SWK, 2024).

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The KMK (2024) proposes the implementation of evidence-based methodologies for the integration of AI within educational settings. The recommendation entails the execution of rigorous academic evaluation and quality assurance mechanisms, with the objective of ensuring the effective, ethical, and age-appropriate utilisation of these technologies within educational environments.

Secondary school
The integration of AI into the classroom environment, as delineated by these standards, occurs in a methodical manner. It is incorporated into teaching through tasks and learning processes that are explicitly designed to leverage digital and AI-supported tools. Digital and AI-driven tools are systematically employed in mathematical modelling, scientific experimentation, data processing, and analytical tasks, emphasising students' active engagement. Learning scenarios involving digital media and AI tools are explicitly designed to foster competencies such as self-directed learning, critical evaluation of digital information, and practical application of theoretical knowledge.

Grammar school
AI and digital tools are methodologically embedded into teaching and learning practices through problem-based learning, project-oriented tasks, and experimental investigations. The approach is competency-oriented, with digital technologies, including AI, being employed to facilitate active learning processes, enhance the understanding of complex phenomena through simulations, modelling, and data analysis, and promote critical reflection on scientific results. Teaching methodologies emphasise structured autonomy, enabling students to develop skills progressively, from guided instruction to independent, research-oriented projects.

What AI tools are utilized (or suggested to be utilized)?

The recommended AI tools span a variety of types, with a significant focus on generative AI models such as ChatGPT. These models are acknowledged for their potential to significantly impact teaching and learning processes, including individualised feedback, collaborative text creation, and adaptive learning environments. The KMK explicitly mentions Intelligent Tutoring Systems (ITS) and adaptive learning environments designed specifically for educational purposes, highlighting their potential in fostering personalised and inclusive educational experiences.

Secondary school
The standards suggest the use of various digital and AI-based tools to support educational activities:
Mathematics: Digital tools include scientific calculators, geometry software, spreadsheet applications, stochastic tools, computer algebra systems, learning assessment apps, and explanatory videos.
Biology, Chemistry, and Physics: Digital simulation tools, virtual laboratories, data analysis software, interactive modeling applications, digital microscopes, and experimental software for simulating natural phenomena are suggested.

Grammar school
While specific AI tools are not enumerated in the standards, general recommendations include the utilisation of digital simulations, virtual experiments, data analysis software, and interactive digital environments. These tools, which may be powered by AI, support tasks such as modelling complex biological systems, simulating chemical reactions, and visualising abstract physical concepts. The standards advocate for the incorporation of these digital resources as essential components in the pursuit of enhanced comprehension and the facilitation of scientific inquiry.

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It is not possible to provide an overview of the AI tools utilised within educational institutions in Germany due to the federal structure of its education system. In the state of Baden-Württemberg, where the participating project university is located, schools are provided with a GDPR-compliant version of the LLM ChatGPT (fairchat), which does not store any student-related data. Furthermore, educational institutions are at liberty to procure AI tools from private providers (for example, Fobizz) for their students, provided that the tools are GDPR-compliant.

What are the basic skills and competences that students will acquire?

The curricula set out more general skills and competencies that students are expected to gain through the integration of AI into education.

- Digital literacy and media competence: Students are taught to utilise digital tools in an effective and responsible manner.
- Critical reflection and ethical judgment: They are encouraged to assess AI outputs critically, recognizing biases and ethical considerations.
- Autonomy and self-regulation: Learners develop competencies in independently managing their learning processes with the aid of digital tools.
- Collaborative and problem-solving skills: The programme places particular emphasis on collaborative problem-based learning, especially in STEM contexts, to activate critical thinking and practical application of knowledge.

Secondary school
Students acquire some competences related to digital and AI tools across all subjects, notably:

- Critical Thinking and Problem-solving: Analyzing, interpreting, and critically evaluating scientific data.
- Digital Literacy: Competent and ethical use of digital and AI-driven tools.
- Scientific Inquiry and Experimental Competence: Planning, executing, and interpreting scientific experiments using digital resources.
- Modeling and Representation: Utilizing digital models to represent scientific phenomena accurately and clearly.
- Autonomy and Self-regulation: Independently managing learning processes with digital aids, including AI tools.
- Responsible Citizenship: Understanding implications of scientific developments and digital technologies on society and environment

Grammar school
The competencies that students acquire through the integration of digital and AI-supported education are as follows:

- Scientific inquiry and experimentation: Competence in planning, performing, and evaluating scientific experiments using digital tools.
- Digital literacy: Proficiency in the judicious and effective utilisation of digital and AI tools for scientific research and communication.
- Critical evaluation and reflection: This entails the ability to critically analyse scientific data and results, including those generated by AI.
- Autonomous and reflective learning: Skilled management of self-directed research and inquiry projects utilising digital resources.
- Communication and collaboration: Competence in digitally-mediated scientific communication, sharing research findings, and collaborating effectively in virtual environments.

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Whether and how is AI combined with STEM subjects?

The integration of AI is strongly associated with the enhancement of STEM education through the promotion of problem-based learning and critical thinking. The German educational recommendations emphasise the combination of AI tools with STEM education through adaptive and personalised learning environments that can significantly support students' mastery of core STEM competencies. The use of AI is regarded as being of particular value in improving mathematical and scientific literacy by rendering instruction more cognitively activating and connected to real-life applications. The integration of AI tools into collaborative problem-solving approaches is explicitly recommended to stimulate active student engagement and effective learning in STEM subjects.

The "MINT Nachwuchsbarometer 2024 report" emphasises the potential of innovative educational methods, such as collaborative and problem-based learning supported by AI, to counteract declining STEM competencies among students and improve the quality and effectiveness of mathematics and science education.

Secondary school
AI and digital technologies should be integrated into STEM subjects:

- Mathematics: AI tools support mathematical modeling, problem-solving, and discovery learning activities.
- Biology: AI-supported digital technologies facilitate investigations of biological systems, modeling of ecological interactions, and genetic research.
- Chemistry: AI-supported digital tools enhance chemical experiments, simulations of chemical reactions, and modeling at sub-microscopic levels.
- Physics: Digital simulations and modeling tools help visualize abstract physical concepts and phenomena, enabling deeper conceptual understanding.
- In all subjects, AI supports collaborative, problem-based learning scenarios that encourage students to engage actively and reflect critically on scientific concepts and methods

Grammar school
Artificial intelligence (AI) and digital tools have become integral components of STEM subjects, particularly in the domains of modelling, simulation, data processing, and analysis tasks that are pivotal to Physics, Chemistry, and Biology.

- Physics: AI tools aid in the modeling and visualisation of complex phenomena, such as electromagnetic fields, quantum mechanics, and wave behaviour, thereby providing students with insights into theoretical concepts and empirical data analysis.
- Chemistry: Digital and AI-driven tools facilitate understanding of chemical reactions and structures, enabling sophisticated simulations and quantitative analyses.
- Biology: The integration of AI supports the analysis of biological data, the modelling of ecological interactions, genetic research, and systems biology, thereby enhancing the depth and breadth of biological understanding through digital simulations.

3.1.2 Greek Curriculum analysis

The analysis of the Greek Curriculum is focused on the Computer Science Course in Middle and High School and the presence of AI courses/learning activities.

From 2021, the IEP (Institution of Educational Policy) in Greece is making a major effort to introduce new curricula and new textbooks in all grades and types of schools, including the curriculum for the Computer Science course. IEP is an executive, scientific and research body

that supports the Ministry of Education, Religious Affairs and Sports as well as the supervised bodies in matters related to primary and secondary education, teacher training, and many other domains in Greece. In 2022, the new general education curricula for the course of Computer Science in middle and high school (i.e., for students from 12 to 17) were finalized (https://iep.edu.gr/el/nea-ps-provoli). These curricula were developed within the action "Upgrading of Curricula and Creation of Educational Materials for Primary and Secondary Education".
There are currently no official student books that include the AI-related units described in this document. There are only some supplementary digital documents that were developed in July 2024 and are available on the IEP's website (https://iep.edu.gr/el/gymnasio/pliroforiki). The new textbooks have already been written and are now in the evaluation phase and will be available from the 2025-26 school year. There will be two or more alternative textbooks for each subject (multiple textbook) and teachers will choose the one that best suits their classroom needs.

How is AI integrated into the school curriculum? (Brief description of the current status of the Computer Science course)

Middle School in Greece: Consists of 3 grades. Students aged between 12 and 14.
High School in Greece: Consists of 3 grades. Students aged between 15 and 17.

AI is integrated into the Greek school curriculum in the context of a Computer Science course. Computer Science is compulsory for all middle school students and for all high school students in the 1st and 2nd grades. In the 3rd grade of high school, the Computer Science course is compulsory only for students who are oriented towards IT and economics. The main scope of the Computer Science course in Greece is to educate students not only to learn about digital tools and technologies but also to learn how to use these tools and technologies in a creative and ethical manner.

In both cases (middle school and high school), the curriculum is divided in thematic areas. Each thematic area is divided in thematic units, and each thematic unit is divided in sub-units or axes.

In middle school, AI is a sub-unit/axis of the thematic unit called "Problem-solving with programming tools", while in high school is part of a thematic unit called "Innovative applications of AI". In both cases, AI is included in the thematic area of "Algorithmics and programming of computer systems". In the same thematic unit (and prior to AI), the students are engaged in the axes of robotics and programming through the lens of STEM education. AI is also included in the thematic unit called "The impact of Computer Science and digital/virtual technologies in society and culture", in which students become aware of the societal impact of AI.
In middle school there is a general overview of AI, while in high school, the curriculum delves into some core concepts of AI.

What are the learning objectives and/or outcomes?

Middle school:
In the first grade (12-year-old students), students are expected to become acquainted with and learn to use AI applications, as well as to become familiar with some events relevant to the history of AI.
In the second grade (13-year-old), students are expected to delve into AI applications and will be able to extend the study of AI applications and distinguish between symbolic processing and

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neural network - Machine Learning (ML) applications. Moreover, they will be able to describe the core concepts and methods of AI, using simple examples.
In the third grade (14-year-old), students are expected to be able to explore, study and program simple AI applications in appropriate educational programming environments. They will also be able to familiarize themselves with, study and critically comment on, applications of AI to the adaptability of web applications. In addition, they will be able to document the impact of AI applications on users, society and the economy, by identifying issues, risks (e.g., biased data) and dilemmas.

High school:
In the first grade (15-year-old), students are expected to be able to identify AI applications and discuss their implementation in society.
In the second grade (16-year-old), students are expected to be able to utilize programming environments for the execution of AI algorithms, as well as to identify innovative digital applications and design their variations.
In the third grade (17-year-old), students are expected to be able to design simple AI algorithms for solving problems.

Description of the methodology for introducing AI

Middle school:
In the 1st grade (12-year-old), teachers introduce AI by presenting some examples of AI and ML applications, including chat bots, digital games and AI services such as speech and image recognition. The students take some time to explore and interact with these examples and reflect on aspects related to the level of natural interaction of such AI systems. The teacher then provides the students with resources on the history of AI. The students have to gather information and historical facts and present them in plenary through various visualizations and mediums, including timelines and concept maps. In this way, and with the help of the teachers, they learn about milestones in the development of AI, and identify key questions and axes of AI.

In the 2nd grade (13-year-old), the students continue their research on AI applications to classify them into symbolic processing (symbolic AI) and neural network - ML applications. By using age-appropriate educational environments and tools, they interact with such applications to identify basic principles of their operation. They do not delve into core mechanisms of neural networks, but they are becoming familiar with basic concepts, methods and services of AI such as automations in robotics, intelligent agents, representation and reasoning, pattern recognition, problem solving, speech recognition and image recognition.

In the 3rd grade (14-year-old), the students, with the guidance of their teacher, become familiar with educational environments for programming AI applications in order to deepen further into their mechanisms and capabilities. Students learn the stages of developing applications with neural networks and become familiar with terms such as training, training dataset, control dataset, positive reinforcement, etc. Then, they explore selected examples of web applications to identify web services that use ML technology to adapt to the user profile (e.g. news selection applications that ask if the news was useful, recommendation and filtering systems for search information, etc). They reflect on and critically discuss this experience and its outcomes. Moreover, in conjunction with the corresponding modules on the social implications of Digital Technology, they critically discuss the usefulness of AI applications including facial recognition, emotion recognition and task automation in terms of their impact on society, the economy and the risks to privacy, personal data, biased information, the manipulation of society and the reproduction of discrimination.

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The teacher's guide contains a learning scenario for the 2nd and 3rd grade. The aim of this scenario is to familiarize students with AI and ML. In particular, they will train a model to recognize dogs and cats. Through this activity they will become familiar with the basic concepts of AI and ML and will become aware of the limitations and risks of AI systems that are based on services such as image and face recognition. For the implementation of this scenario, it is suggested that the students are divided into groups of 2 or 3.

High school:
In the 1st grade, the students explore popular applications of AI that can superimpose visual effects on photos taken with mobile devices, use voice recognition etc., and identify their applications in various fields (medicine, industry, museums, smart homes, etc.).

In the 2nd grade, the students are involved in activities to explore and develop simple AI algorithms. Students use tools/platforms such as the "Machine Learning for Kids" to train a ML model to create an application that classifies photos into two categories (e.g. passenger cars and trucks). Then, they discuss the accuracy of the model and ways to extend the capabilities of the application, but also its use and impact in everyday life.

In the 3rd grade only the students who are oriented towards IT and economic studies are involved in AI related activities. Initially, they explore a learning subject included in Photodentro (http://photodentro.edu.gr/aggregator/lo/photodentro-lor-8521-10694), about the evolution of AI, and they critically comment on the milestones in the evolution of AI. They then explore and experiment with AI applications for mobile/smart devices developed using the open-source deep learning framework TensorFlow Lite. They also analyze and design simple AI algorithms and develop ML models using the TensorFlow.js library.

What AI tools are utilized (or suggested to be utilized)?

The following tools are suggested to be used for AI activities in **middle school**, and specifically to be used by students of the 2nd and 3rd grade (13 and 14 year-old).

https://teachablemachine.withgoogle.com
https://www.microsoft.com/en-us/ai/seeing-ai
https://code.org/oceans
https://machinelearningforkids.co.uk/
https://vo.codes/
https://openai.com/blog/dall-e/

Tools suggested in **High school**
https://machinelearningforkids.co.uk
https://www.tensorflow.org/

What are the basic skills and competences that students will acquire?

Middle school:
- Cooperation
- Communication
- Critical thinking
- Problem solving
- High school

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- Cooperation
- Role allocation
- Communication
- Critical thinking
- Problem solving
- Creativity

Whether and how is AI combined with STEM subjects?

There is not a direct link to STEM, but AI is part of a broader unit that engages students in learning activities related to robotics and other STEM disciplines, such as mathematics, geography and biology. However, STEM is directly linked to AI in the activities included in Skill Labs.

Skill Labs
Skill Labs (https://iep.edu.gr/el/psifiako-apothetirio/skill-labs) are innovative, dynamic, didactic and pedagogical activities that focus on cultivating critical 21st century skills through the use of modern learning methods, and are introduced as new thematic units, in the compulsory kindergarten, primary and secondary school curriculum. The basic principle of the Skill Labs is to combine curricular knowledge areas with the development of students' basic skills, including soft skills, life skills, communication and responsibility, as well as digital learning, technology and science skills, which will help them to become free and responsible citizens. The Skill Labs are divided into 4 different Thematic Axes. AI is included in the "Creation and Innovation - Creative Thinking and Initiative" thematic axis, as part of the "STEM and Robotics" category (https://iep.edu.gr/el/psifiako-apothetirio/skill-labs/1008-stem-steam), and is aimed at students aged 12 to 14.

The main focus of this Skill Lab is to introduce students to AI and its application to everyday life, through STEM methodology and hands-on activities. The lab consists of 7 labs/workshops and is based on the educational model of 5E (Engage, Explore, Explain, Elaborate, and Evaluate). Students work in teams of three or four, while teachers act as facilitators and coaches, encouraging students to follow the think-pair-share strategy (i.e., think individually, interact with team, share in plenary). At the beginning (1st Lab/workshop), the students are involved in activities that help them to become familiar with the definition of AI, while at the same time recognizing applications from everyday life that use AI. Then (2nd and 3rd Lab/workshop), they interact with some applications and recognize how AI uses algorithms to solve a given problem, thus becoming familiar with the concept of Machine Learning (ML). Through these activities students are gradually introduced to ideas related to ethics and the responsible use of AI (4th Lab/workshop), as they realize that AI applications can be trained with biased ML models. They are then encouraged to prepare a presentation (5th Lab/workshop) that summarizes everything they have learned about AI and to share this presentation in plenary, as well as with the wider educational community, through school channels. The next step (6th Lab/workshop) is to train their own ML model to recognize and classify images based on their content (e.g., recognize cars and cups). After training their model, they evaluate the results and share their thoughts in plenary on the effectiveness and the impact of such an ML model (7th Lab/workshop). To facilitate the implementation of these Labs, teacher guides and a set of corresponding student worksheets are provided.

Tools/applications suggested in Skill Labs
Quickdraw https://quickdraw.withgoogle.com/
Autodraw https://www.autodraw.com/
Deepdream https://deepdreamgenerator.com/
Semiconductor https://semiconductor.withgoogle.com/

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Speech-to-text https://speech-to-text-demo.ng.bluemix.net/
Thispersondoesnotexist https://thispersondoesnotexist.com/
Talktobooks https://books.google.com/talktobooks/
Talktotransformer https://app.inferkit.com/demo
Scratch: https://scratch.mit.edu/
Machine learning for kids: https://machinelearningforkids.co.uk
Teachable machine: https://teachablemachine.withgoogle.com/

Skills and competences that students are expected to acquire

- Cooperation
- Communication
- Critical thinking
- Creativity
- Problem solving
- Role allocation

"Experience AI" in greek schools
Recently, Google, with the support of the Ministry of Education, Religious Affairs and Sports launched the "Experience AI" initiative in Greek schools (https://www.naftemporiki.gr/society/1854333/i-google-fernei-sta-ellinika-scholeia-to-experience-ai/). Experience AI (https://experience-ai.org/el) has been designed by the Raspberry Pi Foundation and Google Deep Mind, and provides a set of resources and learning activities to introduce both educators and students (aged 11 to 14) to AI and ML. Currently, the Ministry of Education is supporting this initiative as an extracurricular activity for both public and private schools.

3.1.3 Italian Curriculum Analysis

In Italy, the national Ministry of Education (Ministero dell'Istruzione e del Merito) currently has no curricula for computer science and Artificial Intelligence, but mentions them in some official documents mainly with reference to EU documents.
Computer science (called "Informatica") is not a standalone compulsory subject for all students in lower or upper secondary education.

How is AI integrated into the school curriculum?

At the middle school level (scuola secondaria di primo grado, ages ~11–14), computing concepts are introduced within the broader "Tecnologia" course rather than as a separate class. In high school (scuola secondaria di secondo grado, ages ~14–19), dedicated informatics courses exist only in specific tracks – for example, the "Liceo Scientifico - Scienze Applicate" requires computer science, and even the traditional science high school includes some informatics content integrated into mathematics. For the majority of students in general education paths (e.g. classical, linguistic, or vocational high schools), however, formal instruction in coding or computer science is minimal or optional.

As a result, artificial intelligence (AI) topics are not uniformly mandated in the Italian curriculum. Artificial intelligence literacy is mainly incorporated through the Civic Education programme. In 2019, Italy introduced Civic Education (Educazione Civica) as a mandatory cross-subject curriculum with at least 33 hours per year devoted to themes of digital citizenship (alongside constitutional studies and sustainable development). This provides a structural entry point for AI, framing it within digital competency and ethics.

In the 2024 revision, for instance, guidelines suggest teachers might address AI when covering digital literacy, online safety, or media awareness in civics classes – discussing topics like algorithmic bias or the impact of AI on society as part of forming "responsible digital citizens." Indeed, one of the three key strands in the new Civic Education guidelines is digital citizenship, which inherently includes understanding emerging technologies and their societal implications. Through this lens, AI is treated as a topic for class debates, research projects, or case studies rather than a technical subject for all students.

Beyond the national curriculum framework, some schools and regions have independently implemented AI education initiatives to enrich their students' learning.
An example is the "Syllabus LUCY" – an AI education syllabus developed in 2020–2022 via a public-private partnership promoted by IC3 school in Modena. The syllabus was addressed to middle school students and designed as a guide for students and teachers to discover and understand AI "along a path of contamination between disciplines", emphasizing an interdisciplinary approach to AI literacy.

Another prominent initiative is the regional network of 55 schools in Friuli Venezia Giulia, coordinated by Liceo Classico "Jacopo Stellini" of Udine. In May 2024 this network published Italy's first guidelines for the use of artificial intelligence in schools, focusing especially on generative AI. This project – "Costruire il Futuro – Linee guida sull'utilizzo dell'IA a scuola" – involved school leaders, teachers, and students in crafting recommendations for integrating AI tools responsibly and creatively in teaching. Such bottom-up efforts signal a growing awareness in Italy's education community of the importance of AI, even in the absence of a dedicated nationwide AI curriculum.

What are the learning objectives and/or outcomes?

Because Italy does not have an official AI curriculum with grade-specific standards, learning objectives related to AI tend to be defined by broad guidelines or left to individual schools' syllabi. Generally, the goals of introducing AI in Italian middle and high schools center on building awareness, foundational knowledge, and critical understanding of artificial intelligence, rather than mastery of advanced programming.

Common learning outcomes include:

Basic AI Literacy (Middle School): By the end of middle school (lower secondary), students should recognize what AI is and where it appears in everyday life (e.g. virtual assistants, simple robots, image or speech recognition apps) and learn basic concepts like the difference between a programmed behavior and "learning" behavior. Students also discuss events in the history of AI to see how the field evolved. Following the LUCY syllabus, middle graders even experiment with age-appropriate AI tools: for instance, they might use a block-based coding platform to train a very simple model (e.g. recognizing basic images or guiding a robot with gestures) as a hands-on introduction. The expected outcome at this stage is AI familiarity – students know basic definitions, can give examples of AI around them, and appreciate both the capabilities and limits of modern AI technologies.

Deeper Understanding and Application (High School): At the upper secondary level, in the schools of Stellini's network, AI-related outcomes aim for a more analytical and applied understanding. By roughly age 15–16, students in schools that offer computer science or specialized projects are expected to discuss how AI works at a conceptual level (e.g.

understanding that AI systems learn from data, what algorithms and neural networks are in principle) and identify real-world uses across various fields (medicine, finance, art, etc.). They might debate the impact of AI in society and the economy as part of civic education, demonstrating awareness of ethical issues, data privacy, and potential biases introduced by AI. Where practical opportunities exist, high school students may experiment with designing or training simple AI models. Finally, a critical learning outcome for high schoolers is the ability to reflect on AI's implications – e.g. articulating the risks of AI (like bias or job automation) and proposing ways to address them. The network of schools in Friuli Venezia Giulia explicitly listed goals such as preparing students for the future AI-driven job market and "educating students on ethical responsibility in the use of AI". In summary, by graduation, Italian students exposed to AI education should have both a practical appreciation of how AI systems function and a thoughtful perspective on AI's role in the modern world.

Description of the methodology for introducing AI

Given that AI education in Italy is largely driven by individual initiatives or integrated into broader competencies, teaching methodologies tend to be project-based and interdisciplinary. There is no single prescribed method from the Ministry, so teachers employ a variety of approaches, often focusing on exploration, discussion, and creation rather than direct instruction of complex theory. Some characteristic methodologies include:

- presenting real-world examples
- discussing historical and Ethical aspects
- Project-Based Learning
- hands-on projects
- use of Generative AI with guidance

In summary, Italy's methodology for introducing AI is active and discussion-based. Whether through interactive demos, interdisciplinary projects, or guided use of AI applications, the goal is to engage students' curiosity and critical thinking.

What AI tools are utilized (or suggested to be utilized)?

Since there is no official list of AI tools mandated by the Ministry, Italian educators and independent curricula have curated their own set of educational AI tools and resources. Many of these overlap with the tools used internationally or mentioned in the Greek context, adapted for the local classroom setting. Some of the commonly utilized or recommended tools include:

Block-Based Coding Platforms with AI Extensions: Visual programming environments like Scratch (and its derivatives) for teaching computing in early years, and they can be extended to AI applications (i.e. with Google Teachable Machine extension to create simple AI projects or Machine Learning for Kids platform. These platforms require no prior coding expertise, lowering the barrier for middle school classes to experiment with AI.)

Educational Robotics Kits: Robotics is part of the technology curriculum and extracurriculars in many Italian schools, and AI functionalities are increasingly integrated into these robotics activities. Platforms like LEGO, micro:bit or Arduino-based kits are used to teach programming; with the addition of sensors and smart behaviors, teachers can frame these as AI concepts. These hands-on kits help demonstrate AI in the physical world. Students learn how sensor input (camera, microphone, ultrasonic sensor, etc.) can be processed by software to produce autonomous behavior, which is essentially an applied AI scenario. Such tools reinforce abstract AI concepts with concrete tinkering.

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Online AI Simulations and Apps: Teachers also leverage a variety of web-based AI demos and simulators. A popular choice is Google's Experiments with AI and other free resources – for example, Quick, Draw! (an AI doodle recognition game), as Code.org's AI-themed modules (such as "AI for Oceans" where students train a model to clean up the ocean) have been translated and often used in one-off lessons to pique interest or during events like the Europe Code Week, where schools run coding and AI workshops. They require only a web browser and provide instant, visual feedback, which is great for engaging students with no setup cost.

Generative AI Tools (with supervision): As noted, at the high school level there's emerging use of generative AI like chatbots and image generators as educational tools themselves. For instance, some teachers have begun using ChatGPT (within the bounds of privacy regulations) as a "discussion partner" or to generate examples of text that students then critique. Art teachers might show students DALL-E or similar image-generation tools to discuss creativity and copyright. The Friuli Venezia Giulia network's "IAg" guidelines specifically focus on these tools (IAg stands for Intelligenza Artificiale generativa) and encourage creative and responsible use of them in class. They even produced an e-book repository of AI tools and model use cases for schools.

Data Science and Coding Tools: For more advanced students (typically in upper secondary, especially those in a science/applied track or technical institute), educators might introduce beginner-friendly coding libraries for AI. Python with simple machine learning libraries has been piloted in some technical high schools. Additionally, spreadsheet software is used as a tool for AI fundamentals: teachers have students use Excel/Google Sheets to perform basic data analysis (plotting trends, using linear regression functions) as a stepping stone to understanding AI algorithms. This reinforces that AI isn't magic – it's built on mathematics and data manipulation, which can be illustrated with everyday tools like spreadsheets before moving to specialized AI software.

The tools in use reflect a blend of low-threshold, student-friendly applications (to introduce concepts without coding) and more advanced platforms for optional deep dives. This toolbox is continually expanding as teachers share experiences from independent projects and as international AI-in-education resources become available in Italian.

What are the basic skills and competences that students will acquire?

Even though AI is not a standard subject, there is a range of skills and competences through AI-related learning, in line with the broader objectives of the curriculum. Key skills and competences targeted include:

- Digital Competence and Computational Thinking
- Critical Thinking and Analytical Skills
- Collaboration and Communication
- Creativity
- "Learn to Learn" and Adaptability

3.1.4 Polish Curriculum Analysis

How is AI integrated into the school curriculum?

The Polish secondary school system includes: high schools, technical schools, and vocational schools. The curriculum for all these types of schools are outlined in regulations from May 20, 2024 and other and other supporting documents.

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Currently, Artificial Intelligence (AI) is not explicitly a standalone subject in the Polish secondary school curriculum under the national core curriculum established by the Ministry of Education and Science (MEN). However, elements of AI-related topics are increasingly integrated into existing subjects, particularly Computer Science (basic programming, algorithms, databases and modern technology usage at schools). Computer Science is currently taught in Poland in every class (regardless ist profile) starting from the first class of the primary school and being continued till the last class of the secondary school.

Also many references to AI are included in other educational authorities' endorsed reports, recommendations, and projects.
In addition there are ongoing efforts to expand AI education through government strategies and external programs like the RESOLUTION NO 24 OF THE COUNCIL OF MINISTERS of 21 February 2023 on establishing the government program called "Digital Competence Development Programme. The document sees AI as a universal tool to deal with various problems in many fields and impacts many aspects of schools education and teacher training. Finally, in response to the current high interest in AI, the Polish government has prepared RESOLUTION NO 98 OF THE COUNCIL OF MINISTERS of 12 September 2024 entitled "Digital Transformation of Education Policy." The document set out the plan for transforming Polish education in the next decade: 2024–2035. And AI is deeply embedded in this process and is available in many educational aspects. Although the transformation process is scheduled for a few years, when it is implemented, it will deeply change the official curriculum.

What are the learning objectives or/and the learning outcomes?

The term "Artificial Intelligence" does not appear in the official Polish secondary curriculum; however, several learning objectives, notably those for science subjects, relate to the tasks and topics commonly addressed by AI. Generally, a few objectives repeat in the curriculum in relation to different subjects, almost in the exact wording.
One such standard schema says:

"Creative problem-solving in various fields with the conscious use of methods and tools derived from computer science, including programming the ability to use modern information and communication technologies efficiently, the ability to independently access information, make its selection, synthesis and evaluation."

Similarly, but in a slightly different context:

"Solving problems using methods and techniques stemming from computer science, including logical and algorithmic thinking, programming, using computer applications, finding and using information from different sources, using a computer and basic digital devices."

In the chemistry context:

"Developing digital competence necessary for the effective use of information and communication technology to assess, create, store, present and exchange information."

In relation to Physics:

"Developing the ability to think logically, analyze problems and create models to describe reality."

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Finally, Computer science aims at "the ability to use new technologies creatively and critically [……| and [..] the essence of computer science is the creative discovery of algorithms, learning about problem-solving methods and exploring their effectiveness."
Listed below, detailed Objectives of Computer Science Learning set the basis to use AI tools even if officially not mentioned in the curriculum:

"To understand, analyze, and solve problems based on logical and abstract thinking, algorithmic thinking, and ways of representing information."
"Programming and problem-solving using the computer and other digital devices: arranging and programming algorithms, organizing, finding and sharing information, using computer applications."

Description of the methodology for introducing AI

As in many other countries, AI is not mentioned at all in secondary school curricula in Poland, let alone even changing curricula due to the possibility of using AI.
Consequently, the use of available AI tools depends solely on the creativity of students and teachers. AI seems to be used to a greater extent by students, who mainly use LLM for solving tasks and writing and revising texts.
Many teachers, on the other hand, try to use LLM to do tedious administrative work and pre-assess students' work.
Projects using AI are usually carried out in extra-curricular classes. This is usually done using the project method, while students often rely on LLM to complete assignments.
In general, there is no consistent methodology in practice for using AI in the learning process. Usually, AI is introduced through an experimental method, while the conceptual complexity of the tools and ways of using AI in school is adapted to many and the profile of the class.
In the field of STEAM, AI often appears in the context of robotics and programming, and in general contexts of information retrieval and essay preparation.
In general, despite the definition of many use cases and the collection of experiences from different fields, a universally accepted methodology for the use of AI in education has not yet been developed. AI tools and problem solving with the help of AI in school is mostly implemented using a combination of known methodologies.

Challenges and the idea of transforming education using AI in the future.

What not everyone is aware of, AI has already made a permanent appearance in our lives at least 2 decades ago through the Internet and Google services, and later social networks and other intelligent applications. However, it is only at the beginning of 2024 that we are seeing an explosion of interest and use of AI through Chat GPT and other general-purpose language models. This phenomenon can be seen in terms of a revolution, as for many years society was only an object explored by AI tools, and only recently has everyone been given the opportunity to actively use AI tools.

The use of AI in education cannot be considered in isolation from the wider context. AI will probably gradually revolutionise many areas of our lives and work and, consequently, will also redefine the learning objectives and the expected competencies and skills of students.
The redefined goals of education will be reflected in the programmes, the implementation of which should be supported by AI tools and, at the same time, various AI topics should be included in the curriculum. The whole process will probably gain momentum within a few years and, as a result, the education process will be profoundly reformed, in ways that are currently difficult to predict. Aspects that will certainly have a major impact on education in the age of AI are AI's capabilities for precise information retrieval and the composition of ready knowledge from available information, and for solving a variety of problems. These two

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fundamental capabilities will need to be incorporated into education systems and curricula in a meaningful way.

What AI tools are utilized (or suggested to be utilized)?

Personalised educational platforms
These systems use AI to tailor learning materials and learning pathways to individual stakeholders.

- Khan Academy (https://pl.khanacademy.org)
- Coursera (https://www.coursera.org)
- DreamBox Learning (https://www.dreambox.com)

Smart assistants and chatbots
They are used to provide quick answers to questions, helping to solve problems or clarify difficult concepts.

- Duolingo (language learning chatbot) (https://www.google.com)
- Replika (AI chatbot) (https://replika.com)
- ChatGPT (and other LLMs) (https://chatgpt.com)

Assessment and Analysis Systems
AI can automatically evaluate responses and analyze results to identify areas that require additional attention. These systems can assess both multiple-choice tests and written responses.

1. Turnitin (analysis and evaluation of written work) (https://www.turnitin.com)
2. Gradescope (automatic task grading) (https://www.gradescope.com)
3. Knewton (analysis of student progress) (https://knewton.edu.my)

Educational Games and Simulations
Using AI, games and simulations offer interactive and engaging ways of learning through practical experiences and experimentation.

- DragonBox (math games) (https://dragonbox.com)
- Lightbot (programming game for children) (https://lightbot.com)
- CodeCombat (game for learning programming) (https://codecombat.com)
- Blooket (game for quiz for learning) (https://www.blooket.com)

Natural Language Processing (NLP) Tools
They assist in text analysis, support the development of language and literary skills. They can be used for automatic text summarization or language learning support.

- Grammarly (tool for improving grammar and writing style) (https://www.grammarly.com)
- QuillBot (tool for paraphrasing) (https://quillbot.com)
- Rosetta Stone (tool for language learning) (https://eu.rosettastone.com)

Educational Resource Recommendation Systems
They automatically suggest educational materials such as books, articles, videos, which are most suitable for the interests and progress of students based on their learning history.

- Schoology (learning management system) (https://app.schoology.com)
- Quizlet (tool for creating study sets) (https://quizlet.com)

Emotion and Engagement Analysis Systems
AI systems can monitor and analyze learners' reactions to educational material, adjusting the approach to increase engagement and learning effectiveness.

- Affectiva (emotion analysis) (https://www.affectiva.com)

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- GoReact (tool for analyzing presentations and speeches) (https://get.goreact.com)
- Emotiv (monitoring brain activity and emotions) (https://www.emotiv.com)

Speech Recognition and Voice Assistants
They enable interactive learning through voice commands, which is particularly helpful in language learning or for people with disabilities.
- Google Assistant (voice assistant) (https://assistant.google.com)
- Amazon Alexa (voice assistant)
- Dragon NaturallySpeaking (speech recognition)

Virtual and Augmented Reality (VR/AR)
They offer unique educational experiences through simulations and visualizations, which can be used in various fields, from history to science.
- Google Expeditions (virtual tours and AR)
- zSpace (educational VR/AR) (https://zspace.com)
- Oculus Rift (VR for education)

What are the basic skills and competencies that students will acquire?

The majority of the skills potentially relevant to AI are attributed to learning Computer Science and are listed below:

"To acquire and develop complex problem-solving skills. Analytical and critical, including skillful drawing of conclusions preceded by data analysis"
(Computer Science) Students learn how to design and program solutions to problems from various fields using input/output instructions, arithmetic and logical expressions, conditional instructions, and interactive functions with and without parameters, and test the correctness of programs for different data, particularly program algorithms.
"The most important goal of computer science education for students is the development of skills of computer thinking, focused on creative problem-solving in various fields with conscious use of areas with conscious use of methods and tools derived from computer science, including programming computer science, including programming."

A student completing basic computer science education should be able to use modern digital devices, networks, and operating systems managing their work operating systems that manage their work.

When using social networks, social networks, e-services, e-learning platforms, open resources, and any resources in the cloud, the student should respect the generally accepted rules of netiquette and security in the digital space.

The computer science curriculum defines a set of problems and algorithms that the student should solve and learn in class.
Students should also learn to modify the proposed algorithms and analyze how the modification impacts the algorithm's computational complexity.
Students learn how to write algorithms using a list of steps or pseudo-code and implement them in a programming language of their choice.
Students deal with different algorithmic methods, techniques, and data structures that can be naturally abstracted from problem-solving methods and computer-based implementations.
In addition to programming and algorithmic thinking, students are introduced to various IT tools, including e-learning platforms and distant learning systems. They learn how to use their resources and, at an advanced level, students create their content, such as documents, quizzes, wikis, forums, and assignments.

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Whether and how AI is combined with STEM subjects?

Although the curriculum does not refer to AI, other governments endorsed documents describe AI tools and their application in the learning process.

It seems STEM subjects are not seen as dominant areas of AI impact. AI is usually associated with humanities subjects rather than STEM subjects. Mainly, the AI functions and tools mentioned in the papers are associated with generative AI and LLM. The most important functions of AI are document processing and information searching. Also many potential risks related to AI generated disinformation and information bias are highlighted as well.

3.1.5 Analysis of the UNESCO (2023) "Guidance for generative AI in education and research"

The UNESCO publication "Guidance for Generative AI in Education and Research" (2023) provides a comprehensive framework for integrating Generative Artificial Intelligence (GenAI) into education systems, with a strong emphasis on human-centered, ethical and inclusive approaches. The guidelines recognize the transformative potential of GenAI in teaching and learning, while acknowledging the need for regulatory, pedagogical and curricular adaptations to ensure its responsible and equitable use in schools.

How is AI integrated into the school curriculum?

Globally, the integration of AI into school curricula is still in its infancy. While a few countries, such as China, Finland, Singapore and Spain, have initiated national strategies or teacher training programmes, widespread curricular inclusion of AI remains limited. UNESCO recommends the systematic development of national curricula for schools and lifelong learning institutions that introduce age-appropriate concepts such as data, algorithms and the ethical use of AI. These curricula should also promote an understanding of the implications of AI for society, including its impact on privacy, human rights and social justice. Rather than advocating for isolated AI lessons, the guidance calls for the integration of GenAI across disciplines, in line with broader education goals, particularly those linked to Sustainable Development Goal 4 (quality and inclusive education).

What are the learning objectives or/and the learning outcomes?

The learning objectives outlined in the guidelines cover four main categories: values, basic skills, higher-order thinking skills and vocational skills. In terms of values, education should instil a human-centred approach to technology, supporting ethical reasoning, inclusion, gender equality and cultural diversity. Basic skills such as literacy, numeracy and scientific reasoning remain essential, even in AI-rich learning environments. The use of AI in the classroom should enhance rather than replace these foundations. Higher-order skills such as critical thinking, problem solving and the ability to evaluate the validity and limitations of AI-generated outputs are crucial for learners. Finally, vocational and technical skills related to the understanding, development and responsible deployment of AI systems are increasingly relevant to future employment prospects.

Description of the methodology for introducing AI

To effectively introduce AI into the classroom, UNESCO promotes a co-design methodology involving educators, learners, researchers and policy makers. This participatory approach encourages collaborative curriculum development, lesson planning and integration of GenAI into classroom practices. Teaching strategies should support inquiry-based, project-based and student-centred learning. For example, GenAI tools can serve as "1:1 coaches" to support self-paced acquisition of basic skills, or as partners in creative tasks such as writing, coding, or data analysis. The document advocates pedagogical designs that encourage human-AI interaction, where the educator retains control and responsibility for the learning process, guiding students to critically engage with GenAI outputs rather than passively consume them.

What AI tools are utilized (or suggested to be utilized)?

A range of AI tools is suggested for educational use. General-purpose platforms such as ChatGPT, GPT-4, and Bard are highlighted for their wide accessibility, while more specialized tools such as EduChat, MathGPT, and AI-supported captioning systems are recommended for targeted applications, including language learning and special education. Open-source and ethically designed tools are favoured, and UNESCO stresses the importance of validating AI systems for pedagogical appropriateness, data privacy, and accessibility before classroom implementation.

What are the basic skills and competencies that students will acquire?

Through their engagement with AI, students are expected to develop a wide range of competencies. These include digital and data literacy, computational thinking, the ability to formulate effective prompts, and skills for co-creating content with GenAI tools. Students should also learn to critically evaluate AI-generated information, identify potential biases, and reflect on the ethical dimensions of AI use. Such competencies contribute to learners' autonomy and prepare them to navigate increasingly AI-mediated societies and workplaces.

Whether and how AI is combined with STEM subjects?

Finally, the integration of AI into STEM education is particularly emphasised. GenAI can be used to support self-directed learning in mathematics, to provide feedback on coding exercises, to generate hypotheses in scientific investigations, or to assist in engineering design processes. The application of AI in these disciplines aims not only to enhance subject knowledge, but also to cultivate transversal skills such as creativity, collaboration and scientific reasoning. UNESCO advocates project-based and interdisciplinary approaches that use AI to make STEM subjects more engaging and accessible, while fostering deeper conceptual understanding and ethical reflection.

3.2 Review on scientific papers regarding the use and effectiveness of AI in STE(A)M education (2022 - 2025)

Literature reviews were the most common in terms of utilizing AI in secondary education. We found 23 literature reviews, six papers containing empirical research such as case studies and intervention studies. Two papers were conceptual papers that cover frameworks on how to integrate AI in education.

The review revealed a distinct pattern concerning the frequency with which various domains were examined. Technology emerged as the predominant focus, featuring in 21 studies, significantly outpacing other STEM fields. The fields of Science, Engineering, and Mathematics were each the subject of 10 studies, suggesting an equitable representation across these disciplines. This distribution suggests a balanced interest in these core STEM areas, albeit

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at a lower frequency than Technology. The physical sciences, namely Physics and Chemistry, in conjunction with Computer Science, were each the subject of three studies, indicating a more specialised focus within the broader STEM landscape. Notably, one study transcended conventional STEM boundaries by incorporating Art, adopting the STEAM framework to broaden the scope of inquiry. It is noteworthy that for three studies, the specific STEM domain could not be ascertained from the available texts, which may be indicative of either a multidisciplinary approach or a focus on overarching STEM concepts rather than domain-specific inquiries.

Chatbots and large language models have emerged as the predominant focus, featuring in 11 studies, thereby underscoring their growing significance in educational contexts. Educational robots also garnered substantial attention, being the subject of seven studies, highlighting the increasing integration of robotics in learning environments. Intelligent Tutoring Systems and Machine Learning applications demonstrated equal representation, each being examined in 5 studies, indicating their established importance in AI-enhanced education. Adaptive learning systems, data analysis techniques, and hardware platforms such as Arduino were each explored in 3 studies. Five studies did not explicitly mention specific AI technologies, which indicates a broader, conceptual approach to AI in education or a focus on overarching principles rather than particular technological implementations.

3.2.1 AI Technologies and objectives

Intelligent Tutoring Systems (ITS) are employed chiefly to enhance understanding and retention, increase student engagement and motivation, and adapt to individual learning needs, as noted by Ilić et al. (2024a) and others. Large Language Models (LLMs) like ChatGPT have been shown to enhance student engagement, provide real-time feedback, personalize learning materials, and optimize content difficulty (Chen et al., 2024). AI powered educational robots are employed to develop computational thinking and enhance problem-solving skills in different age groups, as highlighted by Al-Zahrani et al. (2024a) and others.
Furthermore, the utilization of AI-powered Virtual Reality (VR) and Augmented Reality (AR) technologies has emerged as a means to enhance spatial thinking skills and improve teaching quality (Zhao, 2024a). Virtual reality is also considered a means of supporting a constructivist approach to learning, as it enables the construction of knowledge through tangible and lived experience. Virtual environments are immersive environments that allow learners to have a first-person experience by providing immediate and multi-sensory feedback (Christou (2010). Augmented Reality environments offer a very different experience, combining physical and digital aspects. It is argued that they can better support a constructivist approach to learning by overlaying information onto spatial configurations that are already familiar to the user. Therefore, it can be argued that it is not only the spatial aspect that improves the teaching quality, but also the fact that these environments afford embodied interactions.Machine learning algorithms are utilised to personalise learning experiences and optimise educational outcomes (Kim, 2024), while natural language processing (NLP) tools focus on enhancing personalised learning experiences, providing immediate feedback, and reducing grading workload (Mredula et al., 2024). AI powered eye-tracking technology is utilized to analyze student behaviour and understanding, in addition to measuring cognitive load (Chiu, 2021).

AI-powered assessment tools have been shown to streamline assessment processes and provide timely feedback (Iyamuremye et al., 2024), while prompt engineering tools have been shown to simplify complex topics and offer interactive practice opportunities (Li, 2024). Finally, AI-facilitated student/tutor matching enhances individualized support and improves learning outcomes (Zhao, 2024b). Research emphasizes that the efficacy of these AI implementations is contingent upon their integration into specific learning contexts supported by appropriate pedagogical frameworks which means constructivist frameworks (Xu & Fan, 2022).

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Furthermore, these tools are often used in combination to achieve multiple learning objectives simultaneously, especially in complex STEM learning scenarios (Chen et al., 2024). Some authors state that the integration of AI technologies demonstrates their potential to transform educational practices by aligning them with diverse learning goals.

The tools listed above are summarized below:

Intelligent Tutoring Systems (ITS):

- Enhance understanding and retention
- Increase student engagement and motivation
- Adapt to individual learning needs (Ilić et al., 2024)
- Provides adaptive learning and personalized guidance (Nagaraj et al., 2023)
- Enhances academic performance through individualized support (Xu and Ouyang, 2022)

Large Language models:

- Improve student engagement
- Provide real-time feedback
- Personalize learning materials
- Optimize content difficulty (Chen et al., 2024)
- Natural Language Processing tools: Applied for creative writing and literary analysis in STEAM education (Kouvara et al., "Expanding the 'A' in STEAM")

AI-Powered **Educational Robots:**

- Develop computational thinking
- Enhance problem-solving skills (Al-Zahrani et al., 2024)
- Humanoid robots (NAO robot, SAYA type Android): Used for teaching geography, programming, and science concepts (Mertzani and Drigas, 2023)
- Arduino, Raspberry Pi, Circuit Playground: Employed for hands-on workshops and practical AI concept teaching

AI-powered **Virtual Reality (VR) and Augmented Reality (AR):**

- Enhance spatial thinking
- Improve teaching quality (Zhao, 2024)

Machine Learning Algorithms:

- Personalize learning experiences
- Optimize educational outcomes (Kim, 2024)

Natural Language Processing (NLP):

- Enhance personalized learning experiences
- Provide immediate feedback
- Reduce grading workload (Mredula et al., 2024)

Specialized AI Systems:

- RASEDS (Real-time Automated STEM Engagement Detection System): Measures student engagement in STEM activities (Yu and Yang, 2024)
- Virtual and Augmented Reality technologies: Enhances spatial understanding in STEM subjects (Huanhuan, 2024)
- AI-based gamification techniques: Optimize teaching tasks and enhance student learning (Martín-Núñez et al., 2023)

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AI-powered **Eye-Tracking Technology:**

- Analyze student behavior and understanding
- Measure cognitive load (Chiu, 2021)

AI-powered Assessment Tools:

- Streamline assessment processes
- Provide timely feedback (Iyamuremye et al., 2024)
- Data Mining and Learning Analytics: Applied for student behavior detection and performance prediction (Xu and Ouyang, 2022)

Prompt Engineering Tools:

- Simplify complex topics
- Provide interactive practice (Li, 2024)

AI-facilitated Student/Tutor Matching:

- Enhance individualized support
- Improve learning outcomes (Zhao, 2024b)

Table 1: AI Technologies and Implementation in Class

AI Tool and Technology	**Implementation Model**	**Learning Context**	**Educational Objectives**
AI-powered Virtual Reality (VR) and Augmented Reality (AR)	Immersive learning experiences	Chemistry	Enhance spatial thinking and teaching quality
Prompt Engineering Tools	Customized content generation	K-12 STEM education	Simplify complex topics, provide interactive practice
Natural Language Processing (NLP)	Content analysis, language-based learning	Computer Science	Enhance personalized learning experiences
Machine Learning Algorithms	Adaptive learning, performance prediction	Various STEM subjects	Personalize learning experiences, optimize educational outcomes
Large Language Models	Content generation, virtual tutoring	Various STEM subjects	Improve student engagement, provide real-time feedback
Intelligent Tutoring Systems (ITS)	Personalized learning	Computer Science, Mathematics, Science	Enhance understanding and retention, increase student engagement and motivation
AI-powered Eye-Tracking Technology	Cognitive load measurement	Chemical Education	Analyze student behavior and understanding
Educational Robots	Interactive learning	STEAM education	Develop computational thinking, enhance problem-solving skills

AI-powered Assessment Tools	Automated grading, feedback generation	Chemistry	Streamline assessment processes, provide timely feedback
AI-facilitated Student/Tutor Matching	Personalized tutoring	Secondary school science	Enhance individualized support and learning outcomes

3.2.2 AI Tools and platforms to guide AI integration

The studies list manifold tools that can be used for AI integration depending on the particular objective:

1. Large Language Models, Chatbots, 3D-Design and others:
    - ChatGPT
    - Google Bard
    - Bing Chat
    - Claude 3.5
    - GPT-2
    - LLaMA2-7B
    - Blender 9B
    - RoBERTa-Longformer
2. Code Generation and Programming Tools:
    - ChatGPT
    - Github Copilot
    - The Coding Steps web app
    - Microsoft 365 Copilot
3. Educational Robots:
    - NAO Robot
    - SAYA Type Android Robot
    - Educational Robots (general)
4. Hardware Platforms:
    - Arduino
    - Snap Circuits
    - Raspberry Pi
    - Circuit Playground "Interactive Methodology to Teach Artificial Intelligence"
5. Intelligent Tutoring Systems:
    - AutoTutor
    - Cognitive Tutor
    - Conceptual Helper
    - CPP-Tutor
    - ViPS
    - CIRCSIM-Tutor
6. ChiQat-Tutor Analysis and Assessment Tools:
    - Open Broadcaster Software (OBS)
    - Otter.ai
    - Multi-task Cascaded Convolutional Networks (MTCNNs)
    - HSEmotion
    - BERT
7. Specialized Educational Platforms:
    - ChatGPT-based Intelligent Learning Aid (CILA)
    - Amoeba
    - ITAP

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- DEEP STEALTH
- Tooee
- APAMP
- AIF

8. Virtual and Augmented Reality:
   - VR/AR technologies for chemistry education
   - Virtual laboratories

The tools were often used in combination to achieve multiple learning objectives (Chen et al., 2024). Their effectiveness varied depending on the educational context, student level, and implementation approach (Xu and Fan, 2022).

3.2.3 Learning objectives regarding students' AI competencies in STEM

Based on the review data students should cultivate a range of AI-related competencies in STEM classes to prepare for the increasingly AI-integrated future of STEM careers. These competencies are categorised into four primary domains: These are **Technical Competencies**, **Critical Thinking** and **Problem-Solving**, **Ethical and Responsible Use**, and **Collaborative and Communication Skills**, along with **Adaptive Learning Skills**.

Within the domain of **Technical Competencies**, emphasis is placed on cultivating computational thinking skills (Liu et al., 2024), an understanding of the fundamentals of AI and pattern recognition (Al-Zahrani et al., 2024a), and proficiency in programming and coding abilities (Mertzani & Drigas, 2023). Furthermore, data literacy and analytical skills are essential, enabling students to interpret and analyse data effectively (Zhao, 2024a).

The development of **critical thinking and problem-solving skills** is of equal importance. Students should be equipped to evaluate AI-generated content critically (Chen et al., 2024) and utilise AI tools effectively to solve complex problems (Al-Zahrani et al., 2024b). Additionally, students should cultivate robust critical analysis and decision-making capabilities (Kim, 2024) and refine their research skills through the utilisation of AI-powered tools (Tsagareishvili, 2024).

It is imperative for students to comprehend the **ethics and implications of AI** (Interactive Methodology to Teach Artificial Intelligence), as well as the responsible utilisation of AI tools (Li, 2024). Furthermore, it is crucial for students to be cognizant of the limitations and potential biases inherent in AI systems (Chen et al., 2024), thereby ensuring the utilization of AI in a fair and ethical manner.

In terms of **Collaborative and Communication Skills**, students should develop the ability to work with AI in team settings (Cohn et al., 2024b), communicate effectively in AI-enhanced environments (Malinova, 2024), and collaborate using AI-facilitated platforms (Okoye and Mante, 2024). These competencies are imperative for nurturing teamwork and effective communication within an educational environment that is increasingly driven by technology.

Finally, it is imperative to acknowledge the role of **Adaptive Learning Skills** in facilitating student success within the context of AI-enhanced STEM education. Students should be able to engage in self-directed learning using AI tools (Xu and Fan, 2022) and leverage AI for personalised learning (Ilić et al., 2024a). Additionally, students must develop skills in using AI for knowledge synthesis and application (Zhang et al., 2024), enabling them to integrate and apply information effectively.

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These competencies should be developed through practical engagement with AI tools, rather than relying solely on theoretical knowledge (Henze et al., 2022). The focus should be on equipping students with hands-on experience to prepare them for future STEM careers, where AI integration will play an increasingly crucial role (Zhao, 2024a).

3.2.4 Challenges of AI integration in STEM

Integrating Artificial Intelligence (AI) into STEM education poses several significant challenges (Table X). One of the main concerns is technical infrastructure, as many educational institutions face a lack of adequate hardware and internet connectivity, which hinders the effective implementation of AI tools. In addition, teacher training remains a critical issue, with many educators lacking sufficient AI skills, which hinders their ability to effectively integrate AI technologies into their teaching practices.

Ethical concerns also arise in the context of AI adoption, particularly issues related to data privacy, bias and transparency in AI systems. These challenges highlight the need for ethical guidelines to ensure that AI tools are used responsibly and fairly in educational settings. Similarly, curriculum integration is a challenge, as educators often struggle to align AI tools with existing curricula. This misalignment makes it difficult to integrate AI in a seamless and pedagogically meaningful way.

In addition, student readiness is a critical factor, as there are varying levels of technological literacy among students, which may affect how they engage with AI-enhanced learning experiences. The quality of AI-generated content also raises concerns, particularly the potential for inaccuracies or biases in AI-generated materials, which could undermine the quality of the educational experience if not properly addressed.

Another challenge is over-reliance on AI, as there is a risk that over-reliance on AI tools could diminish students' critical thinking skills and reduce their ability to solve problems independently. In terms of assessment challenges, educators face difficulties in assessing AI-assisted work, as traditional assessment methods may not adequately capture the contributions of AI tools. In addition, accessibility issues are a major concern, as the use of AI technologies can potentially exclude students with disabilities if the tools are not designed to be inclusive.

Finally, the rapid pace of technological change in AI presents an ongoing challenge for educators and institutions trying to keep up with evolving technologies. Continuous adaptation is required to ensure that STEM education remains relevant to the latest advances in AI. These challenges highlight the need for comprehensive strategies to support the successful integration of AI into STEM education, ensuring that it is equitable, effective and ethically responsible.

Table 2: Challenges and possible solutions for the utilization of AI in STEM education

Challenge	**Description**	**Proposed Solution**	**Implications for STEM Teaching**
Technical Infrastructure	Lack of adequate hardware and internet connectivity	Investment in IT infrastructure, cloud-based solutions	Ensure equitable access to AI-enhanced STEM education
Teacher Training	Insufficient AI literacy among educators	Comprehensive professional development	Empower teachers to effectively integrate AI in STEM instruction

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		programs, ongoing support	
Ethical Concerns	Issues of data privacy, bias, and transparency	Develop ethical guidelines, ensure transparent AI decision-making	Foster responsible and trustworthy use of AI in STEM education
Curriculum Integration	Difficulty in aligning AI tools with existing curricula	Collaborative curriculum design, flexible AI integration frameworks	Create seamless integration of AI within STEM subjects
Student Readiness	Varying levels of technological proficiency among students	Introductory AI courses, scaffolded learning experiences	Ensure all students can benefit from AI-enhanced STEM learning
Quality of AI-generated Content	Potential inaccuracies or biases in AI-produced materials	Human oversight, continuous improvement of AI models	Maintain high standards of educational content in STEM subjects
Overreliance on AI	Risk of diminishing critical thinking skills	Balance AI use with traditional methods, emphasize AI as a tool	Preserve essential human skills while leveraging AI benefits
Assessment Challenges	Difficulty in evaluating AI-assisted work	Develop AI-aware assessment strategies, focus on process over product	Ensure fair and meaningful evaluation in AI-enhanced STEM education
Accessibility Issues	Potential exclusion of students with disabilities	Develop inclusive AI tools, provide alternative learning paths	Make AI-enhanced STEM education accessible to all learners
Rapid Technological Change	Keeping pace with evolving AI technologies	Establish flexible adoption frameworks, ongoing research partnerships	Ensure STEM education remains current with technological advancements

3.2.5 Possible solutions for the challenges posed by AI in STEM education

The challenges of integrating AI into STEM education can be addressed through a variety of solutions aimed at improving the infrastructure, training and pedagogical practices around AI. One of the key solutions to the technical infrastructure challenge is investment in IT infrastructure and the use of cloud-based solutions, which can ensure that institutions have the necessary hardware and internet connectivity to effectively support AI technologies. In response to the teacher training challenge, comprehensive professional development programmes and ongoing support for educators are essential. These initiatives can help build AI literacy and ensure that teachers are equipped to integrate AI tools into their teaching practices.

To address ethical concerns, it is important to develop ethical guidelines for the use of AI in education and to ensure transparent AI decision-making processes. In terms of curriculum integration, collaborative curriculum design and flexible AI integration frameworks offer potential solutions. These frameworks can help educators align AI tools with existing curricula, facilitating a smoother integration of AI into the educational process.

Introductory AI courses and scaffolded learning experiences are critical to student readiness. These initiatives can help students with varying levels of technological literacy build the skills necessary to engage in AI-enhanced STEM learning. Ensuring the quality of AI-generated content will require solutions such as human oversight and continuous improvement of AI models. These measures will help mitigate inaccuracies or biases in AI-generated materials, thereby maintaining the quality of educational content.

To address the challenge of over-reliance on AI, a balanced approach is recommended. Educators should aim to balance the use of AI with traditional teaching methods, emphasising AI as a tool rather than a replacement for human cognitive engagement. In terms of assessment challenges, developing AI-aware assessment strategies that focus on the process rather than the product is an important solution. This approach ensures that AI-assisted work is assessed fairly and that students' contributions, as well as the role of the AI, are appropriately recognised.

To address accessibility issues, it is essential to develop inclusive AI tools and provide alternative learning pathways that meet the diverse needs of all learners, including students with disabilities. Finally, rapid technological change can be managed by establishing flexible adoption frameworks and ongoing research partnerships to ensure that STEM education evolves with technological advances and remains relevant in the face of new AI developments.

4. Discussion

The discussion is organized as follows. Firstly, the curricula of the countries are compared with each other under the five key questions. The second step specifies which core concepts are guiding for AI and how these are integrated into the curricula presented. In the third step, the results of the curriculum analysis are related to research findings on AI. Finally, conclusions for the integration of AI in secondary school curricula in Europe are derived from this.

4.1 Artificial Intelligence in German, Greek, Italien and Polish School Curricula

4.1.1 Integration of AI into Curricula

Across the examined countries the integration of Artificial Intelligence (AI) into curricula exhibits significant diversity in terms of depth, structure, and educational philosophy.

In Germany, AI is embedded systematically and cross-disciplinarily, particularly within STEM subjects, as part of the broader mandate to foster digital literacy (KMK, 2024; SWK, 2024). AI is introduced cautiously at earlier stages and becomes more prominent in secondary education,

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particularly through problem-based and inquiry-based learning scenarios. Textbook integration is pending.

In Greece, AI is explicitly included within the Computer Science curriculum at both middle and high school levels, partly supported by skill-based interdisciplinary labs (Skill Labs) that apply STEM methodologies (IEP, 2024). However, full-scale textbook integration is still pending.

In Italy, AI topics are integrated predominantly through Civic Education and interdisciplinary projects. Formal AI education exists mainly in certain specialized high school tracks and pilot programs (e.g., LUCY Syllabus; Friuli Venezia Giulia regional network).

In Poland, while AI is not yet formally anchored as a curricular component, it is increasingly present through the broader promotion of digital competencies, national strategic documents, and grassroots extracurricular initiatives (Polish Ministry of Education, 2023; 2024).

Thus, AI education across Europe is characterized by either structured integration within STEM and digital literacy curricula (Germany, Greece) or broader civic and digital competence frameworks (Italy, Poland).

4.1.2 Learning Objectives and Outcomes

Common across all countries are learning objectives focused on four main aspects:

- **Digital Literacy and Media Competence**: Students must understand and apply digital and AI tools responsibly (KMK, 2017; IEP, 2024).
- **Critical Thinking and Ethical Reflection**: Students are taught to critically evaluate AI outputs, assess risks (bias, misinformation), and reflect on ethical implications (SWK, 2024; Experience AI Initiative, 2024).
- **Problem-Solving and Creativity**: Emphasis on problem-solving through AI-supported tasks, developing innovative thinking (IEP, 2024; Friuli Venezia Giulia, 2024).
- **Autonomy and Adaptability**: Promoting self-regulated learning and adaptability to technological changes (KMK, 2024; Polish Digital Transformation Policy, 2024).

There are national variations: Germany emphasizes structured autonomy in research contexts; Greece focuses more on hands-on exploration with educational AI environments; Italy and Poland prioritize critical civic understanding of AI's societal role.

4.1.3 Methodologies for Introducing AI

Across the examined countries, the integration of Artificial Intelligence (AI) into educational settings is characterized by progressive and exploratory pedagogical approaches. In Germany, the implementation follows a phased and research-informed trajectory, whereby initial pilot projects are systematically evaluated to inform broader adoption. This process is closely linked to extensive teacher professional development initiatives, underscoring the importance of educator qualification for sustainable integration (Kultusministerkonferenz [KMK], 2024). In Greece, a more practice-oriented strategy is evident, with scenario-based learning, interdisciplinary project work, and the establishment of STEM-aligned Skill Labs serving as core components. These interventions are frequently structured according to the 5E instructional model, thereby fostering inquiry and conceptual change (Institute of Educational

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Policy [IEP], 2024). Italy pursues a Project-Based Learning (PBL) approach that emphasizes interdisciplinary exploration while simultaneously engaging learners in societal discourse regarding the implications of AI. This is exemplified in the LUCY syllabus, which integrates ethical and civic perspectives into STEM education (LUCY Syllabus, 2022). Poland, in contrast, exhibits a more emergent and experimental pattern of AI integration. Here, both teachers and students act as key agents of innovation, with their initiatives being supported by evolving national policy frameworks (Polish Council of Ministers, 2023; 2024). Collectively, these examples illustrate a broader European tendency to embed AI education within project-oriented, inquiry-based, and reflective pedagogical models, aiming to foster both technological literacy and critical engagement among learners.

4.1.4 Basic Skills and Competences Developed

Students across the examined educational contexts are expected to develop a comprehensive set of competencies that reflect both the technological and societal dimensions of Artificial Intelligence (AI). Central among these are digital literacy, critical reflection on AI and its ethical implications, as well as collaboration and communication skills. Additionally, curricula emphasize problem-solving abilities and algorithmic thinking, fostering students' capacity to engage analytically with complex, technology-mediated challenges. Creativity and innovation are further promoted as essential competencies for navigating and shaping a rapidly evolving digital landscape.

While these competencies are shared across national contexts, their pedagogical anchoring varies. In Germany and Greece, the development of these skills is systematically aligned with the advancement of STEM education. Here, the integration of AI serves not only to enhance subject-specific knowledge, but also to support interdisciplinary learning processes that prepare students for future-oriented scientific and technological fields. In contrast, Italy and Poland emphasize a more civically oriented framework, in which the promotion of digital citizenship and ethical responsibility plays a central role. In these countries, AI education is closely tied to broader societal discourses, encouraging students to critically evaluate the social, cultural, and political dimensions of technological innovation. This divergence highlights the multifaceted role of AI education in supporting both individual competency development and collective democratic engagement.

4.1.5 AI and STEM integration

A strong convergence between Artificial Intelligence (AI) and STEM education is evident across the analyzed national contexts, reflecting a broader pedagogical trend to integrate AI as a means of enriching subject-specific learning and fostering cross-disciplinary competencies. In Germany, AI is systematically embedded within the core STEM disciplines—Mathematics, Biology, Chemistry, and Physics—primarily through the use of modeling, simulation, and inquiry-based learning approaches. These methods serve not only to deepen conceptual understanding but also to promote the application of AI tools for scientific reasoning and problem-solving (KMK, 2024).

In Greece, the integration of AI is closely aligned with the development of robotics and computational thinking, particularly within the framework of STEM-oriented Skill Labs. These labs function as experimental learning environments in which students engage with AI concepts in practical, hands-on contexts, thereby reinforcing their algorithmic thinking and engineering skills (IEP, 2024). Similarly, Italy promotes AI-related competencies through interdisciplinary STEM projects that often involve robotics, data simulations, and the exploration of complex real-world problems. These project-based formats encourage creative experimentation and facilitate the transfer of AI knowledge across disciplinary boundaries (LUCY Syllabus, 2022).

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In Poland, the convergence of AI and STEM is still in a formative stage, with most initiatives occurring in the context of extracurricular programs. Robotics competitions, coding clubs, and student-led programming activities provide informal opportunities to engage with AI concepts, though these are not yet systematically integrated into the formal curriculum (Polish Council of Ministers, 2023; 2024). Despite differing levels of institutionalization, all four countries illustrate a growing recognition of AI as a catalyst for innovation in STEM education.

4.2 The integration of core concepts of AI into curricula

The following section critically analyses the extent to which the integrated AI competences address core concepts of AI. In contemporary AI education research (Touretzky et al., 2019; Long & Magerko, 2020; European Commission, 2021), the following core AI principles are generally identified:

1. Representation and Reasoning: Understanding how knowledge can be represented and manipulated (e.g., search trees, symbolic reasoning).
2. Learning and Adaptation: Understanding machine learning (ML) principles, including supervised learning, unsupervised learning, and reinforcement learning.
3. Perception: Processing inputs such as visual, auditory, or textual data (e.g., image recognition, natural language processing).
4. Interaction: How AI systems interact with humans or environments (e.g., chatbots, robotics).
5. Ethics and Societal Impact: Awareness of bias, privacy concerns, fairness, and broader societal effects.
6. Autonomy and Decision-Making: Understanding autonomous agents and decision-making processes under uncertainty.

A comprehensive AI education should, therefore, address these technical and ethical dimensions across developmental stages.

4.2.1 Germany: Competence-Oriented but Limited Specificity on AI Core Concepts

The German curriculum covers mainly **Ethics and Societal Impact of AI**. There is a strong focus across all age groups (from primary school onward) as part of digital literacy (KMK, 2017; SWK, 2024). **Learning and Adaptation** is introduced implicitly at upper secondary level via discussions around LLMs and AI-supported modeling, but without deep technical formalism. All the other core concepts ((1) **Representation and Reasoning, (3) Perception, (4) Interaction, and (6) Autonomy)** are not (!) addressed in a structured or conceptual way.

On the secondary level AI is conceptualized as a part of general digital literacy and critical reflection. At the upper secondary level (in grammar school) AI is introduced in teaching scientific inquiry, problem-solving (e.g., modeling phenomena in STEM). The employment is application-focused, not principle-focused.

In Germany AI usage is thoughtfully embedded into the curriculum but avoids conceptual AI literacy (e.g., ML structures, perception pipelines), prioritizing critical use and ethics over understanding AI's internal mechanisms. This risks producing "competent users" but not "competent understanders" of AI.

4.2.2 Greece: Stronger Focus on AI Core Concepts in Middle and High School

The Greek curriculum encompasses all core areas, albeit with varying degrees of depth and emphasis. **Representation and Reasoning** is explicitly introduced in middle school via symbolic AI concepts (problem-solving, rule-based systems).
Learning and Adaptation is introduced progressively, starting with basic machine learning concepts (training datasets, classification tasks) at the age of 13–14 years.
Perception is included through examples like image and speech recognition (middle school projects). **Interaction** is practiced through exploration of chatbots and recommendation systems. **Ethics and Societal Impact** is emphasized from early middle school, deeply tied to curricular discussions. **Autonomy and Decision-Making** is introduced in relation to intelligent agents and reinforcement learning basics (middle to high school).

Greece offers a comparatively comprehensive and early conceptual introduction to core AI principles, albeit mostly through surface-level exploration rather than mathematical formalization. The emphasis on ethical considerations alongside technical exploration is commendable and age-appropriate.

4.2.3 Italy: Ethical and Societal Focus, Little Technical Depth

Like Germany, Italy only incorporates a fraction of AI's core principles. **Ethics and Societal Impact** are strongly emphasized throughout Civic Education at both middle and high school levels (Ministero dell'Istruzione, 2019; 2024). All other concepts (**Representation and Reasoning, Learning and Adaptation, Perception, Interaction, Autonomy**) are largely absent or covered only tangentially through project-based initiatives.

In Italy lower secondary (11–14 years) students learn to identify AI systems and reflect on their societal use (LUCY syllabus). Upper secondary students (15–18 years) engage in debates about algorithmic bias, AI impacts on labor markets, privacy risks, but rarely code or model AI systems.

Italy positions AI mainly as a civic literacy topic rather than a technical competency. While the strong ethical focus is valuable, the lack of engagement with core computational concepts risks leaving students unprepared to actively create or modify AI systems.

4.2.4 Poland: Emerging Awareness, Weak Conceptual Embedding

As in Italy and Germany Poland covers mainly **Ethics and Societal Impact** of AI which is increasingly highlighted through national strategies (Digital Competence Development Programme, 2023).
The concepts **Learning and Adaptation, Representation and Reasoning, Perception, Interaction, and Autonomy** are not systematically introduced at present.

In primary and secondary level the computer science classes focus on algorithmic thinking, data management, and problem-solving, which are preparatory skills for later AI understanding. AI-specific concepts (e.g., ML, neural networks) are only experimentally explored in extracurricular contexts.

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Poland is laying the groundwork through strong digital literacy initiatives, but AI education remains fragmented and unsystematic. Without structured exposure to AI principles in the formal curriculum, students may develop user competence but miss conceptual AI literacy necessary for future innovation.

Table 3: Summary of AI core concepts in partner countries

Core Concept	Germany	Greece	Italy	Poland
Representation & Reasoning	not explicit	middle school	not explicit	not explicit
Learning & Adaptation	light touch	middle to high school	not explicit	experimental only
Perception	implicit use	middle school	not explicit	not explicit
Interaction	General	middle school	not explicit	not explicit
Ethics and Societal Impact	Cross-age	from middle school	strong civic focus	strategy documents
Autonomy and Decision-Making	light touch	Middle to high school	not explicit	not explicit

Only Greece systematically introduces students to core AI technical concepts alongside ethics, starting at an early age. Germany emphasizes competent AI usage and critical reflection but avoids technical conceptualization, limiting deeper technological understanding. Italy prioritizes ethical and societal reflection, treating AI more as a civic topic than a computational phenomenon. Poland is at an early stage, with digital literacy frameworks that could support future structured AI education but currently lack conceptual rigor.

4.3 Potentials of AI for innovating teaching practices on a general level

Particularly, scientific papers place high expectations on AI with regard to innovations in teaching and learning. These expectations can be roughly categorized into 10 different topics.

1. Enhanced Personalization: AI enables tailored learning experiences and adaptive content delivery
2. Improved Engagement: AI-powered tools increase student motivation and participation
3. Skill Development: AI facilitates the development of critical thinking and problem-solving skills
4. Real-time Feedback: AI enables immediate assessment and feedback
5. Collaborative Learning: AI tools enhance group work and peer learning
6. Visualization of Complex Concepts: AI-powered simulations and VR/AR improve concept understanding
7. Teacher Support: AI assists in administrative tasks and lesson planning
8. Accessibility and Inclusion: AI tools support diverse learners and learning styles
9. Data-Driven Insights: AI analytics provide deeper understanding of learning processes

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10. Interdisciplinary Learning: AI facilitates connections between different STEM disciplines

These potentials can only be found to a limited extent in the curricular papers.

4.4 AI's potential for innovation, especially in STEM education

The integration of AI in STEM education has given rise to a plethora of innovative teaching methodologies, each of which offers significant potential for enhancing the learning experience. A particularly salient innovation is **AI-enhanced inquiry-based learning**, which supports scientific exploration and hypothesis testing. This approach has been shown to enhance the development of scientific inquiry skills and foster a more profound comprehension of STEM concepts. By leveraging AI tools, educators can facilitate more authentic scientific practices in the classroom, offering students the opportunity to engage in real-world scientific investigations. Supporting evidence indicates that AI-driven inquiry-based learning promotes higher-order thinking and strengthens students' ability to formulate and test hypotheses in dynamic environments.

Another significant development in the field of AI-driven education is the **creation of adaptive learning pathways**. The utilization of AI algorithms enables the personalization of learning sequences, with the delivery of content being tailored to the individual needs of each student, thereby enhancing learning outcomes. This personalized approach ensures that each student can progress at their own pace, leading to more efficient and effective instruction. Evidence suggests that adaptive learning pathways have led to improved academic performance, particularly in students who may struggle with one-size-fits-all approaches.

In the domain of immersive learning, the integration of virtual and augmented reality (VR/AR) has garnered significant attention. **AI-powered VR/AR experiences offer immersive environments** for the visualization of complex STEM concepts, which has been shown to improve spatial understanding and student engagement. These technologies have been found to be particularly effective in subjects such as chemistry, where three-dimensional visualizations of abstract concepts can enhance their perceived tangibility and interactivity. The potential of VR/AR to facilitate the comprehension of complex STEM ideas underscores the transformative impact of AI in education.

Furthermore, **AI-assisted project-based learning** has been demonstrated to be an invaluable tool for supporting collaboration and project management. AI tools assist students in navigating complex projects by providing organizational support and facilitating collaboration. This approach has been shown to enhance problem-solving and teamwork skills, which are crucial competencies for students as they prepare for real-world STEM careers. Evidence suggests that AI-assisted projects foster a deeper level of engagement and help students apply theoretical knowledge to practical challenges, thereby bridging the gap between classroom learning and professional environments.

Intelligent tutoring systems (ITS) represent a significant advancement in the field of AI education. These systems offer personalized guidance and feedback, which has been shown to improve learning outcomes, particularly for students experiencing difficulties. By offering individualized support on a large scale, ITS can address the diverse needs of students and help them overcome barriers to learning. The potential for ITS to deliver tailored instruction underscores the significance of personalized education in promoting student success.

Recent developments in the field of education have seen the emergence of **gamification and AI as powerful tools** for enhancing student motivation and engagement. The integration of AI-

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driven adaptive challenges and rewards within educational games has been demonstrated to enhance student interest and motivation, particularly in STEM subjects. Empirical evidence suggests that the incorporation of gamification into the learning process can render STEM education more enjoyable and accessible, particularly for students who may not traditionally excel in more conventional academic settings. This innovation leverages the motivational power of gaming to create a more engaging learning environment.

The advent of **real-time learning analytics** powered by AI has introduced a new dimension to formative assessment. AI dashboards furnish educators with immediate insights into student performance, thereby enabling timely and targeted interventions. This data-driven approach enables educators to employ responsive teaching practices, whereby instruction can be adapted based on real-time feedback. The capacity to monitor student progress and adapt teaching methods accordingly ensures that learning remains personalised and adaptive.

Another innovation is the use of **collaborative AI tools**, which facilitate peer learning and group problem-solving. These tools enhance collaborative skills and knowledge sharing among students, fostering teamwork and communication skills that are essential in STEM fields. Supporting evidence suggests that AI can create an environment where students collaborate more effectively, leading to a more enriching learning experience.

Furthermore, AI has been found to play a role in the realm of **AI-enhanced assessment**, where automated grading and feedback systems are utilised to provide more frequent and detailed feedback (Jones et al., 2023). These systems have been shown to reduce teachers' workloads while improving the quality and frequency of assessment, particularly in STEM education. By automating routine grading tasks, AI enables educators to focus more on instruction and personalised student support, ultimately enhancing the overall learning experience.

Finally, **cross-disciplinary AI integration** is emerging as a valuable tool for connecting various STEM subjects. The utilisation of AI tools that facilitate interdisciplinary connections between science, technology, engineering, and mathematics (STEM) subjects has been demonstrated to enhance comprehension of the interdisciplinary relationships that underpin these fields. Empirical evidence indicates that this approach enhances students' appreciation for the holistic nature of STEM education, thereby fostering more integrated and comprehensive learning experiences.

5. Conclusion

The integration of artificial intelligence (AI) into STEM education offers profound opportunities to enhance learning, foster critical thinking, and prepare students for the complexities of a digital and data-driven society. The combined review of European curricula (Germany, Greece, Italy, and Poland) and current research literature (2022–2025) reveals both promising practices and significant gaps. To harness AI's educational potential while safeguarding pedagogical integrity and inclusivity, the following recommendations are proposed:

1. Embed AI within Authentic STEM Learning Contexts
AI should not be taught as an isolated topic but integrated into authentic STEM scenarios that emphasize real-world applications. This includes using AI for scientific modelling,data

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analysis, and simulation (e.g., AI-supported physics labs, ecological system models), embedding AI in mathematical problem-solving via tools like intelligent tutoring systems (ITS) and adaptive learning environments and applying ML models in coding tasks or engineering design challenges where students develop, test, and refine solutions.

2. Align AI Activities with Age-Appropriate Competency Frameworks
Curriculum analyses (e.g., Greece, Germany) show implementations when AI is introduced progressively across age groups. Scientific literature further supports scaffolding from conceptual understanding to technical engagement.

Early secondary students should develop AI awareness, focusing on recognizing AI in everyday life and understanding basic operations. Later stages can involve hands-on AI programming, training simple ML models, and evaluating AI outputs.

3. Prioritize Ethical and Reflective AI Literacy
AI literacy must go beyond functionality to include ethical reasoning, critical analysis, and responsible usage. This is a consistent priority in all reviewed curricula (especially Germany and Greece) and heavily emphasized in literature. This includes modules on bias in AI systems, privacy, and the social impact of algorithmic decisions and discussions and debates on real-world AI applications (e.g., facial recognition, recommendation systems).

4. Leverage a Diverse Ecosystem of AI Tools
Both curriculum and research evidence confirm that combining AI tools enhances engagement and learning outcomes. To integrate AI in class a mix of generative AI (ChatGPT, DALL·E), machine learning platforms (Machine Learning for Kids, TensorFlow), robotics (Arduino, NAO), and simulations (VR/AR) could be used. The tools should be open-source, GDPR-compliant, and accessible to learners with diverse needs.

5. Foster Key Competencies through AI-Enriched STEM
Students should acquire a blend of technical and transversal competencies like computational thinking, data literacy, and basic AI design skills, collaborative problem-solving, critical thinking, and creativity, cigital autonomy and adaptive learning abilities. These mirror both UNESCO's GenAI recommendations and the outcomes in leading studies.

6. Build Professional Capacity and Collaborative Development
Effective AI integration depends on empowered educators. Research and curricular insights both underscore the need for ongoing teacher training on AI pedagogy, tools, and ethics, co-design processes involving teachers, learners, and researchers, pilot implementations with feedback loops for refinement

7. Design Inclusive and Adaptable Learning Scenarios
AI should be leveraged to foster inclusion, not deepen digital divides. This includes differentiating learning paths using adaptive AI tutors, supporting diverse learners through multimodal AI tools (e.g., speech-to-text, translation systems), ensuring scenarios are culturally relevant, gender-sensitive, and accessible to learners with disabilities

8. Integrate AI within a Constructivist Pedagogical Framework
Research shows AI is most effective when aligned with constructivist, inquiry-based learning. To implement AI Socratic questioning, project-based tasks, and experiential labs should be used and student agency, reflection, and co-construction of knowledge should be emphasized. The 5E model could be used as a guideline for implementation (Engage, Explore, Explain, Elaborate, Evaluate) or similar constructivist approaches.

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AI holds the potential to enrich STEM education by making it more engaging, personalized, and relevant to the 21st-century learner. However, to move from aspiration to implementation, we must shift from tool-centered to pedagogy-centered integration, grounded in sound curriculum design, ethical foresight, and inclusive practice. The guidelines above provide a foundation for developing AI teaching scenarios that are didactically robust, ethically sound, and developmentally appropriate.

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Part A: Curricula

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In Italy, there are no official ministerial guidelines or curricula for AI education. Instead, the Ministry of Education refers to key documents published by UNESCO and the European Community as primary references.

1. Main publications of UNESCO on AI in Education

AI competency framework for students 2024
https://unesdoc.unesco.org/ark:/48223/pf0000391105

AI competency framework for teachers 2024
https://unesdoc.unesco.org/ark:/48223/pf0000391104

Guidance for generative AI in education and research (Arabic, English, French, Greek, Malay, Portuguese, Russian, Spanish, Turkish) 2023
https://unesdoc.unesco.org/ark:/48223/pf0000386693

AI and education: guidance for policy-makers (Arabic, Chinese, English, French, Korean, Spanish, Russian) 2021
https://unesdoc.unesco.org/ark:/48223/pf0000376709

K-12 AI curricula: a mapping of government-endorsed AI curricula (Arabic, Chinese, English, French, Portuguese, Spanish, Russian) 2022
https://unesdoc.unesco.org/ark:/48223/pf0000380602

Beijing Consensus on AI and Education (Arabic, Chinese, English, French, Spanish, Russian) 2019
https://unesdoc.unesco.org/ark:/48223/pf0000368303

AI in the UAE's computing, creative design and innovation K-12 curriculum: a case study (Arabic, English) 2024
https://unesdoc.unesco.org/ark:/48223/pf0000388652

AI and inclusion: compendium of promising initiatives 2020
https://unesdoc.unesco.org/ark:/48223/pf0000374644

AI in Education: compendium of Promising Initiatives 2019
https://unesdoc.unesco.org/ark:/48223/pf0000370307

International Conference on AI and Education (2019) Report
https://unesdoc.unesco.org/ark:/48223/pf0000370967

International Forum on AI and Education (2020) Report 2021
https://unesdoc.unesco.org/ark:/48223/pf0000377251

International Forum on AI and Education (2021) Synthesis Report 2022
https://unesdoc.unesco.org/ark:/48223/pf0000381226

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https://unesdoc.unesco.org/ark:/48223/pf0000386162

2. Documents from European Community

- DigComp 2.2 (in particular Annex 2)
https://op.europa.eu/en/publication-detail/-/publication/50c53c01-abeb-11ec-83e1-01aa75ed71a1/language-en

- AI report
by the European Digital Education Hub's Squad on artificial intelligence in education
https://op.europa.eu/en/publication-detail/-/publication/9bb60fb1-b42a-11ee-b164-01aa75ed71a1/language-en

Curricula developed by Italian Schools

- Lucy Curriculum IC Modena 3 (k-8)
https://www.ic3modena.edu.it/progetti/lucy-scuola-di-intelligenza-artificiale-per-ragazz/

- Rete di scuole FVG - Liceo Stellini Udine (k-12)
https://stelliniudine.edu.it/wp-content/uploads/sites/724/E-Book-Costruire-il-futuro-maggio-24_def-1.pdf?x19452
Activities proposal - Stellini
https://rise.articulate.com/share/bo6uaWApy_5OsbAgpOiwRlxeUircDElm#/

3. Projects/Curricula

RAISE initiative (MIT)
https://raise.mit.edu/research-projects/

DAILy Curriculum (MIT)
https://everyday-ai.org/resources/curriculum/daily-curriculum
https://everyday-ai.org/resources

Rubric for Evaluating AI Tools for Schools
https://www.controlaltachieve.com/2024/04/rubric-for-evaluating-ai-tools-for.html?utm_source=chatgpt.com

4. Papers

Unpacking the 'Black Box' of AI in Education
https://papers.ssrn.com/sol3/papers.cfm?abstract_id=3945708

5. Higher Education Policies

UniPD (Unofficial)
https://docs.google.com/document/d/1vkptIOH1sUySjVNtITE-VsFRTMQ1dpQi/edit?usp=drive_link&ouid=118419805387637300760&rtpof=true&sd=true

Vanderbuilt: https://as.vanderbilt.edu/gci-ai/syllabus-ai-policies/
MIT: https://ist.mit.edu/ai-guidance
Harvard: https://huit.harvard.edu/ai/guidelines

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NY University: https://www.nyu.edu/life/information-technology/artificial-intelligence-at-nyu.html
Georgia Tech:https://oit.gatech.edu/ai/guidance
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