



Science Curriculum Transformation in the Age of Artificial Intelligence: Integrating Scientific Literacy, Ethics, Inquiry, and Digital Competencies

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Abstract

The development of Artificial Intelligence (AI) has brought significant changes to education and requires science curricula to adapt to emerging technological developments. This article aims to examine science curriculum transformation by integrating scientific literacy, ethics, inquiry, and digital competencies. This study uses a literature review approach by analyzing relevant academic publications and educational policy documents. The results indicate that AI can support science learning by facilitating access to information, data analysis, scientific inquiry, and digital learning. However, its implementation requires students to critically evaluate AI-generated information and understand ethical issues such as privacy, bias, and academic integrity. Therefore, science curricula should position AI as a supporting tool while strengthening students' scientific reasoning, inquiry skills, ethical awareness, and digital competencies.

Keywords: artificial intelligence, science curriculum, scientific literacy, ethics, inquiry, digital competencies.

1. Introduction

Artificial Intelligence (AI) has become an increasingly influential technology in education, affecting teaching, learning, assessment, and educational management. Research on AI in education indicates that AI-based technologies can support different educational functions and create opportunities for more flexible and personalized learning. At the same time, the growing use of AI requires educators to reconsider how technology should be integrated into educational practice and how students should be prepared to interact with AI (Zawacki-Richter et al., 2019).

The potential of AI in education is also reflected in the development of adaptive learning systems. AI-enabled systems can analyze learner information and provide learning experiences that respond to individual needs. Such developments suggest that AI can contribute to more flexible learning environments, although successful implementation depends on appropriate pedagogical design rather than technology alone (Hwang et al., 2021).

Science education is particularly relevant to this transformation because scientific learning requires students to understand concepts, evaluate evidence, investigate phenomena, and apply knowledge to real-world situations. The OECD defines scientific literacy through competencies involving the explanation of phenomena, evaluation and design of scientific inquiry, and interpretation of scientific data and evidence (OECD, 2019).

The emergence of generative AI further increases the importance of scientific literacy because students can now obtain explanations and answers almost instantly. However, AI-generated information may require verification, and students need to understand that technological outputs should not automatically be regarded as scientifically valid. UNESCO therefore emphasizes the need for human-centered and age-appropriate approaches when generative AI is used in education and research (Miao & Holmes, 2023).

Inquiry-based learning provides an important pedagogical foundation for responding to these changes. Science learning should continue to engage students in asking questions, investigating problems, interpreting evidence, and constructing explanations rather than simply receiving information from technological systems. This approach is consistent with the OECD's emphasis on scientific inquiry as a core component of scientific literacy (OECD, 2019).

Ethical considerations are equally important in the transformation of science education. AI can raise concerns involving privacy, fairness, transparency, bias, accountability, and academic integrity. Recent systematic research on AI ethics in education indicates that ethical dimensions need to be considered more explicitly as AI becomes increasingly integrated into educational practices (Mouta et al., 2024).

Digital competence also needs to be strengthened because students require more than technical skills to participate effectively in AI-supported learning. They need to evaluate digital information, understand technological limitations, communicate responsibly, and make informed decisions about the use of AI. Research on AI literacy in school settings highlights the importance of developing students' understanding of AI and their agency in an increasingly AI-mediated society (Sperling et al., 2025).

Based on these developments, science curriculum transformation should not simply involve adding AI tools to existing learning activities. Instead, it should integrate scientific literacy, ethics, inquiry, and digital competencies into a coherent curriculum framework that prepares students to use AI critically while maintaining the central role of human reasoning and scientific investigation.

2. Research Method

This article employed a literature review method to examine the transformation of science curricula in the age of Artificial Intelligence. A literature review was selected because it enables the synthesis of findings from previous studies and policy documents concerning AI in education, science learning, scientific literacy, inquiry, ethics, and digital competencies.

The literature was identified from academic journal articles, systematic reviews, and official publications from international educational organizations. The selected sources included research on AI applications in education, adaptive learning, scientific literacy, generative AI, AI ethics, and AI literacy. The literature was selected based on its relevance to the four main dimensions of this article: scientific literacy, ethics, inquiry, and digital competencies.

The analysis was conducted thematically. First, relevant findings were identified from the selected literature. Second, the findings were categorized according to the four dimensions.

Third, relationships among the dimensions were examined to develop an integrated perspective on science curriculum transformation in the age of AI.

3. Results And Discussion

1. Transformation of Science Curriculum in the Age of AI

The integration of AI into education represents a shift in the educational environment rather than merely the introduction of another technological tool. A systematic review of AI applications in education found that AI has been used for several educational purposes, while also highlighting the need for stronger consideration of pedagogical and ethical dimensions (Zawacki-Richter et al., 2019).

In science education, this transformation means that curriculum objectives should increasingly emphasize students' ability to investigate, evaluate, and apply knowledge. AI can assist students in accessing information and analyzing data, but the curriculum must ensure that students remain responsible for evaluating evidence and constructing scientific explanations.

Generative AI can also be incorporated into curriculum design, teaching, learning, and research activities. UNESCO's guidance emphasizes that such integration should be guided by ethical validation, appropriate pedagogical design, data privacy, and human-centered principles (Miao & Holmes, 2023).

Therefore, science curriculum transformation should focus on the development of competencies rather than technology adoption alone. AI should be integrated when it contributes meaningfully to scientific reasoning, inquiry, collaboration, or problem-solving.

2. Integrating Scientific Literacy

Scientific literacy is a fundamental objective of science education because it enables individuals to engage with science-related issues as informed citizens. The OECD identifies three central scientific competencies: explaining phenomena scientifically, evaluating and designing scientific inquiry, and interpreting data and evidence scientifically (OECD, 2019).

In the AI era, these competencies become increasingly important because students are exposed to large amounts of automatically generated information. Students need to determine whether information is supported by evidence, identify unsupported claims, compare different explanations, and assess the credibility of sources.

AI can therefore become a context for developing scientific literacy. Teachers may ask students to examine AI-generated explanations of scientific phenomena and compare them with scientific sources or empirical evidence. Through this process, students can learn that information requires evaluation before it is accepted as knowledge.

Scientific literacy should consequently include not only knowledge of scientific concepts but also an understanding of how scientific knowledge is generated and justified. The PISA science framework emphasizes the importance of procedural and epistemic knowledge alongside content knowledge in developing scientifically literate individuals (OECD, 2019).

3. Integrating Ethics into Science Curriculum

Ethics is an essential component of AI-supported education because technological systems can influence decisions, access to information, and learning processes. A systematic review of ethics in AI education identified concerns surrounding the responsible use of AI

and emphasized the importance of ethical reflection within educational practice (Mouta et al., 2024).

In science education, ethical learning can address issues such as privacy, data protection, bias, fairness, academic integrity, and accountability. These issues can be introduced through scientific case studies in which students analyze the benefits and potential consequences of AI applications.

Recent research focusing specifically on AI ethics education also indicates that approaches such as case studies and group projects can be useful for developing students' ethical reasoning. However, stronger assessment practices are still needed to determine whether students have effectively developed AI ethics competencies (Borenstein et al., 2025).

Thus, ethics should not be treated as an additional topic separate from science learning. Instead, ethical reasoning should be integrated into scientific problem-solving and decision-making activities involving AI.

4. Inquiry-Based Learning in AI-Supported Science Education

Inquiry is central to science because scientific knowledge is developed through questions, observations, investigations, evidence, and explanations. The OECD science framework explicitly includes evaluating and designing scientific inquiry as one of the major competencies of scientific literacy (OECD, 2019).

AI can support inquiry by helping students organize information, identify possible patterns, generate alternative explanations, or analyze large amounts of data. However, students should not simply accept AI-generated interpretations. They should compare AI outputs with evidence collected through observation, experimentation, or credible scientific sources.

The use of AI-supported tools can therefore create opportunities for more interactive inquiry. For example, students can investigate an environmental problem, collect data, use digital tools to organize the information, and then use AI as one source of analytical support. The final interpretation should remain based on evidence and student reasoning.

This approach maintains the central role of inquiry while taking advantage of AI's computational capabilities. It also helps students understand that AI can assist scientific work but cannot replace the need for appropriate questions, reliable evidence, and critical judgment.

5. Strengthening Digital Competencies

Digital competencies are increasingly important because students need to interact with digital technologies in ways that are effective, critical, and responsible. The emergence of AI has expanded the meaning of digital competence from basic technology use toward understanding how AI systems influence information and decision-making.

Research on AI literacy in middle-school contexts indicates that AI literacy is being conceptualized in diverse ways and that how students understand AI can influence their agency in an increasingly AI-mediated society (Sperling et al., 2025).

In science education, digital competencies can be developed through digital data analysis, scientific databases, simulations, visualization tools, collaborative platforms, and AI-supported learning. Students should learn not only how to use these technologies but also when their use is appropriate and how their outputs should be evaluated.

Digital competency should therefore be connected to scientific literacy. A student who can operate an AI tool but cannot evaluate the accuracy of its output has limited competence for scientific learning. Effective digital competence requires both technical ability and critical judgment.

6. Integration of Scientific Literacy, Ethics, Inquiry, and Digital Competencies

Scientific literacy, ethics, inquiry, and digital competencies should be viewed as interconnected rather than separate curriculum components. Scientific literacy provides the ability to evaluate scientific claims, inquiry provides a process for generating and examining evidence, digital competence enables students to use technological tools, and ethics guides responsible decision-making.

The integration of these dimensions is particularly important because AI technologies can simultaneously provide educational opportunities and create new risks. Research reviewing AI technologies in education has emphasized both the potential educational benefits of AI and the need to address ethical and privacy concerns (Zhang & Aslan, 2021).

Component	Main Focus	Example in Science Learning
Scientific Literacy	Understanding and evaluating scientific knowledge	Checking AI-generated explanations against scientific evidence
Ethics	Responsible and fair use of AI	Discussing privacy, bias, and academic integrity
Inquiry	Investigation and evidence-based reasoning	Formulating questions, collecting data, and drawing conclusions
Digital Competencies	Effective and critical technology use	Using AI, simulations, digital databases, and data-analysis tools

An integrated approach can help students understand that technology is not an independent substitute for scientific reasoning. Instead, AI becomes one component of a broader learning process in which students remain responsible for questions, evidence, reasoning, and decisions.

7. Changing Roles of Teachers and Students

The increasing use of AI also requires changes in teachers' roles. Teachers need to move beyond simply providing information and increasingly act as facilitators who help students evaluate information, design learning activities, interpret AI outputs, and develop responsible technology practices. Research on AI in education has highlighted the importance of educators in the effective implementation of AI-supported learning (Zawacki-Richter et al., 2019).

Students also need to become more active participants in the learning process. Instead of using AI primarily to obtain immediate answers, students should use it to support questioning, exploration, comparison, analysis, and reflection.

This shift is particularly important in science because scientific learning requires students to develop explanations and conclusions based on evidence. AI should support these processes rather than remove the intellectual work required from students.

8. Challenges of Implementation

One major challenge is the possibility that students may become overly dependent on AI-generated answers. When technology provides immediate responses, students may have fewer opportunities to struggle productively with problems, formulate their own explanations, or independently evaluate evidence. This makes the design of learning activities particularly important.

Another challenge involves privacy and data protection. UNESCO's guidance emphasizes that educational institutions need to consider data privacy and develop appropriate policies for the use of generative AI in education (Miao & Holmes, 2023).

Ethical concerns also extend to fairness, transparency, bias, and accountability. Systematic research on AI ethics in primary and secondary education indicates that the rapid adoption of AI requires greater attention to its ethical implications for younger learners and educational institutions (Wieczorek et al., 2025).

Assessment represents another challenge. If students can use AI to produce answers, assessments that focus only on final products may provide limited information about students' actual learning. Science assessment should therefore pay greater attention to inquiry processes, reasoning, evidence use, explanation, and reflection.

4. Conclusion

The transformation of science curricula in the age of Artificial Intelligence requires a comprehensive approach that goes beyond the simple adoption of technological tools. Science education needs to integrate scientific literacy, ethics, inquiry, and digital competencies so that students can benefit from AI while maintaining critical scientific reasoning.

Scientific literacy enables students to evaluate information and evidence, inquiry provides opportunities to investigate scientific problems, digital competencies support effective interaction with technology, and ethics guides responsible AI use. The integration of these dimensions can create a science curriculum that responds to technological developments while maintaining the central role of human judgment.

AI should therefore be positioned as a supporting tool rather than a replacement for students' thinking and scientific inquiry. Through an integrated curriculum, students can develop the ability to evaluate AI-generated information, conduct evidence-based investigations, recognize ethical implications, and use digital technologies responsibly. Such a curriculum can better prepare students to participate in a society increasingly shaped by Artificial Intelligence.

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