



TRANSFORMATION IN SCIENCE EDUCATION: THE ROLE OF TECHNOLOGY AND EMERGING APPROACHES

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From Edison and Tesla conducting experiments under difficult conditions to virtual space travels, from Darwin's peas to the cloned sheep Dolly, a vertiginous development has been taking place. One of the most important contributions of developing technologies is the opportunity for equal access to education, as the internet and mobile devices such as phones and tablets are now available almost everywhere. This is because experiments and practices that were once carried out in physical environments and laboratories can now be presented in virtual settings.

Recent developments have made the evolution and transformation of science education and educational science inevitable. With developments such as space exploration, cell theory, the evolution of computer technology, touchscreens, virtual reality, the metaverse, augmented learning environments, and most recently artificial intelligence, science education has entered a new era (Wong, Chen, & Chang, 2020; Haji Ismail, Shahrill, & Asamoah, 2023; Thohir et al, 2023; Zhang, et al, 2024; Lamanauskas, 2025).

There is a transition from traditional teacher-centered learning environments where textbooks and blackboards are used intensively, to technology-rich teaching environments. While the integration of technology has contributed positively to educational transformation, it also presents certain disadvantages that warrant critical examination. Students have progressively distanced themselves from physical, hands-on learning experiences. Furthermore, the proliferation of digital tools and the intense flow of information have introduced challenges such as decreased attention spans, tendencies towards passive learning, and superficial engagement.

In this context, technology may hinder meaningful learning for some students, diverting their focus from core concepts to peripheral details. For instance, observing experiments through simulations without conducting them physically can lead to an uncritical acceptance of scientific laws, without a foundational understanding of the underlying principles. Moreover, the development of essential motor and practical skills may also be constrained. Tasks such as examining plant cells under a microscope, constructing an electrical circuit, or directly observing chemical reactions, pressure, evaporation, and condensation provide a fundamentally different learning experience compared to watching videos or animations on a screen.

Apparently, one of the key research topics of the new era will be hybrid and blended learning models. Digitally enriched learning supported by real science experiments, inquiry-based learning environments powered by artificial intelligence, and the conscious use of digital tools may become essential components of balanced learning.

Science education is a fundamental indicator of societal progress, as it fosters individuals' critical thinking, problem-solving, and innovative skills. The exponential growth of scientific knowledge and the resulting rapid developments in technology are challenging the boundaries of traditional science education and, making a profound transformation inevitable.

Scientific literacy the acquisition of knowledge, but also the ability to use, question, and produce new knowledge. In this context, the fundamental goal of science education should be to cultivate students as active learners and future scientific literates.



Technology plays an undoubtedly crucial role in the transformation of science education. The widespread accessibility of the internet, mobile devices, and advanced software has radically changed learning environments and materials. Virtual reality (VR) and augmented reality (AR) applications allow students to examine complex molecular structures in three dimensions, take virtual space journeys, and realistically experience historical scientific experiments (Merchant et al., 2014). Ibáñez and Delgado-Kloos (2018) presented a literature review on the use of augmented reality technology to support learning in science, technology, engineering, and mathematics (STEM). For example, in a biology class, students can explore a virtual human anatomy model, observe organ functions closely, or rotate and examine a DNA molecule interactively. These applications make abstract concepts tangible, making learning more engaging and effective.

Simulations and interactive software significantly contribute to the deep understanding of scientific concepts. They enable students to repeatedly experience complex physical movements or chemical reactions in ways not possible in real laboratories. Through this, students can develop their skills in hypothesis formulation, controlling variables, and analyzing results in a safe and controlled environment (Rutten et al., 2012). Additionally, big data analysis and AI-powered learning platforms provide personalized feedback tailored to students' learning styles and pace, helping each student reach their full potential (Roll & Wylie, 2016). AI-based systems can identify areas where students struggle and offer specialized exercises or explanations to optimize their learning processes.

In addition to advanced technology applications, contemporary pedagogical approaches are also driving the transformation of science education. Project-based learning is increasingly adopted as a methodology in science education (Kokotsaki, Menzies, & Wiggins, 2016). This approach requires students to work on long-term projects focused on real-world problems, allowing them to apply their scientific knowledge and skills (Thomas, 2000; Zhang, Ma, 2023). For example, in an environmental science project, students might investigate pollution issues in a local water source, collect data, develop solutions, and present their findings to the community. In addition to providing interdisciplinary practical experiences, such projects also encourage collaborative learning environments, contributing to the development of students' communication, problem-solving and critical thinking skills.

Inquiry-based learning should be the foundation of science education. This approach encourages students to start with curiosity-driven questions, conduct their own research, gather data, analyze information, and reach conclusions (Minner et al., 2010; Liu et al., 2021; Inel-Ekici, & Ekici, 2022; Meulenbroeks, van Rijn, & Reijerkerk, 2024; Arifin, et al., 2025). Instead of merely transmitting knowledge, teachers act as facilitators who guide students in their discovery processes. This method helps students develop scientific thinking skills, problem-solving abilities, and a sense of responsibility for their own learning.

STEM education adopts an interdisciplinary approach that allows students to relate scientific concepts to different fields and develop holistic solutions to real-world problems (Bybee, 2010a, 2010b). In STEM education, scientific knowledge merges with engineering design, technology is used as a tool, and mathematical models provide support. This integrated approach not only enables students to acquire theoretical knowledge but also equips them with the ability to apply and innovate. For instance, in a STEM project, students could design a sustainable energy source by integrating scientific principles, technological tools, engineering design processes, and mathematical calculations.

The role of teachers in this transformation is of vital importance. Teachers need to continuously increase their professional development in order to fully benefit from technology and new pedagogical approaches. They should be proficient in effectively using technological tools, adopting innovative teaching strategies, and actively involving students in scientific processes. Additionally, teachers need to develop skills in data analysis and AI-supported platforms to offer personalized learning experiences.

This transformation process also brings with it some challenges. The lack of technological infrastructure, limited professional training opportunities for teachers, curricula that do not offer sufficient flexibility, and evaluation systems that are not compatible with contemporary pedagogical approaches are among the fundamental problems that limit the effectiveness of this process. In order to overcome these problems, cooperation between governments, educational institutions and civil society organizations needs to be enhanced, investments in the necessary resources and education policies need to be restructured.

In conclusion, the transformation of science education goes beyond merely equipping classrooms with technology; it involves a comprehensive change in teaching-learning processes, pedagogical approaches, and student evaluation. Emerging methodologies like project-based learning, inquiry-based learning, and STEM education offer unique opportunities to nurture students as active, inquisitive, and skilled individuals. This transformation is essential for the development of a society consisting of highly scientifically literate and innovative individuals, and for the development of an educational system that supports social development and is compatible with rapid scientific developments. Science education continue to be a dynamic, inclusive, and continuously evolving field in shaping the future of science.

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Received: May 16, 2025

Revised: May 30, 2025

Accepted: June 15, 2025

Cite as: Usak, M. (2025). Transformation in science education: The role of technology and emerging approaches. *Journal of Baltic Science Education*, 24(3), 396–398. <https://doi.org/10.33225/jbse/25.24.396>

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