CURRENT STUDIES ON

# ARTIFICIAL INTELLIGENCE IN EDUCATION

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ISRES Publishing

**Current Studies on Artificial Intelligence in Education**

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# PREFACE

As we leave the first quarter of the twenty-first century behind, we are witnessing one of the most transformative technological revolutions in human history: the "Age of Artificial Intelligence." Once a subject confined to computer science, artificial intelligence (AI) has now permeated every aspect of life, from health to daily routines, through systems equipped with learning and problem-solving capabilities. Undoubtedly, the most strategic field deeply affected by this transformation, and simultaneously holding the potential to shape it, is education.

This book, *"Current Studies on Artificial Intelligence in Education,"* aims to address the integration of artificial intelligence into the education ecosystem from a multidimensional perspective. The book examines AI not merely as a "technological tool" entering the classroom, but as a comprehensive phenomenon that transforms pedagogical approaches, alters measurement and evaluation paradigms, and brings along ethical and environmental responsibilities.

The studies included in our book blend theoretical discussions with practical applications, aiming to guide educators, researchers, and policymakers. These academic studies, selected through a rigorous peer-review process, are built upon six fundamental chapters:

In the opening chapter of the book, Burcu Akman and Seyit Ahmet Kıray address the future of science education through the axis of artificial intelligence and robotic coding. The authors emphasize that the integration of these technologies transcends the traditional rote-learning model, establishing a dynamic learning environment where students are actively engaged in processes of discovery and creation. The chapter demonstrates how these tools enhance students' scientific process skills, problem-solving abilities, and creativity.

In the second chapter, Uğur Sarı and Hüseyin Miraç Pektaş stand at the intersection of science education and computational thinking skills. The authors examine how AI-supported interactive learning environments support students' higher-order skills such as data collection, modeling, and algorithmic thinking. Through the example of an intelligent tutoring system developed for diagnosing onion epidermis cells, they demonstrate how theoretical knowledge is transformed into a concrete learning experience with AI.

The third chapter focuses on the often-overlooked environmental dimension of technology: sustainability. Munise Seçkin Kapucu, Ezgi Meşe, and Ezgi Nurefşan Demirel open the concept of the "Artificial Intelligence Footprint" to discussion, scrutinizing the effects of these technologies on energy consumption, carbon emissions, and water usage. Advocating that technological advancement must be balanced with the future of the planet, the authors adapt the "Footprint Family" approach to the digital age.

In the fourth chapter, Ramin Feyziyev scrutinizes the role of AI in language education, a fundamental requirement of a globalized world. While discussing opportunities such as personalized learning paths and providing instant feedback, the study also draws attention to ethical challenges like data privacy and algorithmic bias. The author positions AI not as a tool replacing teachers, but as a powerful ally enriching human education.

In the fifth chapter, Celalettin Çelebi and Ferhat Karakuş present a practical guide most needed by educators. This chapter categorizes and examines AI tools used in education, ranging from lesson planning (e.g., ChatGPT, Copilot) to visual design (e.g., Canva, Leonardo), and from video creation (e.g., Fliki, Heygen) to assessment tools. The authors emphasize that the correct and effective use of these tools has the potential to improve educational quality by alleviating teachers' workload.

In the final chapter of the book, Hakan Dağlı and Osman Çardak discuss the transformation in measurement and evaluation processes, one of the most critical stages of education. The authors discuss the transition from traditional test-based approaches to AI-supported, data-driven, and personalized assessment systems. While presenting opportunities such as automated scoring systems and learning analytics, the validity, reliability, and ethical dimensions of these systems are also comprehensively evaluated.

This book is the product of a scientific effort that presents opportunities, risks, ethical concerns, and pedagogical necessities in a balanced manner, rather than a one-sided perspective that solely glorifies or vilifies the place of AI in education. It is a collection of peer-reviewed scientific studies aimed at ensuring that AI technologies do not "dehumanize" education, but on the contrary, serve a "human-centric" transformation that maximizes the potential of teachers and students.

We would like to thank all the valuable chapter authors who contributed to the creation of this work and the reviewers whose feedback enhanced the quality of the manuscript. We also express our gratitude to ISRES Publishing for pioneering the dissemination of scientific knowledge. We hope that this book will shed light for academics working on AI integration in education, teachers in the field, and those steering educational policies.

December, 2025

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# FUTURE SCIENCE EDUCATION WITH ARTIFICIAL INTELLIGENCE AND ROBOTIC CODING

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## Introduction

In the modern global context, the production and assimilation methodology of scientific knowledge is undergoing a radical paradigm shift that is majorly catalyzed by the pervasive influence of digital technologies. The integration of Artificial Intelligence (AI) and robotic coding transcends the conventional rote-learning model in science education, establishing a dynamic learning milieu where students are actively engaged in the processes of discovery, interpretation, and creation. The intrinsic ability of AI to perform real-time analysis of individual learners' needs, together with the capability of robotics applications to make abstract scientific concepts experientially accessible, is contributing simultaneously to making the pedagogy of science both more accessible and more interactive. This chapter aims to provide a comprehensive, holistic view of what the future classroom might look like by critically exploring the many facets that these two technologies are playing in the field of science education.

### What Is Artificial Intelligence? Its Role and Importance in Education

Artificial Intelligence (AI) is defined as a computer system capable of executing cognitive tasks typically associated with the human mind, including learning and problem-solving (Wartman & Combs, 2018). AI manifests human intelligence through capacities such as data analysis, learning, problem-solving, decision-making, generalization, and leveraging experience (Elmas, 2021). In essence, AI can be succinctly characterized as the capacity of computers or machines to perform behaviors that mimic human intelligence. This technology utilizes sub-specialties like Machine Learning (ML), Natural Language Processing (NLP), and Deep Learning to enable machines to execute specific tasks without human intervention (Baker & Smith, 2019). The inception of Artificial Intelligence began in the 1950s, with the term first coined by McCart-

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hy (Russell & Norving, 2003). Today, AI has driven revolutionary innovations across numerous sectors, and has recently gained significant momentum and garnered considerable interest, particularly within the field of education (Richter Zawacki et al., 2019).

Artificial intelligence is increasingly being integrated into the administration, teaching, and learning processes within educational settings (Chtaskol et al., 2018). The incorporation of AI in education has the potential to personalize learning, provide more effective learning experiences, help students explore their abilities, foster creativity, and reduce teachers' workload (Haseski, 2019). By tailoring learning materials to students' individual needs and abilities, AI can create a more personalized learning journey and offer improved learning experiences (Chen et al., 2020). Such personalization enables learners to engage with content at their own pace and according to their preferred learning styles, which may enhance overall achievement. Additionally, AI-supported educational tools can offer automated feedback and promote collaboration among students—further contributing to the benefits that AI brings to contemporary education (Baker & Smith, 2019).

Artificial intelligence can be utilized in educational settings to support instructional delivery, assist teachers in managing classroom activities, and identify students' individual learning needs by diagnosing their difficulties (Çam et al., 2021). Tasks such as automated grading, assignment analysis, and monitoring student behavior in the classroom can be performed by AI systems (Baker & Smith, 2019). As a result, teachers are able to dedicate more time to meaningful, personalized interactions with students and monitor their developmental progress more closely.

Chen et al. (2020) reported evidence that applications of artificial intelligence in education have advanced far beyond the traditional perception of simple computer systems. AI is now being employed in areas such as curriculum and content development, enriching students' learning experiences and creating opportunities that extend beyond the physical boundaries of the classroom. By incorporating more complex technologies—including robotics, embedded systems, and computational tools—AI enhances the effectiveness of instructional processes. Overall, artificial intelligence brings transformative changes to the field of education, making teaching and learning more efficient, effective, and personalized.

The implementation of artificial intelligence in education not only enriches students' learning experiences but also significantly reduces teachers' workload. Automated feedback, individualized assessments, and AI-supported personalized learning pathways enable each learner to reach their full potential. Moreover, the integration of more advanced AI applications into educational processes extends beyond traditional instructional methods, enhancing classroom practices and allowing physical limitations to be overcome. Consequently, artificial intelligence offers innovative and effective educational solutions, shapes future learning environments, and holds the potential to improve student achievement levels (Gulnar et al., 2024).

### Robotics Programming in Education

It would not be incorrect to state that robotic programming is a product of modern technology. Programming involves developing commands to solve a problem identified by a computer and applying these commands to reach a solution. Coding with robots allows this process to become tangible. Robotics refers to the activation of stationary robot components through technological controls (Soypak & Eskici, 2023). With the global recognition of the importance of skills such as analytical and critical thinking, reasoning, problem-solving, and design-oriented thinking, coding and robotics education is being incorporated into curricula at early ages. This enables children to develop algorithmic thinking skills through interdisciplinary interactions, thereby fostering 21st-century competencies (Goksoy & Yılmaz, 2018). Students engage in coding practice; it can be argued that this positively contributes to the development of problem-solving, creative thinking, algorithmic thinking, critical thinking, logical reasoning, classroom participation, computational thinking, and practical professional skills (Ramazanoglu, 2021). These skills are essential for students to succeed in the future labor market (Eguchi, 2016). Through robot programming activities, students have the opportunity to design and program their own robots, transforming theoretical knowledge into practical application.

The use of robots in education significantly contributes to the acquisition of higher-order thinking skills. Various studies conducted with high school students have found that robotic tools, such as Lego Mindstorms EV3, help enhance students' STEM skill levels, improve their problem-solving abilities, and positively influence their attitudes toward the course. Moreover, the utilization of robots as educational materials positively affects the learning process of individuals with special needs, while simultaneously fostering positive attitudes and improving students' computer skills. Collectively, these studies indicate that robotics education enhances students' computational thinking skills as well as their social competencies (Kaya et al., 2020; Kılıc, 2022; Kim & Lee, 2016; Ramazanoglu, 2021; Turk & Korkmaz, 2023).

Robotics programming activities enable students to apply theoretical knowledge in practice, thereby developing 21st-century skills such as problem-solving, creative thinking, and critical thinking (Karatas, 2021). Research indicates that the use of robotics in education enhances STEM skills, improves problem-solving abilities, and positively influences students' attitudes toward the course (Yalcın & Akbulut, 2021; Gezgin & Mihci, 2023), while also supporting the development of students' computer skills.

### The Use of AI and Robotics in Science Education: Why Is It Important?

The 2018 Science Curriculum aims to educate individuals in the field of scientific knowledge by providing foundational knowledge, developing scientific process skills, increasing environmental awareness, enhancing problem-solving abilities, raising awareness about careers and entrepreneurship, and fostering an understanding of scientific production processes. It also seeks to cultivate interest in knowledge and natural phenomena to promote safe working practices, improve reasoning and decision-making skills, and apply universal ethical values and principles in scientific ethics (Ministry of National Education [MEB], 2018). A key point to emphasize here is the concept of the scientifically knowledgeable individual. Scientific literacy is a process that enables individuals to effectively use scientific knowledge in all areas of daily life. This process not only involves memorizing scientific concepts but also aims to make these concepts meaningful and applicable through practical implementation (Kavak et al., 2006). The use of robotics and artificial intelligence can be effective in achieving the goals of science education. According to Sullivan (2008), learning robotics is closely linked to three fundamental objectives of scientific culture. First, robotics research requires the use of four core skills among scientifically competent individuals: computation, prediction, manipulation, and observation. Second, robotics actively engages students in the scientific inquiry process through technology design and computer programming activities. Third, robotics education provides students with in-depth knowledge about systems, which is an important topic in science education. The use of robots can yield positive outcomes not only in achieving educational objectives but also in fostering a positive attitude toward science courses (Guven & Sulun, 2020).

The use of digital technologies, such as artificial intelligence (AI), in science education plays a significant role in enabling students to learn scientific concepts more easily, effectively, and engagingly. AI has the capability to collect, analyze, and interpret data obtained by students from scientific experiments (Kızılay, 2023). Another important benefit of using AI and robotic technologies is the provision of personalized learning opportunities. Since each student has a different learning pace and style, these technologies can offer educational programs tailored to individual needs. AI-based educational systems can analyze students' learning outcomes, identify gaps, and provide appropriate, personalized learning pathways to support their development. This approach can be particularly beneficial in knowledge-intensive fields like science education, helping students to learn more effectively and improve their academic performance.

From the educators' perspective, artificial intelligence (AI) and robotic technologies can make the teaching process more effective. For instance, with AI-based tools, teachers can monitor students' learning more closely and intervene more quickly when necessary. Systems that provide automatic assessment and feedback reduce teachers' workload, allowing them to devote more time to direct interaction with students. Additionally, by using AI and robotic tools, teachers can make science topics more dynamic and engaging, which can, in turn, enhance students' motivation to learn.

Artificial intelligence (AI) and robotic technologies play a vital role in fostering 21st-century skills. In today's workforce, skills such as technological literacy, problem-solving, analytical thinking, and the ability to generate creative solutions are highly valued. Students who engage with AI and robotic tools during science education have the opportunity to develop these skills

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from an early age. This, in turn, helps prepare them for future careers and equips them with a stronger technological proficiency.

The use of artificial intelligence (AI) and robotic technologies in science education provides significant benefits for both students and teachers. These technologies can make learning experiences more effective and engaging, increasing students' interest in science and transforming them into more motivated and engaged learners. Additionally, by offering opportunities for problem-solving, critical thinking, and interdisciplinary learning, they help prepare students for their future careers. Therefore, the integration of AI and robotic technologies into science education should be considered an essential component of modern education and promoted widely.

## The Significance of Robotics Programming in STEM Education

In contemporary education, STEM (Science, Technology, Engineering, and Mathematics) fields stand out as an interdisciplinary approach aimed at developing students' problem-solving, critical thinking, and innovation skills (Akdur et al., 2024; Erdogan et al., 2017; Hernandez, 2014). The goal of education in these fields is to ensure that students not only understand theoretical concepts but also apply them to real-world problems (Thomasian, 2011). According to Cameron (2005), robotics programming is becoming a significant tool in STEM education. Robotics programming can enhance students' creative thinking abilities and their skills in actively utilizing technology, thereby increasing their interest in STEM disciplines (Cakir, 2020). For example, a line-following robot project can help students learn basic programming skills and understand how technological components, such as motors and sensors, function. This project will teach students the stages of the engineering design process and how to use mathematical concepts to optimize the robot's movement. In this way, theoretical mathematics and engineering skills can be transformed into practical experience.

Robotics programming also enhances students' connections with the sciences (Altin & Pedate, 2013). For example, robotic projects can interact with the environment using sensors such as light, distance, and temperature sensors. Such applications develop students' abilities to collect and analyze scientific data (Koc & Buyuk, 2014). A robot project that measures environmental changes allows students to formulate hypotheses and evaluate their results, enabling them to apply scientific approaches (Koc Senol, 2012).

Robotics programming provides students with experience in computer science and software development from a technological perspective. In such projects, algorithmic thinking skills and programming languages are crucial. Acquiring various skills, from creating algorithms to debugging, is necessary to write code that enables the robot to perform the desired tasks (Ozdinc & Mumcu, 2022). Robotics programming also makes a significant contribution to STEM education. In robot design, students follow engineering processes such as planning, prototyping, testing, and improvement (R. Elmas, 2022). This approach can help students gain a realistic understanding of how engineering disciplines work, preparing them to become the engineers of the future.

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**Investigating Science Through Robotics-Based Activities**

One of the fundamental disciplines that helps us understand how nature works is science. However, teaching the theoretical topics of these disciplines in the classroom can sometimes be challenging (Lacin Simsek, 2020). Robotics projects can serve as an excellent tool to make scientific concepts more engaging and easier to understand.

Robotic applications can make learning and exploring core subjects such as physics, chemistry, and biology enjoyable. A simple balance robot, for example, can be used to observe Newton's laws of motion. While controlling the robot's movement, students can observe the relationship between force and acceleration, thereby learning these concepts. Such projects transform abstract concepts into tangible experiences and can enhance students' scientific process skills. In his study, Kirtay (2019) investigated the effects of robotics applications on students' scientific process skills (observation, measurement, classification, recording data, formulating hypotheses, using data and modeling, manipulating and controlling variables, conducting experiments) and motivation toward science education in the Force and Motion unit (MEB, 2018). The results indicated that robotics applications facilitate learning and contribute to the development of scientific skills.

In chemistry lessons, it is possible to measure the temperature, pH, and humidity levels of various environments using robotic sensors. By analyzing the data collected by their robots, students can learn about the effects of environmental changes on chemical processes. This provides knowledge of scientific research methods and develops critical skills such as data collection and analysis. Robotics can also be used in exploring biology. For example, biomimetic projects have the potential to produce robots that imitate the movements of living organisms in nature. These projects can be used to teach the mechanics of muscles and joints. A robot simulating an animal's walk can help students better understand the functioning of the muscular and skeletal systems.

Robotics projects contribute to the education of STEM (Science, Technology, Engineering, and Mathematics) fields. These projects teach students both theoretical and practical knowledge (Altunel, 2018). To learn more about renewable energy sources and energy transformations, students can design

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a solar-powered robot car. Such projects can also teach the concept of sustainability by enabling people to gain more knowledge about the environment. According to K. Simsek (2019), robotics projects bring science out of the classroom and make learning an active process. This not only helps students develop their scientific skills but also enhances their ability to solve future problems using technology (Cam, 2019). Exploring science through robotics projects can make education more lively, interactive, and inspiring, opening new horizons for students.

**Implementing Artificial Intelligence and Robotics Programming in Classroom Settings**

Robotics programming and artificial intelligence (AI) are gaining increasing importance in education as technology rapidly advances (Akdeniz & Ozdinc, 2021; Yildiz Durak, 2020). These innovative tools can help students improve in areas such as science, mathematics, and engineering, and can transform the in-class learning experience (Demircioglu et al., 2024; Koray & Uzuncelebi, 2023; Seckin Kapucu, 2023; Tekin & Keser, 2020). Robotics programming and AI can make classroom instruction more interactive and student-centered. Here are some examples of in-class applications of artificial intelligence (AI):

*Personalized Learning with Intelligent Learning Systems:* AI-supported intelligent learning systems adapt to students' learning styles and paces (Baker & Abu-Naser, 2019). These systems can identify students' strengths and weaknesses and provide personalized instructional content. For example, an AI system can offer additional topics for students struggling in mathematics, thereby providing a personalized learning experience.

*Automated Assessment and Feedback*: AI-supported automated assessment tools accelerate the evaluation process of exams or assignments. These tools can analyze students' responses and provide instant feedback to both teachers and students. This allows students to quickly identify areas in which they are deficient and makes the learning process more efficient.

*Chatbots and Digital Student Assistants*: Chatbots are AI-powered conversational agents designed to interact with humans through visuals, voice messaging, or text (Baris, 2020). Students can receive assistance from AI-based chatbots and digital assistants outside of class. These tools continue the learning process by answering students' questions and enabling faster acquisition of information (Kane, 2016). For example, students can ask their digital assistant about the causes of a war in history class and receive an immediate response.

*Content Creation and Language Processing*: Natural Language Processing (NLP) is the area of AI that enables computers to understand, analyze, and emulate human language (Korkmaz, 2023). Text analysis and NLP techniques can also assist in the creation of instructional materials. AI-supported tools can speed up teachers' processes in preparing lesson notes or exam questions.

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### Applying Robotics Programming in Classroom Settings

Robotics programming is particularly important in STEM (Science, Technology, Engineering, and Mathematics) courses because it enables students to transform theoretical knowledge into practical skills (Ouyang & Weiqi, 2024). In-class robotics programming helps students develop problem-solving, creative thinking, and coding skills (Alboria & Alsaleh, 2022). The use of robotics programming in the classroom can be implemented as follows:

***Hands-On Project-Based Learning*:** Robotics programming allows students to work on real-world tasks. For example, students can design a simple robot and program it to perform a specific task. In this process, students develop both coding language skills and algorithmic and logical thinking abilities (Castelblanco et al., 2019). Completing tasks such as moving the robot along a specific path or transporting objects can help enhance students' coding and engineering skills.

***Robot Competitions and In-Class Activities*:** Students can apply the knowledge they have learned through robot competitions and classroom activities (Kaji et al., 2019). Competitions not only foster teamwork and collaboration skills but also increase students' motivation (Huei Chen et al., 2020). Students attempt to program their robots to complete tasks within a given time frame, making learning more engaging and competitive.

***Coding and Robotics Workshops*:** Schools can support students' engagement with robotics programming outside of class. In these workshops, students can work on more complex projects to further develop their knowledge and skills. Such activities can capture students' interest and enhance their curiosity toward science and technology.

### Challenges and Considerations in Robotics Programming

Robotics programming and artificial intelligence offer great opportunities for in-class applications, they also present certain challenges. For these technologies to be used effectively in the classroom, teachers must possess sufficient knowledge and skills (Schina et al., 2021). Additionally, it is crucial to provide schools with the necessary infrastructure and resources for such applications (Akcay et al., 2019; Aydogan, 2021; G. Guven & Cakir, 2020). In locations with limited technological resources, ensuring equal educational opportunities for all students can be difficult.

### Educational Benefits of Interactive Learning through Artificial Intelligence and Robotics

Robotics and artificial intelligence (AI) are important tools for enhancing interactive learning in education and enabling students to actively participate in the learning process (Caka, 2022; Nalbant, 2021). These technologies allow students to develop their cognitive skills and gain deeper access to knowledge.

**Enhancing Creativity and Critical Thinking: Robotics and artificial intel**

ligence (AI) help students develop their critical and creative thinking skills (E. Altun, 2024; Kucukaydin & Bor, 2021). Robotics projects provide students with opportunities to solve challenging problems and generate novel solutions (Gezgin & Mihci, 2023).

***Developing Teamwork and Collaboration Skills*:** Robotics projects typically require group work. This helps students improve their communication, collaboration, and teamwork skills (Gezgin et al., 2022). By combining different perspectives, students can produce innovative solutions (Tatlısu, 2020).

***Acquiring 21st Century Skills*:** Robotics and AI provide students with the opportunity to acquire essential 21st-century skills. Competencies such as technological literacy, problem-solving, communication, and critical thinking are highly valued in today's workforce (F. Erdogan, 2023). Therefore, AI and robotics applications help prepare students for their future careers.

Creating interactive learning experiences for students using robotics and AI not only enhances instruction but also increases students' active engagement, providing a more effective learning environment. Educators' effective use of these technologies in the classroom positively impacts students' learning experiences and prepares them for the future.

**Creating a Science Education Curriculum Integrating Artificial Intelligence and Robotics Programming**

With the rapid advancement of technology and digitalization in recent years, significant changes have occurred in education (Surer, 2020). The approach to science education has also evolved as a result of these changes. Robotics programming and artificial intelligence (AI) play an important role in renewing science education to meet the demands of the current era (Erdogan, 2023). Therefore, AI and robotics programming courses in science education can be crucial for helping students develop scientific thinking skills and prepare for the digital world.

Robotics programming and AI facilitate the development of skills such as problem-solving, critical thinking, creativity, and collaboration (M. Altun et al., 2023; Anilan & Gezer, 2020). Science education aims to equip students with the ability to use evidence, reason inductively and deductively, classify, make scientific predictions, formulate hypotheses, conduct experiments, draw scientific conclusions, develop scientific models, and engage in scientific inquiry (MEB, 2020). In this context, AI and robotics programming serve as effective tools to support the acquisition of these skills.

The use of AI in science education enables students to enhance scientific process skills such as data collection, analysis, and interpretation (Sarioglu, 2023). For example, students can analyze the effects of environmental variables using sensors (V. Kilic, 2021). Additionally, by learning data classification and modeling processes through AI tools, students can gain a deeper understanding of scientific methods (Diyer et al., 2022).

On the other hand, robotics programming allows students to apply concepts learned in science and participate in the engineering design process (Ucar & Sezek, 2024). Through robotics projects, students can connect the digital and physical worlds. For instance, by programming robots, students can directly observe and experiment with the effects of electrical applications while studying electrical circuit components. Such applications enable students to apply theoretical knowledge in practice and promote lasting learning (B. Kaya & Bozyigit, 2024).

### Development of the Curriculum: Key Principles and Learning Objective

In designing a curriculum for artificial intelligence (AI) and robotics programming in science education, certain principles and objectives should be considered. These principles include:

- **Hands-On Learning and Experiential Engagement:** The curriculum should include activities that promote active student participation and enable learning through experience (Hancer et al., 2003). Robotics programming and AI projects facilitate students' understanding of science concepts (Erdogan, 2023; Erten, 2019).

- **Development of Scientific Thinking Skills:** Students should be provided with foundational knowledge about analytical thinking, problem-solving, scientific inquiry, as well as AI algorithms and robotic systems.

- **Technological Literacy and Digital Skill Development:** Integrating robotics programming and AI into education equips students with essential skills for the digital age. Students who learn to use technology can generate innovative solutions and navigate the modern world with confidence (Et & Gomleksiz, 2023).

- **Interdisciplinary Approach:** The curriculum should create connections among various disciplines, such as science, mathematics, computer science, and engineering, allowing students to integrate knowledge from multiple domains (Bati et al., 2017). This enables students to approach complex problems with a broader perspective (Sultan Qurraie, 2024).

- **Ethics and Social Responsibility Awareness:** Given the societal impact of robotic systems and AI technologies, students should act with a sense of ethical responsibility (Efe, 2021). Education should address both the advantages and disadvantages of AI to raise awareness among students.

The AI and robotics programming curriculum should be structured to suit students at different levels and include a variety of topics. Some key topics and learning activities that can be incorporated into the curriculum include:

- **Fundamentals of Artificial Intelligence:** This section provides information on the emergence of AI, fundamental concepts, and various application areas. Students need to understand the basic operating principles and how AI is applied in everyday life.

Machine Learning and Data Analysis: Basic machine learning algorithms and simple data analysis techniques can be introduced. These activities provide students with foundational skills in data collection, analysis, and model building. Connecting these concepts to experimental data used in science classes can make the learning experience more meaningful.

**Fundamentals of Robotics and Programming:** Core concepts such as sensors, actuators, and robot components can be taught. Additionally, students can gain knowledge about robotic programming languages and platforms, which enables them to build and program simple robots.

**Projects and Experiments:** Students should be given the opportunity to work on robotics- or AI-based projects. Such projects allow for the practical application of theoretical concepts and encourage creative problem-solving.

**Ethical and Societal Issues:** The societal impact and ethical concerns of technologies like robotics and AI can be discussed. This helps students understand the social and moral implications of technology on human life.

During the implementation of an AI and robotics programming curriculum in science education, certain challenges may arise. Key challenges include teachers' insufficient technological knowledge and the lack of infrastructure in schools (Kuzgun & Ozdinc, 2017). To address these issues, the following recommendations can be made:

- **Teacher Training and Professional Development:** Training programs on robotics programming and AI should be developed for teachers. These programs enable teachers to effectively guide students using technology (Sayin, 2020).

- **Improving Infrastructure:** Schools should be provided with the necessary software and hardware infrastructure to implement the curriculum effectively (Ceylan & Gundogdu, 2018). This includes programming platforms, AI software, and robotics kits.

- **Interdisciplinary Collaboration:** Collaboration among teachers from different disciplines allows for a more comprehensive and effective curriculum implementation (Bakar, 2023). Cooperation between technology, science, mathematics, and computer science teachers should be encouraged.

- **Interactive and Student-Centered Learning Environments:** Interactive learning environments should support experiential and hands-on learning. This increases student engagement and promotes more lasting learning outcomes (Dogac & Gok, 2020).

Robotics programming and AI introduce a novel approach to science education and serve as important tools for developing 21st-century skills (Celık, 2021). Integrating these technologies into science education helps students enhance scientific thinking skills and prepares them for the digital world. For successful curriculum implementation, attention must be paid to teacher training, school infrastructure, and interdisciplinary collaboration. Effectively

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implementing AI and robotics education programs is a crucial step toward cultivating future scientists and individuals prepared for a technology-driven world.

**Example for curriculum**

**Level:** 6thGrade

**Duration:** 4 weeks (8 lessons

**Core Science Learning Outcomes:**

- Explain the difference between heat and temperature.
- Propose solutions to everyday problems related to heat insulation.

**Table 1:** *Integrated Skill Areas*

| Area | Objective |
|---|---|
| Science | Scientific process skills (observation, experimentation, analysis) |
| Technology | Sensors, data collection systems |
| Engineering | Design of insulated models |
| Mathematics | Data analysis, graph interpretation |
| Artificial Intelligence | Algorithms that make decisions based on temperature data |
| Robotics & Coding | Systems integrating temperature sensors and motors |

**Week1: Concept Exploration and Experimentation**

**Activities:**

- Demonstrate the difference between heat and temperature through experiments.
- Examine Arduino-based temperature sensors.
- Discuss how data is measured and collected.

**AI Integration:**

- Convert sensor data into graphical representations.
- Pattern recognition in data (e.g., under which conditions does the temperature rise accelerate?).

**Week2: Engineering Design**

**Activities:**

- Design a mini greenhouse or "food container" to provide heat insulation.

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- Discuss material selection and AI-assisted proposals for “models that reduce heat loss.”

**AI Integration:**

- Develop simple decision-making algorithms (if-then conditions) that evaluate the insulation efficiency of different materials.

**Week 3: Robotics and Coding Application**

**Activities:**

- Students program a warning system using a temperature sensor.
- Objective: Motor activates or LED lights up when a certain temperature is exceeded.
- Scratch or mBlock can be used.

**AI Integration:**

- Include “simple recommendation systems analyzing temperature data” in the code (e.g., “If the temperature continuously rises over x days, trigger a warning”).

**Week 4: Project Presentation and Evaluation**

**Activities:**

- Students present their projects.
- Determine which model provides the best insulation.
- Examine how AI decisions interact with the robotic system.

**Assessment Criteria:**

- Scientific explanation competence
- Coding accuracy
- Explainability of AI-based decision logic
- Group collaboration and presentation skills

**Additional Learning Outcomes:**

- 21st-century skills (critical thinking, creativity)
- Problem-solving
- Data literacy
- Basic AI literacy
- Recognition and control of robotic system components

**Emerging Trends in Education and Strategies for Technological Integration**

The rapid advancement of technology has led to a significant transformation in the education sector today (Eser, 2014). Digitalization, AI-supported education, and personalized learning are new trends that are surpassing traditional educational approaches (Ekin, 2022). These innovations can make learning more effective and efficient (Parlak, 2017). Emerging trends in education and approaches to technological integration are reshaping students' access to knowledge, the role of teachers, and the time and place of learning (Ryan & Bagley, 2015).

Emerging trends in education are practices that arise alongside technological opportunities, making learning processes more flexible, accessible, and personalized. Some of the prominent trends in contemporary education include:

- **Personalized Learning:** This approach tailors education to each student's learning pace, interests, and needs. It enables students to manage their learning processes more effectively and achieve their goals. Adaptive learning systems and AI-based educational platforms support personalized learning (Yoruk, 2024).

- **Remote and Hybrid Learning:** Rapidly adopted during the COVID-19 pandemic, remote and hybrid learning allows students to combine online and face-to-face educational opportunities. Hybrid learning models provide teachers the chance to integrate different teaching methods while offering students a flexible learning experience (Goksel & Adiguzel, 2024).

- **Game-Based and Gamified Learning:** Incorporating game elements (points, rewards, levels) into lesson content makes learning more enjoyable and motivating. Game-based learning directly utilizes digital games designed for educational purposes, while gamification applies game mechanics to conventional learning (Kirmaci & Cakmak, 2022; Bayirtepe & Tuzun, 2007). These approaches increase student engagement and make the learning process more interactive (Bolat et al., 2017; Ulkudur, 2016).

- **AI-Supported Education:** Artificial intelligence plays a crucial role in monitoring student performance, providing feedback, and enabling personalized learning experiences. AI-powered educational systems assess students' strengths and weaknesses and provide tailored content and learning paths (Isler & Kilic, 2021).

- **Virtual Reality (VR) and Augmented Reality (AR):** AR and VR technologies help students better understand lessons and enhance their learning experiences (Shelton & Hedley, 2002; Tepe et al., 2016). For example, students can explore a virtual model of the human body in biology or participate in a virtual tour of ancient civilizations in history classes.

- **Social and Emotional Learning (SEL): S**EL focuses on developing students' social skills and emotional intelligence. It aims to teach self-regulation, collaboration, empathy, and problem-solving skills, fostering a more inclusive and supportive learning environment (Aygun, 2019).

The effective use of technology in education requires redesigning teaching strategies and adapting digital tools to learning environments (Koyuncuoglu & Taspinar, 2024). Key factors for successful technological integration in education include:

- **Selection of Digital Tools and Platforms:** Digital tools and platforms used in education should meet students' needs and support learning objectives. Teachers need to understand how to integrate various digital tools into lesson content and maximize the benefits of the features they offer.

- **Teacher Training and Professional Development:** For successful technology integration in education, teachers must be equipped and skilled to implement these tools effectively in the classroom.

In conclusion, continuous professional development programs should be organized and support should be provided to enable teachers to use technology effectively. Teachers who are experts in educational technologies are better equipped to guide students in utilizing digital tools to meet the demands of the modern era (Metin, 2018).

***Content Development and Adaptation:*** Lesson content to be used in digital environments should be adapted to provide meaningful and effective learning experiences for students. Educational materials should be revised and updated as necessary, considering the interactivity and visual advantages offered by digital tools (Cevik et al., 2024).

***Digital Security and Ethical Use:*** The use of technology in education also requires raising students' awareness of digital security and ethics. Students should be taught how to navigate online environments safely, use digital tools responsibly, and protect their personal data (Sahin et al., 2022).

***Creating Interactive and Participatory Learning Environments:*** Technology enables students to participate more actively in interactive learning environments. Applications such as AR, virtual classrooms, digital simulations, and game-based learning enhance students' engagement and involvement in lessons (Bahsi & Gencer, 2024).

Technological integration in education provides significant benefits for both students and teachers. These benefits help make learning easier, more efficient, and more effective (Doger, 2016):

- **Personalization of Learning Processes:** Technology allows students to progress at their own pace by offering personalized learning paths. AI-supported educational tools and adaptive learning systems provide content and recommendations tailored to students' needs (Gunduz, 2023).

- **Easy Access to Information and Flexibility:** Digital platforms give students access to information anytime and anywhere (M. E. Simsek, 2024), making learning independent of spatial and temporal constraints (Depe et al., 2023). This is particularly advantageous in an era with remote and hybrid learning models.

- **Increasing Student Engagement and Motivation:** Interactive digital tools and gamification techniques enhance students' interest in lessons and encourage more active participation in the learning process. Technologies such as game-based learning and AR make lessons more engaging and enjoyable (R. Cakir et al., 2015).

- **Feedback and Performance Monitoring:** Digital tools allow students to receive immediate feedback, enabling them to manage their learning more effectively. Additionally, teachers can easily monitor students' progress and provide additional support when necessary (Çapar, 2024).

During the process of technological integration in education, some challenges and obstacles may arise. The following strategies can be developed to overcome these issues:

- **Infrastructure Deficiencies:** In some schools, digital infrastructure and access to technology may be insufficient (Akıncı & Tunç, 2021). To address this, government support, public-private partnerships, and cost-effective technological solutions can be utilized.

- **Educators' Adaptation to Technology:** Effectively using technology can be challenging for some teachers. Therefore, continuous professional development and technology training should be provided (Başaran et al., 2021).

- **Digital Inequality:** Students' access to the internet and digital tools may vary (Çapar, 2024). Schools can address this issue by providing students with services such as tablets, laptops, and internet access.

- **Digital Security and Data Privacy:** The widespread use of technology in education raises concerns about the security and protection of student data (Çapar, 2024). Educational institutions should train students in online safety and strengthen digital security measures.

New trends in education and approaches to technological integration can make learning more dynamic, interactive, and efficient. In shaping future educational models, it is crucial to create learning environments that meet students' needs and to leverage the opportunities provided by technology effectively.

### Teaching Students Ethical and Responsible Technology Use

Robotics and artificial intelligence (AI) are becoming increasingly prevalent in education and daily life. Although these technologies hold significant potential, ethical and appropriate usage issues are crucial. Teaching students how to use these technologies responsibly is essential for enabling them to make informed decisions in the future.

### The Importance of Ethical and Responsible Technology Use

- **Informed Usage:** AI and robotics are complex systems that involve data analysis, decision-making, and automation processes. Using these systems ethically ensures that students can interact with technology consciously. It is

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critical for students to understand how these technologies work, as well as their benefits and potential harms.

- **Social Responsibility:** AI and robotic systems can significantly impact society. Encouraging students to consider the effects of these technologies on humans fosters social responsibility (Yar Sevmiş, 2023). For instance, discussing the impact of robots on the workforce or the data privacy implications of AI systems can engage students more deeply with these issues.

- **Decision-Making Skills:** Teaching students ethical decision-making techniques prepares them for challenges they may face in the future (Kiranli Güngör & İlğan, 2007). Discussing ethical dilemmas related to AI and robotics can enhance students' problem-solving and analytical thinking skills.

**Methods for Teaching Ethical and Responsible Technology Use**

- **Project-Based Learning:** Students can experience ethical issues concretely through AI and robotics projects. They should consider how a robot interacts with humans and the ethical dimensions of those interactions. Project-based learning encourages critical thinking and idea generation (Yanarateş, 2022).

- **Scenario Analysis:** Ethical dilemmas help students develop critical thinking skills. By discussing potential ethical problems related to AI applications or robotic systems, students learn to evaluate different perspectives. For example, they might debate how autonomous vehicles should behave in accident scenarios.

- **Virtual Discussions and Forums:** Organizing virtual discussions and forums allows students to explore ways to use technology ethically. These platforms enable students to listen to peers' viewpoints, share their own, and develop diverse perspectives.

- **Gamification:** Game-based learning can make understanding ethical technology use more engaging. For example, AI simulations can be used to design games in which students must make decisions according to specific moral standards, making learning more interactive and enjoyable.

**Implementation Recommendations:**

- **Integrate into Lesson Plans:** Incorporating content on ethical and responsible use into AI and robotics courses ensures a comprehensive treatment of the topic.

- **Conduct Virtual Workshops:** Students can learn practical ways to use robotics and AI technologies through virtual workshops, which should also address ethical issues.

- **Collaboration with Parents:** Parents play a crucial role in their children's technology use. Informative seminars can be organized to raise parental awareness about responsible technology use.

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Teaching students the ethical use of AI and robotic technologies helps them grow into responsible and conscious individuals. Educators' efforts in this area support the development of students who can use technology effectively, responsibly, and morally.

## Conclusion

Artificial intelligence (AI) and robotic coding in science education serve as essential tools for developing students' scientific thinking, problem-solving, creativity, and digital competencies. These technologies enable students to acquire scientific process skills such as data collection, analysis, modeling, and experimentation, while also facilitating the practical application of theoretical knowledge. In designing the curriculum, principles such as experiential learning, interdisciplinary approaches, ethical awareness, and technological literacy should be prioritized. Furthermore, teachers' technological proficiency, the schools' infrastructure, and interactive learning environments are critical factors for the successful implementation of the curriculum. Emerging educational trends, including personalized learning, hybrid education, gamification, AI-supported instruction, and virtual and augmented reality applications, enhance learning effectiveness and motivation, while digital security and ethical responsibility remain essential for fostering students' conscientious use of technology. Thus, integrating AI and robotic coding into science education provides a holistic approach that prepares students for both scientific and societal challenges in the future.

## REFERENCES

Akcay, A. O., Karahan, E., & Turk, S. (2019). Bilgi islemsel dusunme becerileri odakli okul sonrasi kodlama surecinde ilkokul ogrencilerinin deneyimlerinin incelenmesi. *Eskisehir Osmangazi Universitesi Turk Dunnyasi Uygulama ve Arastirma Merkezi (ESTUDAM) Egitim Dergisi*, 4, 38–50.

Akdeniz, M., & Ozdinc, F. (2021). Egitimde yapay zeka konusunda Turkiye adresli calismalarin incelenmesi. *Yuzuncu Yil Universitesi Egitim Fakultesi Dergisi*, 18, 912–932.

Akdur, T. E., Demir, R., & Dogan, U. (2024). *STEM egitimi icin teknoloji odakli ogrenme senaryolari-1* (Vol. 1). MEB Yenilik ve Egitim Teknolojileri Genel Mudurlugu.

Akin, F. A., & Atici, B. (2015). Oyun tabanli ogrenme ortamlari nin ogrenci basarisina ve goruslerine etkisi. *Turkish Journal of Educational Studies*, 2(2), Article 2.

Akinci, M., & Tunc, M. P. (2021). Uzaktan egitim uygulamalarinda matematik ogretmen adaylarinin karsilastiklari sorunlar ve cozum onerileri. *Ekev Akademi Dergisi*, 85, Article 85.

Aksoy, N. C., & Kelleci, O. (2023). Enhancing pre-service teachers' TPACK skills and self-efficacy beliefs via teaching practice assisted by AI-based simulation environment. *The Journal of International Education Science*, 10(36), 148–171.

Alboria, R., & Alsaleh, N. (2022). Educational robots and creative thinking skills. *The Scientific Journal of King Faisal University*, 23(9), 10–19. https://doi.org/10.37575/h/edu/210080

Altin, H., & Pedate, M. (2013). Learning approaches to applying robotics in science education. *Journal of Baltic Science Education*, *12*(3), 365–377.

Altun, E. (2024). Yapay zeka ve pedagoji: Egitimde firsatlar ve zorluklar. *Dijital Teknolojiler ve Egitim Dergisi*, 3(1), Article 1. https://doi.org/10.5281/zenodo.12637335

Altun, M., Ucar Altun, S., & Kutlu, E. (2023). *Ogretmenler icin yapay zeka uygulamalari*. MEB.

Altunel, M. (2018). *STEM egitimi ve Turkiye: FirSatlar ve riskler. SETA Perspektif, Sayı 207.*

Anilan, H., & Gezer, B. (2020). Kodlama etkinliklerine ve analitik dusunme becerisine yonelik sinif ogretmenlerinin goruslerinin incelenmesi. *Anadolu Universitesi Egitim Fakultesi Dergisi*, *4*(4), Article 4. https://doi.org/10.34056/aujef.801254

Aydogan, S. (2021). *Maker hareketi kapsaminda yapilan tasarim fabrikasi egitiminin 4. sinif ogrencilerinin problem cozme becerisi algilarina etkisinin incelenmesi* (Unpublished master's thesis). Bahcesehir Universitesi Lisansustu Egitim Enstitusu.

Aygun, H. E. (2019). Sosyal bilgiler ogretim programinin sosyal-duygusal ogrenme becerileri acisindan incelenmesi. *Egitim ve Teknoloji*, *1*(1), Article 1.

Bahsi, N., & Gencer, G. (2024). Egitimde dijital arac gerecler. In I. H. Yurdakal (Ed.), *Dijital Egitim I* (pp. 143–163). Egitim Yayinevi.

Bakar, E. (2023). Fen bilimleri dersinde beceri egitimi icin disiplinlerarasi iliskilendirme. *Milli Egitim Dergisi*, *52*(1), Article 1. https://doi.org/10.37669/milliegitim.1309008

Baker, H. M. S., & Abu-Naser, S. S. (2019). An intelligent tutoring system for learning TOEFL. *International Journal of Academic Pedagogical Research*, *2(*12), 9–15.

Baker, T., & Smith, L. (2019). *Educ-AI-tion rebooted?* Nesta.

Baris, A. (2020). A new business marketing tool: Chatbot. *GSI Journals Serie B: Advancements in Business and Economics*, *3*(1), 31–46. https://doi.org/10.5281/zenodo.4030216

Basaran, M., Ulger, I. G., Demirtas, M., Kara, E., Geyik, C., & Vural, O. F. (2021). Uzaktan egitim surecinde ogretmenlerin teknoloji kullanim durumlarinin incelenmesi. *OPUS International Journal of Society Researches*, *17*(37). https://doi.org/10.26466/opus.903870

Bati, K., Caliskan, I., & Yetisir, M. I. (2017). Fen egitiminde bilgi islemsel dusunme ve butunlestirilmis alanlar yaklasimi (STEAM). *Pamukkale Universitesi Egitim Fakultesi Dergisi*, *41*, Article 41.

Bayirtepe, E., & Tuzun, H. (2007). Oyun tabanli ogrenme ortamlari nin ogrencilerin bilgisayar dersindeki basarilari ve oz-yeterlik algilari uzerine etkileri. *Hacettepe Universitesi Egitim Fakultesi Dergisi*, *33*, Article 33.

Bayzan, S., & Ozçbilen, A. (2012). Dunyada internetin guvenli kullanimina yonelik uygulama ornekleri ve Turkiye'de bilinclendirme faaliyetlerinin incelenmesi ve Turkiye icin oneriler. *Engineering Sciences*, *7*(2). https://doi.org/10.12739/nwsaes.v7i2.5000066858

Bolat, Y. I., Simsek, O., & Ulker, U. (2017). Oyunlastirilmis cevrimici sinif yantlama sisteminin akademik basariya etkisi ve sisteme yonelik gorusler. *Abant Izzet Baysal Universitesi Egitim Fakultesi Dergisi*, *17*(4). https://doi.org/10.17240/aibuefd.2017.17.32772-363964

Breiner, J. M., Harkness, S. S., & Johnson, C. C. (2017). What is STEM? A discussion about conceptions of STEM in education and partnerships. *School Science and Mathematics*, *112*(1), 1–11.

Bybee, R. W. (2010). Advancing STEM education: A 2020 vision. *Technology and Engineering Teacher*, *70*(1), 30–35.

Caka, C. (2022). Robotic technologies in education and educational robotic applications. *Bilim, Egitim, Sanat ve Teknoloji Dergisi (BEST Dergi)*, *6*(2), 179–189.

Cakir, B. (2020). *Ortaokullarda kodlama egitiminin ogrencilerin yaratıcı problem cozme ve bilisustu farkindaliklarina etkisi* (Yuksek lisans tezi). Adnan Menderes Universitesi.

Cakir, R., Solak, E., & Tan, S. S. (2015). Artilmis gerceklik teknolojisi ile Ingilizce kelime ogretiminin ogrenci performansina etkisi. *Gazi Egitim Bilimleri Dergisi*, *1*(1).

am, E. (2019). *Robotik destekli programlama egitiminin problem cozme becerisi, akademik basari ve motivasyona etkisi* (Doktora tezi). ProQuest Dissertations Publishing. https://www.proquest.com/docview/2700779154/

Cam, M. B., Celik, N., Guntepe Turan, E., & Durukan, U. G. (2021). Ogretmen adaylarinin yapay zeka teknolojileri ile ilgili farkindaliklarinin belirlenmesi. *Mustafa Kemal Universitesi Sosyal Bilimler Enstitusu Dergisi*, *18*(48), 263–285.

Cameron, R. G. (2005). *Mindstorms Robolab: Developing science concepts during a problem-based learning club* (Yuksek lisans tezi). University of Toronto.

Capar, D. (2024). Egitimde dijital donusum. In S. Karatas (Ed.), *Egitim Bilimleri Alaninda Uluslararasi Arastirmalar XXIII* (pp. 35–55). Egitim Yayinevi.

Castelblanco, O. J., Donado, L. M., Gerlein, E. A., & Gonzalez, E. (2019). KALA: Robotic platform for teaching algorithmic thinking to children. IEEE. https://doi.org/10.1109/DEVLRN.2019.8850694

Cavus, M. N. (2024). Egitimde yapay zeka tabanli olcme ve degerlendirme uzerine bir derleme. *International Journal of English for Specific Purposes (JOINESP)*, *2*(1), 39–54.

Celik, S. (2021). *Lise ogrencilerinin 21. yuzyil becerilerini algilama duzeylerinin incelenmesi* (Yuksek lisans tezi). Biruni Universitesi. http://openaccess.biruni.edu.tr/xmlui/handle/20.500.12445/2073

Ceylan, V. K., & Gundogdu, K. (2018). Bir olgubilim calismasi: Kodlama egitiminde neler yasaniyor? *Egitim Teknolojisi Kuram ve Uygulama*, 8(2). https://doi.org/10.17943/etku.340103

Cevik, M., Uysal, A., Kellerlioglu, H. A., Ugras, N. H., & Erturk, A. (2024). Egitimde dijital icerik gelistirme stratejileri. *International QMX Journal, 3*(2).

Chassignol, M., Khoroshavin, A., Klimova, A., & Bilyatdinova, A. (2018). Artificial intelligence trends in education: A narrative overview. *Procedia Computer Science*, *136*, 16–24. https://doi.org/10.1016/j.procs.2018.08.233

Chen, L., Chen, P., & Lin, Z. (2020). Artificial intelligence in education: A review. *IEEE Access*, 8, 75264–75279.

Demircioglu, E., Yazici, C., & Demir, B. (2024). Yapay zeka destekli matematik egitimi: Bir icerik analizi. *International Journal of Social and Humanities Sciences Research*, *11*(106), 771–785.

Depe, E. F., Ertunc, G., & Kokoglu, H. (2023). Almanca ogretim ve ogreniminde cevrimici derslerin motivasyon ve onemi. *Biruni Saglik ve Egitim Bilimleri Dergisi*, 6(1).

Diyer, O., Achtaich, N., & Najib, K. (2022). Assessment of scientific learning skills based on artificial intelligence. In *2022 2nd International Conference on Innovative Research in Applied Science, Engineering and Technology (IRASET)* (pp. 1–5). IEEE. https://doi.org/10.1109/IRASET52964.2022.9738044

Dogac, E., & Gok, F. (2020). Yaparak yasayarak ogrenme yonteminin 5. sinif ogrencilerinin astronomiye karsi tutumlarina ve fen ogrenme motivasyonlarina etkisi. *Turkiye Egitim Dergisi*, 5(2).

Doger, M. F. (2016). *Bilgisayar destekli egitimlere katilan ogretmenlerin gorus ve deneyimlerine bagli olarak egitimde teknoloji kullanimini etkileyen dinamikler* (Yuksek lisans tezi). ProQuest. https://www.proquest.com/docview/3086152721/

Efe, A. (2021). Yapay zeka risklerinin etik yonunden degerlendirilmesi. *Bilgi ve Iletisim Teknolojileri Dergisi*, 3(1).

Eguchi, A. (2016). RoboCupJunior for promoting STEM education, 21st century skills, and technological advancement through robotics competition. *Robotics and Autonomous Systems*, *75*(B), 692–699. https://doi.org/10.1016/j.robot.2015.05.013

Ekin, C. C. (2022). Egitimde yapay zeka uygulamalari ve zeki ogretim sistemleri. In T. Talan (Ed.), *Egitimde dijitallesme ve yeni yaklasimlar*. Efe Akademi Yayinlari.

Elmas, C. (2021). *Yapay zeka uygulamalari* (5. bs). Seckin Teknik.

Elmas, R. (2022). STEM egitimi yaklasimi. In R. Akarsu, N. Okur Akcay, & R. Elmas (Eds.), *STEM egitimi yaklasimi* (1. bs, pp. 1–12). Pegem Akademi Yayinclik.

Erdogan, F. (2023a). *Matematik ve fen bilimleri egitiminde yeni yaklasimlar 2023-II*. Efe Akademi Yayinlari.

Erdogan, F. (2023b). *Robotik uygulamalarinin kodlama basarisina, tutumuna ve 21. yuzyil becerilerine etkisi* (Yuksek lisans tezi). Canakkale Onsekiz Mart Universitesi. http://acikerisim.comu.edu.tr/xmlui/handle/20.500.12428/4651

Erdogan, I., Ciftci, A., Yildirim, B., & Topcu, M. S. (2017). STEM education practices: Examination of the argumentation skills of pre-service science teachers. *Journal of Education and Practice*, *8*(25), 164–173.

Erol, A., & Erol, M. (2022). Turkiye'de erken cocuklukta STEM egitimi: Arastirmalarda egilimler. *Journal of Education for Life*, *36*(3), 590–609. https://doi.org/10.33308/26674874.2022363442

Erten, E. (2019). *Kodlama ve robotik ogretimi uzerine bir durum calismasi* (Yuksek lisans tezi). Balikesir Universitesi Fen Bilimleri Enstitusu. http://dspace.balikesir.edu.tr/xmlui/handle/20.500.12462/10109

Eser, E. (2014). Kuresellesme sureci ve egitime etkisi. *Anemon Mus Alparslan Universitesi Sosyal Bilimler Dergisi*, *2*(2).

Et, S. Z., & Gomleksiz, M. (2023). Fen Bilimleri Dersi Ogretim Programinin teknoloji okuryazarligi acisindan incelenmesi. *Firat Universitesi Sosyal Bilimler Dergisi*, *33*(3). https://doi.org/10.18069/firatsbed.1241459

Gezgin, D. M., Azaz, E., & Atabay, E. (2022). Ortaokul ogrencilerinin robotik ve kodlama egitimi basarilarina isbirlikli ogrenme tutumu, problem cozme becerisi algisi ve kisilik tiplerinin etkisi: Bir nedensel karsilastirma arastirmasi. *Journal of Instructional Technologies and Teacher Education*, *11*(2). https://doi.org/10.51960/jitte.1165083

Gezgin, D. M., & Mihci, C. (2023). Robotic technology in special education: Practices, challenges and ethical considerations. *4. Uluslararasi Istanbul Guncel Bilimsel Arastirmalar Kongresi*, Istanbul.

Goksel, S., & Adiguzel, A. (2024). Hibrit ogrenme modeli uzerine bir meta sentez calismasi: Uluslararasi ornekler. *Milli Egitim Dergisi*, *53*(243). https://doi.org/10.37669/milliegitim.1252931

Goksoy, S., & Yilmaz, I. (2018). Bilisim teknolojileri ogretmenleri ve ogrencilerinin robotik ve kodlama dersine iliskin gorusleri. *Duzce Universitesi Sosyal Bilimler Enstitusu Dergisi*, *8,* 178–196.

Gulnar, B., Tuglu, B., Saralar Arasi, I., Saban, M., & Sevil, S. (2024). *Egitimde yapay zeka uygulamalari uluslararasi forumu raporu* (p. 164). Milli Egitim Bakanligi.

Gunduz, A. Y. (2023). Egitimde yapay zeka ve oyunlastirma. In M. A. Ocak & O. Cakir (Eds.), *Egitim ve kultur calismalarinda yenilikci yaklasimlar* (pp. 1–15). Berikan Yayinlari.

Gur, Y. E., Ayden, C., & Yucel, A. (2019). Yapay zeka alanindaki gelismelerin insan kaynaklari yonetimine etkisi. *Firat Universitesi IIBF Uluslararasi Iktisadi ve Idari Bilimler Dergisi*, 3(2), 137.

Guven, E., & Sulun, Y. (2020). Ortaokul 5. sinif fen ogretiminde Arduino destekli robotik kodlama etkinliklerinin kullanilmasi. *Erzincan Universitesi Egitim Fakultesi Dergisi*, *25*(2), 225–236. https://doi.org/10.17556/erziefd.1116283

Guven, G., & Cakir, N. K. (2020). Investigation of the opinions of teachers who received in-service training for Arduino-assisted robotic coding applications. *Educational Policy Analysis and Strategic Research*, *15*(1), 253–274. https://doi.org/10.29329/epasr.2020.236.14

Hancer, A. H., Sensoy, O., & Yildirim, H. I. (2003). Ilkogretimde cagdas fen bilgisi ogretiminin onemi ve nasil olmasi gerektigi uzerine bir degerlendirme. *Pamukkale Universitesi Egitim Fakultesi Dergisi*, *13*(13).

Haseski, H. I. (2019). What do Turkish pre-service teachers think about artificial intelligence? *International Journal of Computer Science Education in Schools*, *3*(2). https://doi.org/10.21585/ijcses.v3i2.55

Hernandez, J. F. (2014). *The implementation of an elementary STEM learning team and the effect on teacher self-efficacy: An action research study* (Doktora tezi). Capella University.

Huei Chen, C., Kun Yang, C., Huang, K., & Chao Yao, K. (2020). Augmented reality and competition in robotics education: Effects on 21st century competencies, group collaboration and learning motivation. *Journal of Computer Assisted Learning*, *36*(6), 1052–1062. https://doi.org/10.1111/jcal.12469

Isler, B., & Kilic, M. Y. (2021). Egitimde yapay zeka kullanimi ve gelisimi. *Yeni Medya Elektronik Dergisi*, *5*(1), 1–11. https://doi.org/10.17932/IAU.EJNM.25480200.2021/ejnm_v5i1001

Kabadayi, G. S. (2019). *Robotik uygulamalarinin okul oncesi cocuklarin yaratici dusunme becerileri uzerine etkisi* (Yayimlanmamis yuksek lisans tezi). Hacettepe Universitesi.

Kaji, Y., Kawata, J., & Fujisama, S. (2019). Educational effect of participation in robot competition on experience-based learning. *Journal of Robotics and Mechatronics*, *31*(3), 383–390. https://doi.org/10.20965/jrm.2019.p0383

Kane, D. (2016). The role of chatbots in teaching and learning. *UC Irvine LAUC-I and Library Staff Research*, 131–156.

Karatas, H. (2021). 21. yy. becerilerinden robotik ve kodlama egitiminin Turkiye ve dunyadaki yeri. *21. Yuzyilda Egitim ve Toplum, 10*(30), 693–729.

Kavak, N., Tufan, Y., & Demirelli, H. (2006). Fen teknoloji okuryazarligi ve informal fen egitimi: Gazetelerin potansiyel rolu. *Gazi Egitim Fakultesi Dergisi*, *26*(3), 17–28.

Kaya, B., & Bozyigit, R. (2024). Cografya egitiminde bir sinif disi ogrenme ortami: Meram Dere Vadisi (Konya). *Necmettin Erbakan Universitesi Eregli Egitim Fakultesi Dergisi*, *6*(2).

Kaya, M., Korkmaz, O., & Cakir, R. (2020). Oyunlastirilmis robot etkinliklerinin ortaokul ogrencilerinin problem cozme ve bilgi islemsel dusunme becerilerine etkisi. *Ege Egitim Dergisi*, *21*(1), 54–70. https://doi.org/10.12984/egeefd.588512

Kilic, S. (2022). Robotik programlamanin on lisans ogrencilerinin bilgi islemsel dusunme becerisi gelisimine etkisi. *Afyon Kocatepe Universitesi Sosyal Bilimler Dergisi*, *24*(2), 480–494. https://doi.org/10.32709/akusosbil.919479

Kilic, V. (2021). Yapay zeka tabanli akilli telefon uygulamasi ile kan sekeri tahmini. *Avrupa Bilim ve Teknoloji Dergisi*, *26*. https://doi.org/10.31590/ejosat.950914

Kirmaci, O., & Cakmak, E. K. (2022). Oyunlastirilmis ogrenme ortami tasariminda bireysel ozellikler ve oyuncu tipi iliskisi. *Ahi Evran Universitesi Kirsehir Egitim Fakultesi Dergisi*, *23*(1). https://doi.org/10.29299/kefad.1032536

Kirtay, A. (2019). *Fen egitiminde robotik uygulamalarinin ogrencilerin bilimsel surec becerileri ve fen egitimine yonelik motivasyonlarina etkisi* (Yuksek lisans tezi). Mersin Universitesi.

Kizilay, E. (2023). Fen bilimleri egitiminde dusunme becerileri. In F. Erdogan (Ed.), *Matematik ve fen bilimleri egitiminde yeni yaklasimlar 2023-II* (1. bs). Efe Akademi Yayinlari.

Kim, S. W., & Lee, Y. (2016). The effect of robot programming education on attitudes towards robots. *Indian Journal of Science and Technology*, *9*(24). https://doi.org/10.17485/ijst/2016/v9i24/96104

Kiranli Gungor, S., & Ilgan, A. (2007). Egitim orgutlerinde karar verme asamasinda etik. *Mehmet Akif Ersoy Universitesi Elektronik Egitim Fakultesi Dergisi*, *8*(14).

Koc, A., & Buyuk, U. (2014). Fen egitiminde robotik kullanimi ve bilimsel surec becerilerini gelistirmeye yonelik etkisi. In *Fen ve matematik egitiminde bilgi teknoloji kullanimi* (ss. 916–922).

Koc Senol, A. (2012). *Robotik destekli fen ve teknoloji laboratuvar uygulamalari: Robolab* (Yuksek lisans tezi). Erciyes Universitesi.

Koray, A., & Uzuncelebi, B. H. (2023). The effect of educational robotics applications on students' academic achievement and problem-solving skills in science education. *Journal of Education in Science, Environment and Health*, *9*(2), 317–327. https://doi.org/10.55549/jeseh.1381251

Korkmaz, A. (2023). Dijital dilin yolculugu: ChatGPT ve yapay zekanin dogal dil isleme dunyasindaki rolu. 2. *BİLSEL International World Science and Research Congress*, 16-17 September 2023, İstanbul/Türkiye, (ss. 348–358).

Koyuncuoglu, A., & Taspinar, M. (2024). Okul yoneticilerinin egitimde teknoloji entegrasyonu konusunda gorev ve sorumluluklarina iliskin gorusleri. *Heterotopic View*, *2*(1). https://doi.org/10.5281/zenodo.12172972

Kucukaydin, M. A., & Bor, S. S. (2021). Yapay zeka baglaminda sosyobilimsel konu ogretiminin ilkokul ogrencilerinin problem cozme ve yaratici yazma becerilerine etkisi. *Bati Anadolu Egitim Bilimleri Dergisi*, *12*(2). https://doi.org/10.51460/baebd.904806

Kuzgun, H., & Ozdinc, F. (2017). Okul oncesi egitimde teknoloji kullanimina yonelik ogretmen goruslerinin incelenmesi. *Usak Universitesi Sosyal Bilimler Dergisi*, *10*(ERTE Ozel Sayisi). https://doi.org/10.12780/usaksosbil.373856

Lacin Simssek, C. (2020). *Fen ogretiminde okul disi ogrenme ortamları* (2. bs). Pegem Akademi Yayincilik.

MEB. (2018). *Fen bilimleri dersi ogretim programi*. Milli Egitim Bakanligi.

MEB. (2020, Aralik 22). Milli Egitim Bakanligi. https://www.meb.gov.tr

Metin, E. (2018). Egitimde teknoloji kullaniminda ogretmen egitimi: Bir durum calismasi. *Journal of STEAM Education*, *1*(1).

Nalbant, K. G. (2021). The importance of artificial intelligence in education: A short review. *Journal of Review in Science and Engineering*. Article ID : JRSE-2106302112361

Okur Akcay, N. (2022). STEM yaklasiminda fen egitimi. In M. Akarsu, N. Okur Akcay, & R. Elmas (Eds.), *STEM egitimi yaklasimi* (1. bs). Pegem Akademi Yayincilik.

Ouyang, F., & Weiqi, X. (2024). The effects of educational robotics in STEM education: A multilevel meta-analysis. *International Journal of STEM Education*, *11*(7), 2–18. https://doi.org/10.1186/s40594-024-00469-4

Ozbilen, A. G. (2018). STEM egitimine yonelik ogretmen gorusleri ve farkindaliklari. *Scientific Educational Studies*, *2*(1).

Ozdinc, F., & Mumcu, F. (2022). Disiplinlerarasi fen ogretiminde teknolojinin rolu. In B. Aydogdu & N. Yildiz Duban (Eds.), *Disiplinlerarasi fen ogretimi* (ss. 93–116). Ani Yayincilik.

Paaskesen, R. B. (2020). Play-based strategies and using robot technologies across the curriculum. *International Journal of Play*, *9*(2), 230–254. https://doi.org/10.1080/21594937.2020.1778272

Parlak, B. (2017). Dijital cagda egitim: Olanaklar ve uygulamalar uzerine bir analiz. *Suleyman Demirel Universitesi Iktisadi ve Idari Bilimler Fakultesi Dergisi*, *22*(KAYFOR 15 Ozel Sayisi).

Ramazanoglu, M. (2021). Robotik kodlama uygulamalarinin ortaokul ogrencilerinin bilgisayara yonelik tutumlarina ve bilgi islemsel dusunme becerisine yonelik oz yeterlik algilarina etkisi. *Turkiye Sosyal Arastirmalar Dergisi*, *25*(1), 163–174.

Richter Zawacki, O., Marin, V. I., Bond, M., & Gouverneur, F. (2019). Systematic review of research on artificial intelligence applications in higher education: Where are the educators? *International Journal of Educational Technology in Higher Education*, *16*(39). https://doi.org/10.1186/s41239-019-0171-0

Russell, S., & Norving, P. (2003). *Artificial intelligence: A modern approach* (2nd ed.). Pearson Education.

Ryan, T., & Bagley, G. (2015). Nurturing the integration of technology in education. *Egitimde Kuram ve Uygulama*, *11*(1). https://doi.org/10.17244/eku.15490

Sarioglu, S. (2023). Bilimsel surec becerilerinin yapay zeka ile yordanmasi, ogrenciler ve ustun yetenekli ogrencilerdeki etkililigi. https://hdl.handle.net/11452/38818

Sayin, Z. (2020). Ogretmenlerin kodlama egitiminde egilimlerinin belirlenmesi. *Journal of Instructional Technologies and Teacher Education*, *9*(1).

Schina, D., Esteve-Gonzalez, V., & Usart, M. (2021). An overview of teacher training programs in educational robotics: Characteristics, best practices and recommendations. *Education and Information Technologies*, *26*, 2831–2852.

Seckin Kapucu, M. (2023). Studies on robotic coding education in science education: A systematic literature review. *Journal of Education in Science, Environment and Health*, *9*(1), 74–84. https://doi.org/10.55549/jeseh.1239093

Selvi, M., & Yildirim, B. (2018). STEM ogretme ogrenme modelleri: 5E ogrenme modeli, proje tabanli ogrenme yaklasimi ve STEM modeli. In S. Cepni (Ed.), *Kuramdan uygulamaya STEM+A STEM+E egitimi* (4th ed.). Pegem Akademi Yayincilik.

Shelton, B. E., & Hedley, N. R. (2002). Using augmented reality for teaching Earth–Sun relationships to undergraduate geography students. *The First IEEE International Workshop Augmented Reality Toolkit*, 8 pp. https://doi.org/10.1109/ART.2002.1106948

Soypak, B., & Eskici, M. (2023). Lise-ortaokul matematik, fen derslerinde robotik kodlama uygulamalarina yonelik arastirmalarin incelenmesi: Bir icerik analizi calismasi. *Fen, Matematik, Girisimcilik ve Teknoloji Egitimi Dergisi*, *6*(3), 214–229.

Sullivan, F. R. (2008). Robotics and science literacy: Thinking skills, science process skills and systems understanding. *Journal of Research in Science Teaching*, *45*(3), 373–394.

Sultan Qurraie, B. (2024). Sinematik ilhamin grafik, mimarlik ve moda tasarimi egitimine etkisi. *Online Journal of Art and Design*, *12*(4).

Surer, A. G. (2020). Egitimde dijitallesme cagi. *Kapadokya Egitim Dergisi*, *1*(1).

Sahin, A., Ozkan, R. A., & Turan, B. N. (2022). Ilkokul ogrencilerine yonelik dijital okuryazarlik olceginin gelistirilmesi: Gecerlik ve guvenirlik calismasi. *Ana Dili Egitimi Dergisi*, *10*(3), 619–630. https://doi.org/10.16916/aded.1109283

Senocak, D. (2020). Acik ve uzaktan ogrenme ortamalarinda yapay zeka: Firsatlar ve endiseler. *Acikogretim Uygulamalari ve Arastirmalari Dergisi*, *6*(3), 56–78.

Simsek, K. (2019). *Fen Bilimleri dersi Madde ve Isi unitesinde robotik kodlama uygulamalarinin etkisi* [Yuksek lisans tezi]. https://www.proquest.com/docview/2469157976

Simsek, M. E. (2024). Dijital din egitimi. *Ilahiyat Akademi*, 19. https://doi.org/10.52886/ilak.1435052

Tatlisu, M. (2020). *Egitsel robotik uygulamalarda probleme dayali ogrenmenin etkisi* [Yuksek lisans tezi]. https://www.proquest.com/docview/2572552531

Tekin, Y., & Keser, H. (2020). Matematik ogretiminde robotik etkinlikler kullaniminin basariya etkisi. *Akdeniz Egitim Arastirmalari Dergisi*, *14*(34), 472–493. https://doi.org/10.29329/mjer.2020.322.22

Tepe, T., Kaleci, D., & Tuzun, H. (2016). Egitim teknolojilerinde yeni egilimler: Sanal gerceklik uygulamalari. In *10th International Computer and Instructional Technologies Symposium (ICITS)* (Vol. 16, No. 18, pp. 547-555).

Thomasian, J. (2011). *Building a science, technology, engineering, and math education agenda*. NGA Center for Best Practices.

Tol, H. Y. (2018). *Matematik konularinin tarihsel gelisimlerinin senaryo tabanli ogrenme yontemi ile anlatilmasinin etkileri* [Yuksek lisans tezi]. https://www.proquest.com/docview/2572152836

Turan, S., & Aydogdu, F. (2020). Effect of coding and robotic education on pre-school children's scientific process skills. *Education and Information Technologies*, *25*, 4353–4363.

Turk, E. F., & Korkmaz, O. (2023). Egitsel robot setleri ile gerceklestirilen STEM etkinliklerinin etkililigi: Deneysel bir calisma. *Ahmet Kelesoglu Egitim Fakultesi Dergisi*, *5*(1), 92–118. https://doi.org/10.38151/akef.2023.46

Ucar, A., & Sezek, F. (2024). Fen ogretiminde Lego robotik uygulamalarinin akademik basariya etkisi. *Abant Izzet Baysal Universitesi Egitim Fakultesi Dergisi*, *24*(2). https://doi.org/10.17240/aibuefd.2024..-1311405

Ulkudur, M. A. (2016). *Proje tabanli ogrenme etkinlikleri ile oyun tabanli ogrenme etkinliklerinin etkisi* [Yuksek lisans tezi]. ProQuest.

Wartman, S. A., & Combs, D. (2018). Medical education must move from the information age to the age of artificial intelligence. *Academic Medicine*, *93*, 1107–1109. https://doi.org/10.1097/ACM.0000000000002044

Yalcin, N., & Akbulut, E. (2021). STEM egitimi ve robotik kodlama egitimlerinin incelenmesi: Kizilcahamam Kodluyor ornegi. *Turkiye Sosyal Arastirmalar Dergisi*, *25*(2), 469–490.

Yanarates, E. (2022). Fen bilimleri ogretimi ve teknoloji kullanimina guncel yaklasimlar. In T. Talan (Ed.), *Egitimde dijitallesme ve yeni yaklasimlar*. Efe Akademi Yayinlari.

Yar Sevmis, B. (2023). Dijital vatandaslik egitimi. In B. G. Sen (Ed.), *Dijital Egitim ve Toplum* (pp. 173–189). Efe Akademi Yayinlari.

Yildiz Durak, H. (2020). The effects of using different tools in programming teaching of secondary school students. *Technology, Knowledge and Learning*, 25(1), 179–195. https://doi.org/10.1007/s10758-018-9391-y

Yoruk, T. (2024). Egitimde yapay zeka ve kisisellestirilmis ogrenme. In S. Karatas (Ed.), *Egitim Bilimleri Alaninda Uluslararasi Arastirmalar XXIII*. Egitim Yayin Evi.

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# SCIENCE EDUCATION AND COMPUTATIONAL THINKING: INTERACTIVE LEARNING WITH ARTIFICIAL INTELLIGENCE

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## INTRODUCTION

The rapidly transforming knowledge and technology ecosystem of the twenty-first century has shifted the focus of science education from mere transmission of concepts to the holistic development of twenty-first-century skills such as critical thinking, creative problem-solving, collaboration, communication, digital literacy, and data literacy. In this context, science education aims to cultivate learners who are not passive recipients explaining natural phenomena, but active participants who collect and analyze data, construct models, and generate solutions through computational tools. Learning experiences designed around interdisciplinary connections and real-world problems integrate inquiry-based learning processes, modeling and simulation, evidence-based reasoning, and ethical awareness, thereby making science learning meaningful and enduring.

Computational Thinking (CT) and Artificial Intelligence (AI) are among the key driving forces of this transformation in science education. CT represents a contemporary way of thinking that encompasses systematic problem solving, decomposition into subproblems, abstraction, the development of algorithmic solutions, modeling/simulation, and the iterative cycle of testing, debugging, and generalization (Juškevičienė et al., 2021; Tsarava et al., 2022). Within the science context, CT makes relationships between variables visible, integrates the triad of experiment–data–model, and enables students to deepen their scientific reasoning through quantitative and computational tools. AI, in turn, supports this process through personalized feedback, learning analytics, pattern recognition, and adaptive simulations or virtual laboratories, thereby enhancing the visualization of abstract concepts, data-driven decision-making, and higher-order thinking skills (García et al., 2019). Consequently, the synergy of CT and AI can create an interactive, evidence-based, and productive learning ecosystem within science classrooms.

The purpose of this chapter is to examine the interaction between CT and AI in science education from both theoretical and practical perspectives. The chapter first defines CT and its core components, followed by an exploration of how this mode of thinking can be integrated into science education through inquiry-based learning environments. Subsequently, the conceptual connection between CT and AI is discussed, highlighting how the algorithm–data–model cycle intersects with the perception, learning, and representation dimensions of AI. The following section focuses on AI-supported interactive learning applications, examining intelligent tutoring systems, data analysis through machine learning, adaptive simulations, virtual laboratories, and feedback mechanisms based on learning analytics through illustrative activities. The chapter concludes with implications for teachers and researchers, including applicable instructional principles, assessment and evaluation approaches, and ethical considerations.

## Computational Thinking: Definition and Components

Computational thinking (CT) is an approach to thinking that enables individuals to solve complex problems systematically, creatively, and algorithmically (Sarı et al., 2025). The concept was first introduced by Papert (1980) to explain the cognitive effects of computer use in education, but it gained widespread recognition through Wing's (2006) definition. According to Wing (2006), CT is "*the thought process involved in formulating problems and their solutions so that the solutions are represented in a form that can be effectively carried out by an information-processing agent*." This definition positions CT not merely as a programming skill but as a universal mode of thought that every individual can use to solve problems encountered in everyday life.

Barr, Harrison, and Conery (2011) define CT as a multifaceted cognitive framework encompassing processes such as data collection and analysis, algorithm development, automation, solution generation, and generalization. Grover and Pea (2013) emphasize that at the core of this approach lie abstraction, decomposition, algorithmic thinking, debugging, and generalization. Similarly, Kalelioğlu et al. (2016) relate CT to the problem-solving process, describing it as involving the sequential steps of problem redefinition, solution planning, testing, and generalization of results. In this sense, CT can be viewed not only as a product of computer science but also as a digital-age adaptation of fundamental cognitive processes. To solve a problem, an individual first decomposes the complex structure into smaller parts (decomposition), selects relevant information (abstraction), transforms the solution into a series of logical steps (algorithmic thinking), tests outcomes, and applies them to new situations (generalization). Each of these processes constitutes a systematic cognitive problem-solving cycle. Although different classifications exist in the literature, most researchers share similar perspectives regarding the core components of CT (Barr & Stephenson, 2011; Grover & Pea, 2013; Kalelioğlu et al., 2016; Weintrop et al., 2016). These components can be summarized as follows:

- ***Decomposition:*** The ability to break down complex problems into smaller, manageable subproblems.

- ***Pattern Recognition:*** The skill of identifying similarities and differences in data to make generalizations.
- ***Abstraction:*** The process of selecting the essential information relevant to the problem while eliminating unnecessary details.
- ***Modeling and Simulation:*** The capability to construct and test representative models of real-world systems.
- ***Algorithmic Thinking:*** The ability to develop logical, step-by-step procedures to solve problems.
- ***Data Handling:*** The process of collecting, organizing, analyzing, and interpreting relevant data.
- ***Automation:*** The ability to perform repetitive processes using computer-assisted tools.
- ***Parallelism:*** The cognitive awareness that allows for the simultaneous management of multiple processes.
- ***Debugging:*** The process of verifying the correctness of solutions, identifying errors, and correcting them.
- ***Generalization:*** The ability to apply developed solutions to similar problems.

Taken together, these components demonstrate that CT is not merely a computational process but also one of the fundamental pillars of analytical thinking, systematic inquiry, and problem-solving ability. As individuals acquire these processes, they become more efficient problem solvers, better interpreters of data, and more capable of generating transferable knowledge across contexts.

CT is not limited to cognitive processes alone; it also encompasses affective dimensions such as self-confidence, patience, curiosity, collaboration, and perseverance (Barr & Stephenson, 2011). Especially when dealing with open-ended and ill-defined problems, learners' willingness to experiment, learn from mistakes, and develop strategies throughout the process are crucial factors supporting the development of CT. In this respect, CT strengthens both learners' cognitive flexibility and learning autonomy (Shute, Sun, & Asbell-Clarke, 2017).

In summary, CT is an interdisciplinary mode of thought that integrates cognitive, algorithmic, and creative dimensions of problem solving. This framework extends beyond programming skills to include thinking with data, developing systematic strategies, and producing adaptable solutions for new situations. The next section explores the relationship between this mode of thinking and science education, focusing on how CT skills can be developed in students and integrated into science learning processes.

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### Computational Thinking and Science Education

CT, as a mode of thought that supports interdisciplinary problem-solving processes beyond the scope of computer science, has gained increasing importance in science education. The primary goal of science education is to enable students to make sense of natural phenomena, develop and test hypotheses, and derive meaningful conclusions from scientific data. Throughout this process, students are expected to employ skills such as inquiry-based reasoning, data analysis, modeling, and evidence-based argumentation. CT provides a cognitive framework that aligns closely with these skills (Weintrop et al., 2016; Sarı & Karaşahin, 2020).

Science problems are often open-ended, involve multiple variables, and require experimental approaches. CT enables students to understand complex systems, develop solutions by decomposing problems into subcomponents, and adopt systematic habits of mind (Grover & Pea, 2013; Malik et al., 2018). During experimental inquiry, students define the problem, identify variables, collect and analyze data, and then generalize the findings. This process directly corresponds to the computational cycle of decomposition, abstraction, algorithmic thinking, modeling, testing, and generalization (Sarı et al., 2025). Therefore, CT can be integrated into both the cognitive and methodological structures of science teaching.

Science learning environments, by their nature, are well suited for computational processes. Experiments, measurements, and observations are based on specific algorithms; data are systematically collected and analyzed. For instance, when designing an experiment, students follow steps such as determining measurement intervals, adjusting repetition frequencies, and interpreting data sets. These steps are cognitively equivalent to algorithmic operations (Sarı et al., 2025). Additionally, identifying and correcting errors during experimentation parallels the "debugging" process in computation. This approach not only helps students reach accurate results but also allows them to evaluate and refine their problem-solving processes.

Modeling and abstraction processes in science teaching also correspond closely with the key components of CT. When students attempt to explain a physical phenomenon, they simplify the model, eliminate unnecessary variables, and construct an abstract representation of the system. This directly mirrors the concept of abstraction in CT (Sarı & Karaşahin, 2020; Zakwandi & Istiyono, 2023). Similarly, the generalization and testing of experimental outcomes under different conditions align with the process of generalization. In this way, students simultaneously engage in both scientific and computational reasoning.

The effective use of CT in science education has become increasingly feasible with the proliferation of technology-enhanced learning environments. Microcontroller-based systems (e.g., Arduino), sensors, and data acquisition software directly enhance students' data processing and analysis skills (Sarı, 2019; Papadimitropoulos, Dalacosta, & Pavlatou, 2021). Using these tools, students collect experimental data, create graphs in digital environments, and interpret results algorithmically. Through this process, they experientially learn both automation and data analysis skills. Moreover, simulations and virtual laboratories allow students to visualize complex systems and explore the effects of parameter changes. Such digital tools concretize abstract concepts and enable students to test their own models and hypotheses (Sarı et al., 2020). Hence, technology-supported science activities transfer CT components directly into practice, reinforcing students' higher-order thinking skills (Sarı et al., 2025).

STEM education integrates science, technology, engineering, and mathematics disciplines to foster problem-solving and innovative thinking skills in students (Sarı et al, 2022). CT serves as the cognitive engine of this integrative framework. There are clear parallels between the engineering design process and the CT process—both involve defining the problem, conducting research, developing solutions, creating prototypes, testing, and improving them (Sarı & Karaşahin, 2020). In these processes, students employ both scientific and computational reasoning to produce innovative solutions. Moreover, CT and STEM share a common foundation for fostering twenty-first-century skills. Creativity, critical thinking, collaboration, communication, and algorithmic reasoning lie at the core of both CT and STEM (Korkmaz, Çakır, & Özden, 2017). In this sense, science classrooms evolve into dynamic learning environments where students not only acquire scientific knowledge but also apply these skills to real-world problems.

In conclusion, the integration of CT into science education deepens students' scientific process skills while supporting the development of higher-order abilities such as cognitive flexibility, self-regulation, and learning motivation. CT-based science activities promote systematic thinking in processes such as data collection, modeling, testing, and generalization, thereby enhancing students' active engagement in the learning process.

## Computational Thinking and Artificial Intelligence

Computational thinking (CT), as a cognitive framework that integrates computational power into problem-solving processes, shares a strong conceptual relationship with artificial intelligence (AI). Through skills such as algorithmic thinking, data analysis, modeling, and abstraction, CT systematizes the human mode of reasoning, while AI transfers these cognitive processes into the digital domain, enabling machines to learn (Wing, 2008; Floridi, 2019). Therefore, integrating AI into computational thinking frameworks is crucial for understanding the intersection of human and machine cognition in problem-solving contexts.

In an AI-based learning ecosystem, the scope of CT extends beyond algorithm design to include more complex cognitive processes such as data classification, prediction, modeling, and evaluation. Brummelen et al. (2019) and García et al. (2019) identify five core computational concepts associated with AI: classification, prediction, generation, training/validation/testing, and evaluation. These stages closely parallel the cyclical structure of CT—data collection and processing, algorithm construction, model formation, testing, and generalization. In this way, AI transforms CT from merely a way of thinking into an applied field at the level of "learning systems."

Machine learning, as a core component of AI, allows computers to emulate human learning processes and improve their performance over time (Essinger & Rosen, 2011). While CT systematizes human problem-solving processes, machine learning translates these processes into digital environments (Heintz, 2022). Thus, both concepts play complementary roles in problem solving. Through machine learning applications, students develop computational skills such as data analysis, pattern recognition, prediction, and model construction (García et al., 2019; Dohn et al., 2022). Consequently, AI-supported learning activities not only foster technical knowledge but also stimulate higher-order cognitive abilities such as analytical thinking, creativity, and critical decision-making.

The integration of AI into education expands students' cognitive awareness while deepening their understanding of ethical, social, and philosophical dimensions. Gadanidis (2017) and Gadanidis et al. (2024) emphasize that AI is not merely a technology but a learning environment that transforms how students think. In this context, students move beyond understanding how AI systems function to questioning their outcomes, recognizing biases, and evaluating the societal implications of algorithmic decision-making. Thus, when considered together, CT and AI provide a holistic learning approach encompassing both cognitive and ethical dimensions.

AI literacy has gained increasing significance within contemporary educational systems. Incorporating AI-related content into K–12 curricula is essential for helping students grasp fundamental concepts of artificial intelligence. In studies conducted by Ho and Scadding (2019), two AI activities at the elementary level exemplify this approach. In the first activity, students learned about data labeling and feature extraction through a card-matching task that mimicked facial recognition. In the second activity, they engaged with machine learning principles using Lego Mindstorms EV3 robots, constructing their own "learning systems" through cycles of prediction, trial and error, and feedback. Such activities bridge abstract AI concepts with tangible science learning experiences.

The K–12 initiative and the AI4K12 standards link AI literacy to computational thinking skills and define five core themes: perception, representation and reasoning, learning (machine and deep learning), natural interaction, and societal impact (Touretzky et al., 2019). These themes aim to help students understand the cognitive functioning of AI while developing a human-centered perspective. Choi (2019) and Min and Shim (2021) highlight that the assessment of AI-related competencies remains an emerging area, whereas Kim and Lee (2020) developed tools for measuring students' attitudes toward and literacy in AI. These findings indicate the need for educational systems to restructure their AI assessment criteria.

In recent years, AI has also demonstrated a transformative impact in the context of teacher education and learning design. Annuš (2024), Foster (2024), and Ajlouni et al. (2023) have shown that AI technologies contribute significantly to improving lesson planning, developing instructional materials, and personalizing learning processes. Likewise, Ali et al. (2019) and Wong (2020) emphasize that teachers and school systems must pedagogically integrate AI's potential through innovative approaches. In this regard, AI functions not merely as a tool but as a cognitive partner that enables the redesign of learning processes.

In conclusion, the integration of computational thinking and artificial intelligence enhances not only students' problem-solving abilities but also their critical awareness, ethical reasoning, and social responsibility. This integration demonstrates that AI-supported computational thinking in science education has evolved into a learning paradigm that is both cognitively and value-oriented.

### Artificial Intelligence–Supported Interactive Learning in Science Education

In recent years, the convergence of increased computational capacity, large data sets, and advanced machine learning algorithms has paved the way for remarkable progress in artificial intelligence (AI) technologies. As a subfield of computer science, AI encompasses the design of systems capable of performing cognitive processes traditionally associated with human intelligence, such as learning, reasoning, adaptation, and self-correction (Dobrev, 2012). This development necessitates the integration of knowledge and skills related to AI into educational processes to prepare individuals to participate effectively in an AI-driven world (Eaton et al., 2018).

The integration of AI into education is not confined to higher education; it is increasingly recommended that foundational concepts be introduced at early ages to help students understand these technologies (Heintz, 2021). AI-supported teaching and learning applications have rapidly expanded across disciplines such as language education (Pokrivcakova, 2019), mathematics (Gadanidis, 2017), biology (Perrakis & Sixma, 2021), and physics (Cheah, 2021). These systems provide personalized and interactive learning environments through intelligent tutoring assistants (Kim et al., 2020) and learning agents (Petersen et al., 2021) that adapt content to learners' profiles. Large language models such as ChatGPT demonstrate transformative potential in education by offering dynamic, inquiry-driven, and feedback-based learning experiences (Baidoo-Anu & Owusu Ansah, 2023).

Machine learning, one of the most influential components of AI in science education, personalizes learning experiences according to individual differences and transforms learning into an interactive process (Alam, 2022). The integration of computational processes such as data analysis, model construction, and hypothesis testing with AI in science teaching enhances students' scientific and algorithmic reasoning skills. Indeed, studies conducted at the university level have shown that AI has been used to identify misconceptions related to topics such as the greenhouse effect and electricity (Kökver et al., 2024; Pektaş et al., 2025), and that automatic AI modules have been developed to analyze preservice teachers' learning styles (Pektaş, 2025). However, systematic investigations of AI applications in science education, particularly at the primary and secondary levels, remain limited (Akgun & Greenhow, 2021; Xu & Ouyang, 2022). The use of AI in science teaching is often examined within the contexts of STEM or e-learning, while holistic approaches from a general science education perspective are still emerging (Tang et al., 2023). This highlights the need for comprehensive studies that reveal the potential of AI-supported interactive learning environments in science education.

AI-based learning environments support both students' scientific process skills and higher-order cognitive competencies. Children, often unconsciously, interact with AI-based applications in their daily lives, such as facial recognition or voice assistant technologies. Therefore, understanding how AI systems function enables them to interpret the digital world they inhabit more consciously. Developing AI awareness at an early age is not only a technological skill but also a crucial step in fostering critical thinking, ethical reasoning, and social responsibility.

Kandlhofer and Steinbauer (2021) and Su and Zhong (2022) emphasize that introducing AI education at an early age strengthens students' abilities to understand and create technology. Furthermore, integrating AI into science classes increases students' interest in science, encourages them toward innovative applications, and contributes to cultivating future AI experts (Ali et al., 2019; Heintz, 2021). In this respect, AI is not merely a tool in science education but an interactive learning partner that deepens students' computational thinking processes.

## A Sample Activity Integrating Computational Thinking and Artificial Intelligence in Science Education

This section presents an example of an AI-supported learning activity that integrates computational thinking (CT) skills into science education. In this activity, students are tasked with developing an intelligent tutoring system based on machine learning. The system analyzes onion epidermis cell images obtained through a microscope and provides feedback to students on visual quality and accuracy using learning analytics. Through this process, students have the opportunity to experience AI's mechanisms of data processing, classification, and feedback generation within a science laboratory context. The activity is structured around the core stages of computational thinking—abstraction, decomposition, modeling, algorithm design, testing and debugging, automation, and generalization. The stages of the activity and the operations performed are described below.

### Activity Title: If Only I Could Automatically Find the Cell

### Abstraction

In this phase, students focused on the essence of the problem by moving away from complex data and identifying the main objective: *"When an image is displayed, the system should be able to recognize whether it is an onion epidermis*

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*and assess its clarity to provide feedback."* Students captured onion epidermis images using a microscope and also collected additional microscopic onion epidermis images from the internet for comparison. They recorded colored images using staining chemicals such as Lugol's solution (see **Figure 1**) and methylene blue (see **Figure 2**) and as additional data. The image without onion epidermis is shown in **Figure 3**. During this process, a dataset of 535 onion epidermis images was created.

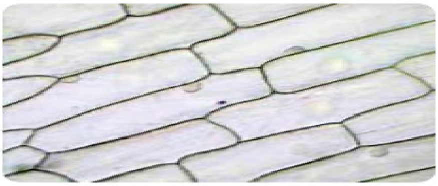

**Figure 1.** *Clear Image*

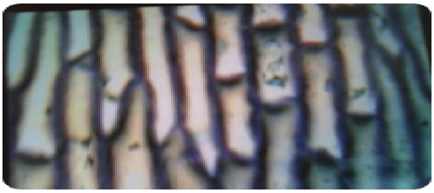

**Figure 2.** *Blurred Image*

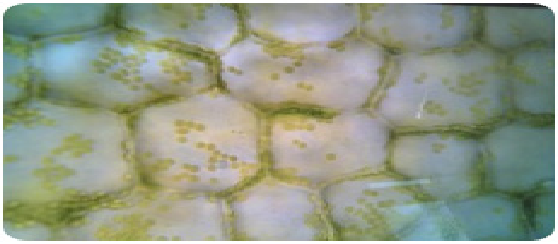

**Figure 3.** *Image Not Showing Onion Epidermis*

### Decomposition

In this stage, students decomposed the image data and performed a classification process. They categorized the images into three distinct groups: non–onion epidermis images, blurred images, and clear images. As a result of this process, the dataset was divided into 148 blurred images, 160 non–onion epidermis images, and 227 clear images. (see **Figure 4**).

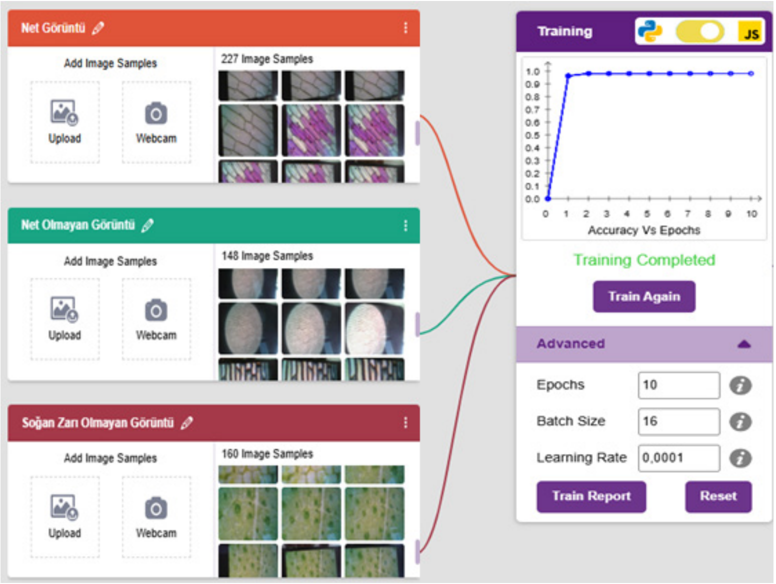


**Figure 4.** *Image Classification and Model Training Process*

### Modeling

In this stage, students divided the problem situation into subproblems and identified the variables for each. The first subproblem concerned the classification of images, while the second focused on the feedback generated by the learning analytics system. Using an artificial intelligence tool, the students trained the system with the collected data and prepared it for implementation. In this model, the value **0** represented images that were *not onion epidermis*, **1** indicated *blurred images*, and **2** denoted *clear images*. (see **Figure 5**).

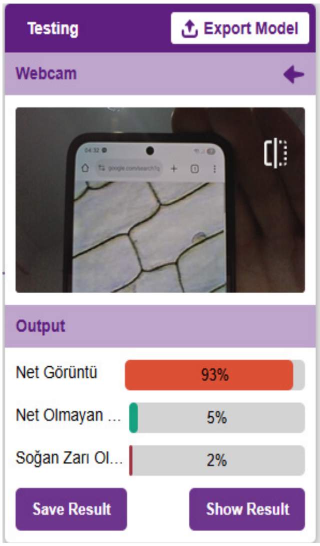


**Figure 5.** *Developed Artificial Intelligence Model*

### Algorithm Design

After completing the training of the dataset, students were required to test the results by capturing an image of the onion epidermis through the microscope and uploading it to the instructional material via a mobile phone. If the image was clear, it would be classified under category **2**; if it was not clear, under category **1**; and if it was not an onion epidermis image, under category **0**, with corresponding accuracy rates displayed. As a result, an AI-supported instructional material was designed to enable students to test the accuracy of their microscopic images of the onion epidermis with high precision. Therefore, in this stage, students were required to develop an algorithm. The designed algorithm is presented below:

- When the **space key** is pressed, open the image recognition window.
- Start the **video stream**.
- If the image is clear, display the message: *"Congratulations!"*
- If the image is blurred, display the message: *"The image is not clear; please recheck the specimen!"*
- If the image is not an onion epidermis, display the message: *"This is not an onion epidermis image!"*

At this stage, students used algorithmic thinking and conditional statements (*if–else*) to understand how AI systems make decisions.

### Testing and Debugging

Working collaboratively, students made real-time improvements to enhance image quality. To ensure the AI model functioned efficiently, they created additional and more diverse image datasets. Consequently, the developed AI model was continuously tested with new images, minimizing potential errors through iterative refinements. Through this process, students directly experienced the "learning" nature of machine learning via testing and debugging cycles.

### Automation

After writing the algorithm, students realized that they needed to include a plugin enabling continuous repetition. A *"repeat forever"* command was added to keep the system running constantly, allowing the model to automatically generate new feedback when encountering different images. Through this step, students gained an understanding of the importance of automation and cyclic execution within an algorithmic process (see **Figure 6**).

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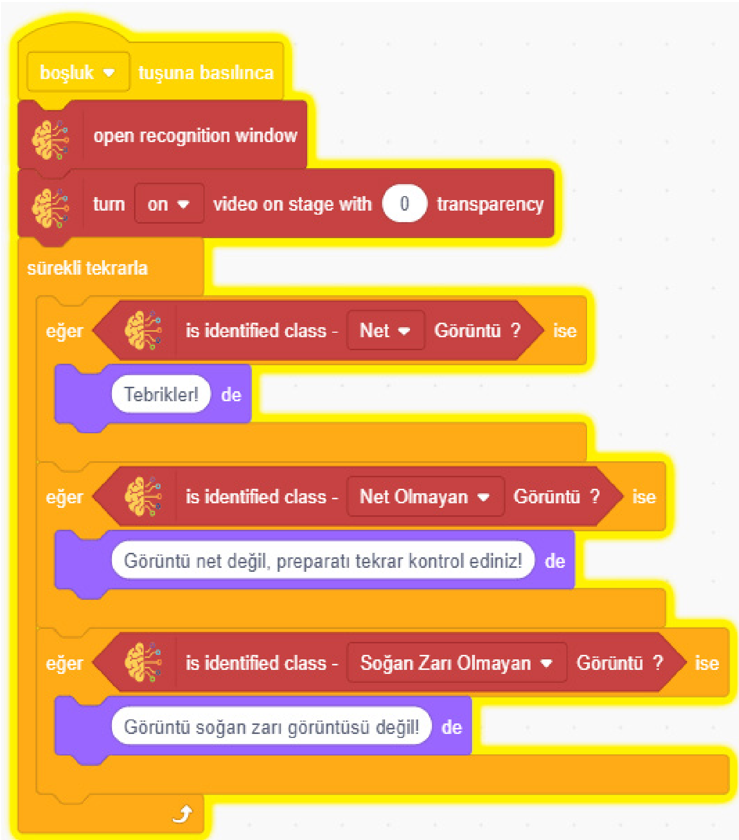


**Figure 6.** *Development of the Continuously Repeating Artificial Intelligence Module*

Students read the feedback displayed by the learning analytics system and repeatedly followed the given steps to obtain a clear and accurate image.

## Data Collection, Representation, and Analysis

Students examined whether the developed artificial intelligence (AI) model functioned correctly and collected data to make inferences. First, they gathered data related to the model's accuracy rates (*see* **Figure 7**). By evaluating the learning analytics results, students identified in which categories the system performed more successfully and represented their findings using graphical visualizations. The data related to other artificial intelligence computations are presented in **Figure 8**. **Figure 9** presents the data obtained from learning analytics.

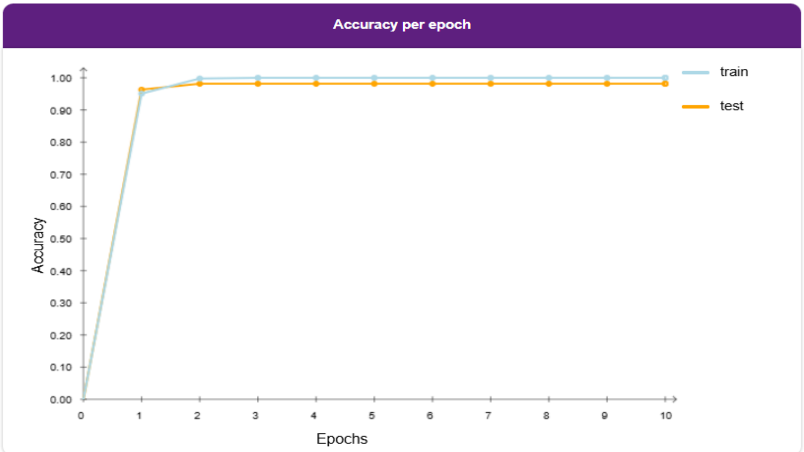


**Figure 7.** *Data Related to Accuracy Rates*

| Class | Accuracy | Precision | Recall | #Samples |
|---|---|---|---|---|
| Net Görüntü | 0.9565 | 1.0000 | 0.9565 | 46 |
| Net Olma... | 0.9375 | 0.9375 | 1.0000 | 30 |
| Soğan Za... | 1.0000 | 1.0000 | 1.0000 | 32 |

**Figure 8.** *Class, Accuracy, Precision, and Recall*


**Figure 9.** *Data Related to Learning Analytics*

## Generalization

At the end of the activity, students realized that the AI model they developed was not limited to microscopic images but could also be applied to other science topics—such as cell division and plant tissue identification. In this way, the generalization component of computational thinking was concretized within an interdisciplinary context.

## REFERENCES

Ajlouni, A., Almahaireh, A., & Whaba, F. (2023). Students' perception of using ChatGPT in counseling and mental health education: the benefits and challenges. *International Journal of Emerging Technologies in Learning (iJET), 18*(20), 199-218.

Akgun, S., Greenhow, C. (2022). Artificial intelligence in education: Addressing ethical challenges in K-12 settings. *AI and Ethics, 2,* 431–440. https://doi.org/10.1007/s43681-021-00096-7

Alam, A. (2022). A digital game based learning approach for effective curriculum transaction for teaching-learning of artificial intelligence and machine learning. Paper presented at the *2022 International Conference on Sustainable Computing and Data Communication Systems (ICSCDS)*, 69–74.

Ali, S., Payne, B. H., Williams, R., Park, H. W., & Breazeal, C. (2019). Constructionism, ethics, and creativity: Developing primary and middle school artificial intelligence education. Paper presented at the *International Workshop on Education in Artificial Intelligence K-12 (eduai'19), 2* 1–4.

Annuš, N. (2024). Educatıonal software and artıfıcıal intellıgence: Students'experıences and innovatıve solutıons. *Information Technologies and Learning Tools, 101(*3), 200.

Baidoo-Anu, D., & Owusu Ansah, L. (2023). Education in the era of generative artificial intelligence (AI): Understanding the potential benefits of ChatGPT in promoting teaching and learning. *Available at SSRN 4337484.*

Barr, D., Harrison, J. & Conery, L. (2011). Computational thinking: A digital age skill for everyone. *Learning & Leading with Technology, 38*(6), 20-23.

Barr, V. & Stephenson, C. (2011). Bringing computational thinking to K-12: What is involved and what is the role of the computer science education community? *ACM Inroads, 2*(1), 48–54. https://doi.org/10.1145/1929887.192990

Brummelen, J. V., Shen, J. H., & Patton, E. W. (2019). The Popstar, the Poet, and the Grinch: Relating Artificial Intelligence to the Computational Thinking Framework with Block-based Coding, *Proceedings of International Conference on Computational Thinking Education*. Hong Kong: The Education University of Hong Kong, p. 2.

Cheah, C. W. (2021). Developing a gamified AI-enabled online learning application to improve students' perception of university physics. *Computers and Education: Artificial Intelligence*, *2*, 100032.

Choi, S. (2019). Review of domestic literature based on system mapping for computational thinking assessment. *The Journal of Korean Association of Computer Education, 22*(6), 19–33.

Dobrev, D. (2012). A definition of artificial intelligence. *arXiv Preprint arXiv*:12101568.

Dohn, N. B., Kafai, Y., Mørch, A., & Ragni, M. (2022). Survey: Artificial intelligence, computational thinking, and learning. *KI-Künstliche Intelligenz, 1*, 5–16.

Drigas, A. S., & Ioannidou, R. (2013). A review on artificial intelligence in special education. *Information Systems, E-Learning, and Knowledge Management Research: 4th*

*World Summit on the Knowledge Society, WSKS 2011, Mykonos, Greece, September 21–23, 2011.Revised Selected Papers 4*,, 385–391.

Eaton, E., Koenig, S., Schulz, C., Maurelli, F., Lee, J., Eckroth, J., Crowley, M., Freedman, R. G., Cardona-Rivera, R. E., & Machado, T. (2018). Blue sky ideas in artificial intelligence education from the EAAI 2017 new and future AI educator program. *AI Matters*, *3*(4), 23–31.

Essinger, S. D., & Rosen, G. L. (2011). An introduction to machine learning for students in secondary education. *2011 Digital Signal Processing and Signal Processing Education Meeting* (DSP/SPE), 243–248. https://doi.org/10.1109/DSP-SPE.2011.5739219

Floridi, L. (2019). *The logic of information: A theory of philosophy as conceptual design*. Oxford University Press.

Foster, M. E. (2024). Evaluating the impact of supplemental computer-assisted math instruction in elementary school: A conceptual replication. *Journal of Research on Educational Effectiveness, 17*(1), 94-118.

Gadanidis, G. (2017). Artificial intelligence, computational thinking, and mathematics education. *The International Journal of Information and Learning Technology*, *34*(2), 133–139.

Gadanidis, G., Li, L., & Tan, J. (2024). Mathematics & artificial intelligence: Intersections and educational implications. *Journal of Digital Life and Learning, 4*(1), 1-24.

García, J. D. R., León, J. M., González, M. R., & Robles, G. (2019, November). Developing computational thinking at school with machine learning: An exploration. In *2019 International Symposium on Computers in Education* (pp. 1-6). IEEE.

Grover, S., & Pea, R. (2013). Computational thinking in K–12: A review of the state of the field. *Educational researcher*, *42*(1), 38-43. https://doi.org/10.3102/0013189X12463

Heintz, F. (2021). Three interviews about K-12 AI education in America, Europe, and Singapore. *KI-Künstliche Intelligenz*, *35*(2), 233–237.

Heintz, F. (2022). The computational thinking and artificial intelligence duality. In S. C. Kong, & H. Abelson (Eds.), *Computational thinking education in K–12: Artificial intelligence literacy and physical computing* (pp. 143–151). MIT Press.

Ho, J. W., Scadding, M., Kong, S. C., Andone, D., Biswas, G., Hoppe, H. U., & Hsu, T. C. (2019, June). Classroom activities for teaching artificial intelligence to primary school students. In *Proceedings of international conference on computational thinking education* (pp. 157-159). The Education University of Hong Kong.

Hong, S., Cho, B., Choi, I., Park, K., Kim, H., Park, Y. & Park, J. (2020). Artificial intelligence and edu tech in school education. *Korea Institute for Curriculum and Evaluation*. RRI, 2.

Hwang, G., Xie, H., Wah, B. W., & Gašević, D. (2020). Vision, challenges, roles and research issues of Artificial Intelligence in Education. *Computers and Education: Artificial Intelligence*, *1*, 100001.

Juškevičienė, A., Stupurienė, G., & Jevsikova, T. (2021). Computational thinking development through physical computing activities in STEAM education. *Computer Applications in Engineering Education*, *29*(1), 175-190. https://doi.org/10.1002/cae.22365

Kalelioglu, F., Gülbahar, Y., & Kukul, V. (2016). A framework for computational thinking based on a systematic research review. *Baltic Journal of Modern Computing*, *4*(3), 583-596.

Kandlhofer, M., Steinbauer, G., Lassnig, J., Menzinger, M., Baumann, W., Ehardt-Schmiederer, M., Bieber, R., Winkler, T., Plomer, S., & Strobl-Zuchtriegl, I. (2021). EDLRIS: A european driving license for robots and intelligent systems. *KI-Künstliche Intelligenz*, *35*, 221–232.

Kim, J., Merrill, K., Xu, K., & Sellnow, D. D. (2020). My teacher is a machine: Understanding students' perceptions of AI teaching assistants in online education. *International Journal of Human– Computer Interaction*, *36*(20), 1902–1911.

Kim, S., & Lee, Y. (2020). Attitudes toward artificial intelligence of high school students in Korea. *Journal of the Korea Convergence Society, 11*(12), 1–13.

Kökver, Y., Pektaş, H. M., & Çelik, H. (2025). Artificial intelligence applications in education: Natural language processing in detecting misconceptions. *Education and Information Technologies*, *30*(3), 3035-3066. https://doi.org/10.1007/s10639-024-12919-1

Kong, S., Cheung, W. M., & Zhang, G. (2021). Evaluation of an artificial intelligence literacy course for university students with diverse study backgrounds. *Computers and Education: Artificial Intelligence*, *2*, 100026.

Korkmaz, Ö., Çakir, R., & Özden, M. Y. (2017). A validity and reliability study of the computational thinking scales (CTS). *Computers in Human Behavior*, *72*, 558-569. https://doi.org/10.1016/j.chb.2017.01.005

Malik, S. I., Mathew, R., Al-Nuaimi, R., Al-Sideiri, A., & Coldwell-Neilson, J. (2019). Learning problem solving skills: Comparison of E-learning and M-learning in an introductory programming course. *Education and Information Technologies*, *24*(5), 2779-2796. https://doi.org/10.1007/s10639-019-09896-1

Min, J., & Shim, J. (2021). A study on domestic research trends in secondary school computer education. *The Journal of Korean Association of Computer Education, 24*(1), 29–36.

Ouyang, F., Zheng, L., & Jiao, P. (2022). Artificial intelligence in online higher education: A systematic review of empirical research from 2011 to 2020. *Education and Information Technologies*, *27*(6), 7893–7925.

Papadimitropoulos, N., Dalacosta, K., & Pavlatou, E. A. (2021). Teaching chemistry with Arduino experiments in a mixed virtual-physical learning environment. *Journal of Science Education and Technology*, *30*(4), 550-566. https://doi.org/10.1007/s10956-020-09899-5

Papert, S. (1980). *MINDSTORMS, children, computers, and powerful ideas*. Basic Books.

Pektaş, H. M., Karamustafaoğlu, O., & Çelik, H. (2025). The Role of Educational Data Mining and Artificial Intelligence Supported Learning Analytics on Conceptual Change: New Approaches to Differentiated Instruction. *Journal of Science Education and Technology*, 1-26.

Perrakis, A., & Sixma, T. K. (2021). AI revolutions in biology: The joys and perils of AlphaFold. *EMBO Reports, 22*(11), e54046.

Petersen, G. B., Mottelson, A., & Makransky, G. (2021). Pedagogical agents in educational vr: An in the wild study. Paper presented at the *Proceedings of the 2021 CHI Conference on Human Factors in Computing Systems*, 1–12.

Pokrivcakova, S. (2019). Preparing teachers for the application of AI-powered technologies in foreign language education. *Journal of Language and Cultural Education*, *7*(3), 135–153.

Sari, U. (2019). Using the Arduino for the experimental determination of a friction coefficient by movement on an inclined plane. *Physics Education*, *54*(3), 035010.

Sari, U., Çelik, H., Pektaş, H. M., & Yalçın, S. (2022). Effects of STEM-focused Arduino practical activities on problem-solving and entrepreneurship skills. *Australasian Journal of Educational Technology*, *38*(3), 140-154.

Sarı, U., Duygu, E., Şen, Ö. F., & Kırındı, T. (2020). The Effects of STEM education on scientific process skills and STEM awareness in simulation based ınquiry learning environment. *Journal of Turkish Science Education*, *17*(3), 387-405.

Sarı, U., Ulusoy, A., & Pektaş, H. M. (2025). Computational thinking in science laboratories based on the flipped classroom model: computational thinking, laboratory entrepreneurial and attitude. *Journal of Science Education and Technology*, 1-25. https://doi.org/10.1007/s10956-024-10192-y

Shute, V. J., Sun, C., & Asbell-Clarke, J. (2017). Demystifying computational thinking. *Educational research review*, *22*, 142-158. https://doi.org/10.1016/j.edurev.2017.09.003

Su, J., & Zhong, Y. (2022). Artificial Intelligence (AI) in early childhood education: Curriculum design and future directions. *Computers and Education: Artificial Intelligence*, *3*, 100072.

Su, J., Ng, D. T. K., & Chu, S. K. W. (2023). Artificial intelligence (AI) literacy in early childhood education: The challenges and opportunities. *Computers and Education: Artificial Intelligence*, *4*, 100124.

Tang, L., Li, J., & Fantus, S. (2023). Medical artificial intelligence ethics: A systematic review of empirical studies. *Digital Health*, *9*, 20552076231186064.

Touretzky, D., Gardner-McCune, C., Martin, F., & Seehorn, D. (2019). Envisioning AI for K-12: What should every child know about AI? In *Proceedings of the AAAI Conference on Artificial Intelligence*, 33(01), 9795–9799.

Tsarava, K., Moeller, K., Román-González, M., Golle, J., Leifheit, L., Butz, M. V., & Ninaus, M. (2022). A cognitive definition of computational thinking in primary education. *Computers & Education*, *179*, 104425.

Weintrop, D., Beheshti, E., Horn, M., Orton, K., Jona, K., Trouille, L., & Wilensky, U. (2016). Defining computational thinking for mathematics and science classrooms. *Journal of Science Education and Technology, 25*(1), 127–147. https://doi.org/10.1007/s10956-015-9581-5

Wing, J. M. (2006). Computational thinking. *Communications of the ACM*, *49*(3), 33-35. https://doi.org/10.1145/1118178.111821

Wing, J. M. (2008). Computational thinking and thinking about computing. Philosophical Transactions of the Royal Society A: Mathematical. *Physical and Engineering Sciences, 366*(1881), 3717–3725. https://doi.org/10.1098/rsta.2008.0118

Wong, G., Ma, X., Dillenbourg, P., & Huan, J. (2020). Broadening artificial intelligence education in K-12: Where to start? *ACM Inroads, 11*(1), 20–29.

Xu, W., & Ouyang, F. (2022). The application of AI technologies in STEM education: A systematic review from 2011 to 2021. *International Journal of STEM Education*, *9*(1), 1–20.

Zakwandi, R., & Istiyono, E. (2023). A framework for assessing computational thinking skills in the physics classroom: study on cognitive test development. *SN Social Sciences*, *3*(46), 1-15. https://doi.org/10.1007/s43545-023-00633-7

Zawacki-Richter, O., Marín, V. I., Bond, M., & Gouverneur, F. (2019). Systematic review of research on artificial intelligence applications in higher education–where are the educators? *International Journal of Educational Technology in Higher Education*, *16*(1), 1–27.

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# THE FOOTPRINT OF ARTIFICIAL INTELLIGENCE: ADVANCED TECHNOLOGY OR A SUSTAINABLE FUTURE?

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## INTRODUCTION

While users having ChatGPT draw a picture or simply say *"thank you"* may seem like ordinary, simple actions at first glance, such digital interactions create significant energy consumption each time and have serious impacts on environmental sustainability (Crawford, 2024; Sellman, 2024). Training, developing, and running artificial intelligence (AI) models require enormous amounts of electricity, and the impact is twofold: carbon emissions on one side and the heavy water use needed to cool data centers on the other. Indeed, one study reported that approximately 5.4 million liters of water were consumed during the training of GPT-3, one of the large language models (LLMs) (Li et al., 2025). This clearly demonstrates that data centers require significant water resources for their processing operations. On the other hand, only 2.5% of the water on Earth consists of freshwater sources, and since a large portion of this is stored in glaciers or underground, the amount of directly usable drinking water is quite limited (UNESCO, 2020). While people's access to water is limited on a global scale, the uninformed use of technologies such as AI, which require high energy and water consumption, poses a serious threat to sustainability.

With the increasing use of ChatGPT, one of the most popular tools of recent times, AI-based technologies have become more prevalent in everyday life (Lo, 2023; Rahman & Watanobe, 2023). A review of the literature reveals that the unconscious use of AI-based models and technologies could pose a significant threat to a sustainable future. Users' unconscious consumption of technology brings with it concerns about the future of the environment. Every user must be a conscious consumer when using these technologies for our future. In this case, a conceptual framework is needed to understand and make visible the environmental impacts of AI use.

The concept of *footprint*, developed to measure the impact of human activities on nature, has long been used to conceptualize this relationship. Galli et al. (2012) expanded this framework by proposing the *Footprint Family* approach. This approach consists of three fundamental concepts: the ecological footprint, the carbon footprint, and the water footprint. The authors argue that these concepts must be considered together and suggest thinking of these three concepts as a *family*.

However, users of these technologies are often unaware of the environmental consequences of their individual actions. This lack of awareness makes not only consumption but also responsibility invisible. At this point, some questions become inevitable. To what extent are individuals using generative artificial intelligence (GenAI) aware of the effects they may have in the future? Have we ever considered the true cost of a composition written by ChatGPT, an image created by Midjourney, a video produced through Runway, or a voice cloned by ElevenLabs and similar GenAI tools? Each time we click the *"try again"* button, it is not only the algorithms that are strained, but in a quiet way, the planet itself. So, who will take responsibility for these invisible traces? Perhaps the real question is this: while benefiting from these technologies, are we genuinely aware of the footprint we leave behind?

## Purpose of the Chapter

The aim of this chapter is to re-evaluate the Footprint Family approach proposed by Galli et al. (2012) in light of the environmental realities of the digital age. By examining the environmental impacts of widespread technology use, it argues that, in addition to traditional footprint types, the new generation of footprints born of the digital age must also be defined and included in this family. In this context, the chapter explains the emergence and development of the footprint concept in the context of sustainability and then covers the concepts of ecological footprint, carbon footprint, water footprint, technological footprint, digital and artificial footprint. After all, this book chapter invites us to reconsider the Footprint Family approach proposed by Galli et al. (2012).

## Environmental Sustainability and Sustainable Development

### Environment

When examining the literature, the concept of environment is defined in its broadest sense as the entirety of natural, artificial, social, and cultural conditions necessary for living beings to sustain their lives (ÇŞİDB, 2022; Sevil & Dimişli, 1999). The Ministry of Environment, Urbanization, and Climate Change of the Republic of Turkey defines the environment as the external environment with which living beings interact and maintain relationships throughout their lives (ÇŞİDB, 2022). This definition shows that the environment has not only physical but also social and cultural dimensions. Palmer (1998), considers the environment as a system that should be evaluated together with the social, cultural and biophysical structures of the individual and emphasizes that environmental education should be taught to individuals within this integrity (e.g. **Figure 1**).

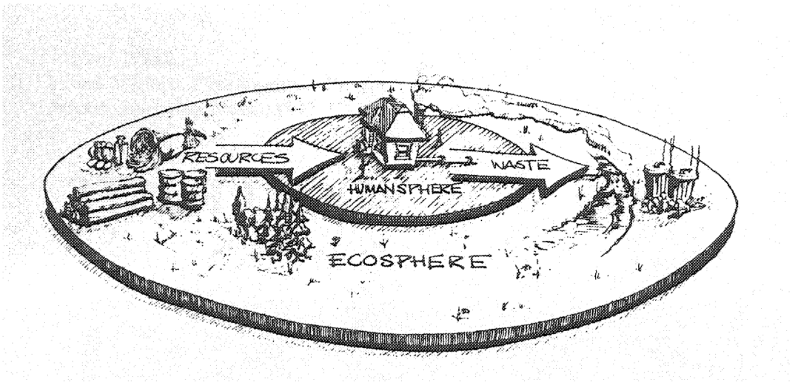


**Figure 1.** *Ecological Footprint Model*
Explanatory note. Adapted from Our Ecological Footprint: Reducing Human Impact on the Earth (Rees & Wackernagel, 1996). © New Society Publishers.

Today, environmental problems are becoming not only an ecological but also a socio-economic crisis. It is observed that the basis of these problems is the destruction of nature by human hands, unconscious consumption of natural resources and insensitivity to the environment. Erten (2004) defines this situation as a result of human beings' ruthless use of nature for their own interests. And he especially emphasizes that industrialization increases environmental destruction. In the same study, it is said that environmental problems such as air, water and soil pollution are effective on a global scale and threaten the right to life of all living things.

It is seen that academic studies in the field of environmental education in Turkey generally focus on environmental attitudes, behaviors, knowledge levels and environmental problems (Bahar & Kiras, 2017). This trend reveals that environmental education is being handled with increasing interest, but it also shows that the content for early age groups is limited.

On the other hand, studies that environmental education should be supported not only at the cognitive level but also in affective and visual ways draw attention. For example, it is emphasized that film and animation-based content is effective in raising environmental awareness in students, and the integration of such materials into curriculum is recommended (Duran, 2019).

Taken together, these findings highlight the need to broaden the scope of environmental education both thematically and pedagogically. There is a growing call for programs that go beyond transferring knowledge to also nurture emotional awareness and adopt multidimensional, age-appropriate learning approaches.

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## Sustainable Development

When definitions and educational perspectives on the environment are examined together, it becomes clear that this field must now be addressed within the framework of sustainable development. Today's environmental problems affect not only ecosystems but also people's daily lives and the economic structures of societies. For this reason, environmental policies should move beyond the simple protection of nature and adopt a broader, more holistic understanding that supports social transformation.

Sustainable development is commonly described as meeting present needs without limiting the ability of future generations to meet theirs (WCED, 1987). This principle seeks to balance environmental, economic and social priorities. It also argues that progress should be assessed not only through economic growth but by considering ecological stability and social justice. Palmer (1998), points out that one of the key goals of environmental education is to cultivate responsibility toward the environment and to develop sustainable living skills. He further emphasizes that education plays an important role in achieving this balance and must be an integral part of the sustainability process.

Recent studies emphasize that environmental education plays a key role in raising awareness of the goals of sustainable development. Bulut and Özer (2024) discuss sustainability through the idea of an environmental footprint, highlighting the link between individual consumption habits and broader social transformation. Drawing on ecological modernization theory, they suggest that environmental education should be viewed as a multidimensional process that promotes behavioral change rather than only offering cognitive knowledge.

When all these studies are evaluated together, it is understood that sustainable development goals should be supported not only on the economic or political level, but also through educational processes. In this context, it is envisaged that sustainability-based programs included in the education system will enable students to develop a sense of responsibility towards nature, question consumption habits, and grow up as individuals who will contribute to social change.

## Environmental Footprint and the Concept of Footprint

### Environmental Footprint

When the literature is examined, the importance of the effect of individual behaviors on the environment is emphasized in environmental education studies (Carson, 1962, as cited in Hynes, 1989; Sheehan, 2008). In this context, environmental footprint can be defined as the measurement of the natural resource consumption and environmental damage caused by individuals or societies. According to Keleş and Aydoğdu (2010), the ecological footprint is the sum of the production areas needed by the individual depending on their consumption habits and the biologically productive areas required for the wastes generated in this consumption process to be balanced by natural systems. In the same study, it is emphasized that the ecological footprint is not only a technical concept but also an effective educational tool. They further argue that this concept should not be viewed only as a technical calculation but also as a valuable educational instrument that helps children develop sustainability awareness and behavioral sensitivity.

Sheehan (2008), similarly, observes that environmental education can foster meaningful changes in behavior, but such transformation becomes more lasting when individuals can connect their own actions with environmental consequences. Through this connection, the notion of the environmental footprint turns from a numerical indicator into a tool for reflection and behavioral change.

Carson's *Silent Spring* (Hynes, 1989) also shows how human activities intertwine with specific ecological threats such as chemical pollution. Her work illustrates that the environmental footprint is not limited to present-day consumption habits; it also invites questioning of the historical relationship between humans and nature.

Taken together, these studies suggest that the concept of the environmental footprint should be approached from a holistic perspective—one that extends beyond the cognitive focus of environmental education to include the values, attitudes and behaviors that shape everyday life. Designing programs around this concept, not only through content but through experiences that encourage behavioral and attitudinal transformation, represents a necessary step toward educating individuals for a sustainable future.

**Footprint**

Understanding the environmental impact of human consumption and achieving sustainability goals has become increasingly important today. In this context, several concepts have been developed to measure environmental impacts. One of the most used concepts is the footprint (e.g. **Figure 2**). First introduced in the 1990s in the context of sustainability, this concept has been used specifically to express ecological impacts in concrete terms (Rees and Wackernagel, 1996).

The concept of ecological footprint was originally used to express the physical impact of an object on nature or the amount of land it occupies. However, over time, this definition has expanded and begun to address human-induced environmental pressures more extensively (Hoekstra & Wiedmann, 2014). Ecological footprint was first developed and defined in the literature by *Mathis Wackernagel and William Rees at the University of British Columbia in 1990* (Global Footprint Network, 2023).

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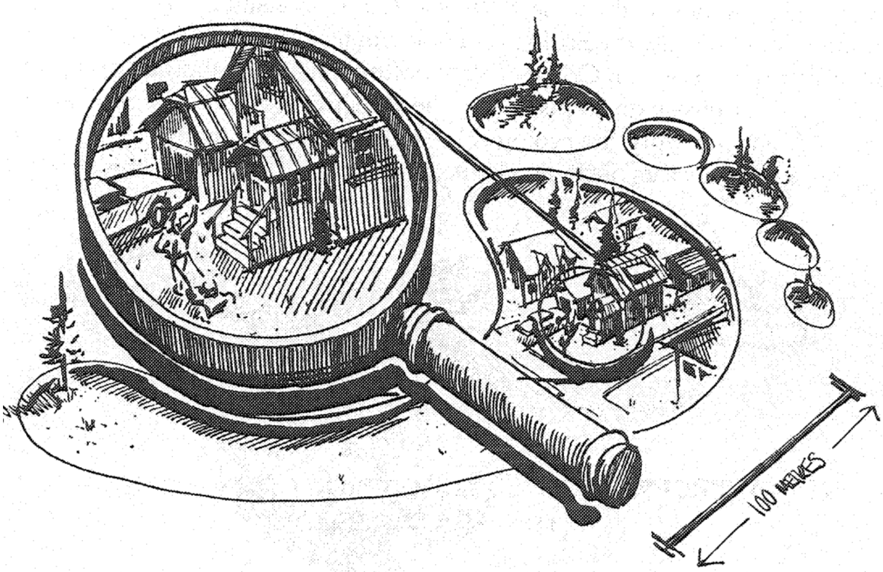

**Figure 2.** *Footprint*

Explanatory note. Adapted from Our Ecological Footprint: Reducing Human Impact on the Earth (Rees & Wackernagel, 1996). © New Society Publishers.

Today, the footprint concept is considered a multifaceted assessment tool that includes not only ecological impacts but also social and economic dimensions (Čuček et al., 2012). Due to its broad scope, this concept has been adopted by the media, civil society organizations, and the business world, leading to its well-known use (Galli et al., 2012). However, there are some differences in the literature regarding the definition and calculation methods of the footprint. The concept represents both environmental pressure and resource consumption, which has led to the emergence of different approaches (Fang et al., 2016).

This chapter of the book aims to examine the concept of footprint from both traditional and innovative perspectives. It will focus particularly on the new dimensions that AI and digitalization have added to this concept. Furthermore, the concept of footprint will be analyzed through a multidimensional and comprehensive approach, covering both ecological and technological types of footprints.

Galli et al. (2012) introduced the concept of *Footprint Family* to address the effects of human activities in a multidimensional way in the context of environmental sustainability (e.g. **Figure 3**). This approach advocates for the combined evaluation of ecological, carbon and water footprints, allowing for a more overall analysis of environmental impacts.

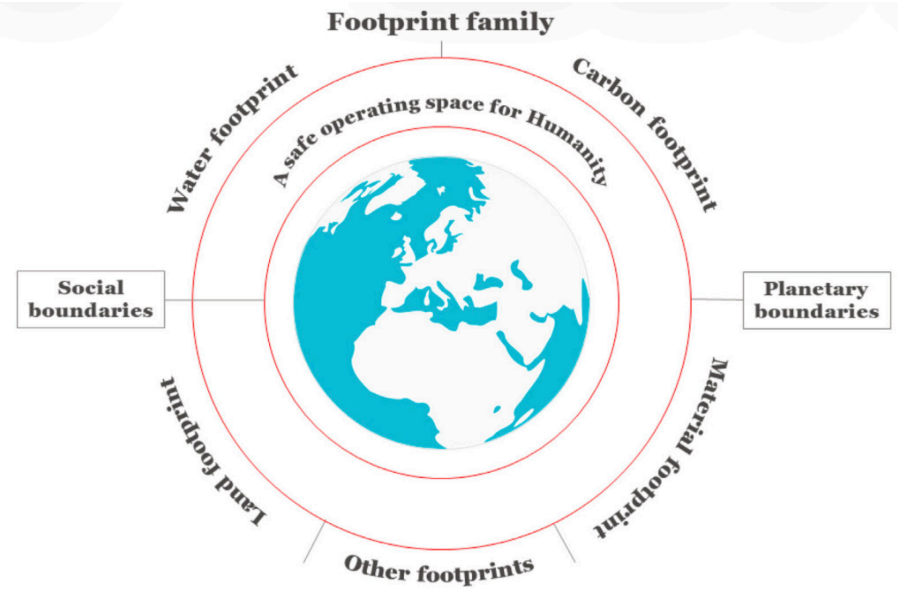


**Figure 3.** *Footprint Family*

Explanatory note. Adapted from What is a footprint? A conceptual analysis of environmental footprint indicators, Matuštík & Kočí (2021).

Based on the Footprint Family approach, this image reveals that human activities should take place in a safe space without exceeding the carrying capacity of the planet and in a way that meets basic socio-economic needs (Raworth, 2017). While there are different types of footprint concepts in the literature (agricultural footprint, fashion footprint, etc.), this book chapter will focus on the ecological, carbon, and water footprint concepts addressed by Galli et al. (2012) within the framework of the Footprint Family.

## Footprint Family

### Ecological Footprint

First developed by Rees and Wackernagel (1996), the concept of the ecological footprint is defined as the amount of biologically productive land and water area, measured in hectares, required to regenerate the resources consumed and absorb the waste produced by a given population or individual. In other words, the ecological footprint is a calculation tool that allows us to measure and recognize the extent to which we own nature and how much of it we use, both globally and nationally (Keleş et al., 2008).

Akıllı et al. (2008) states that the concept of ecological footprint is based on the idea of sustainability, which aims to preserve the environment for future generations. Durkaya (2022) defines ecological footprint as a measure of how sustainably people use natural resources. The ecological footprint is a sustainability indicator that expresses the impact of human resource consumption and waste production on nature's capacity for renewal (Global Footprint Network, 2023; WWF, 2020). When these definitions are considered together, the ecological footprint is a measure that helps us understand environmental impacts at both the individual and societal levels ( e.g. **Figure 4**).

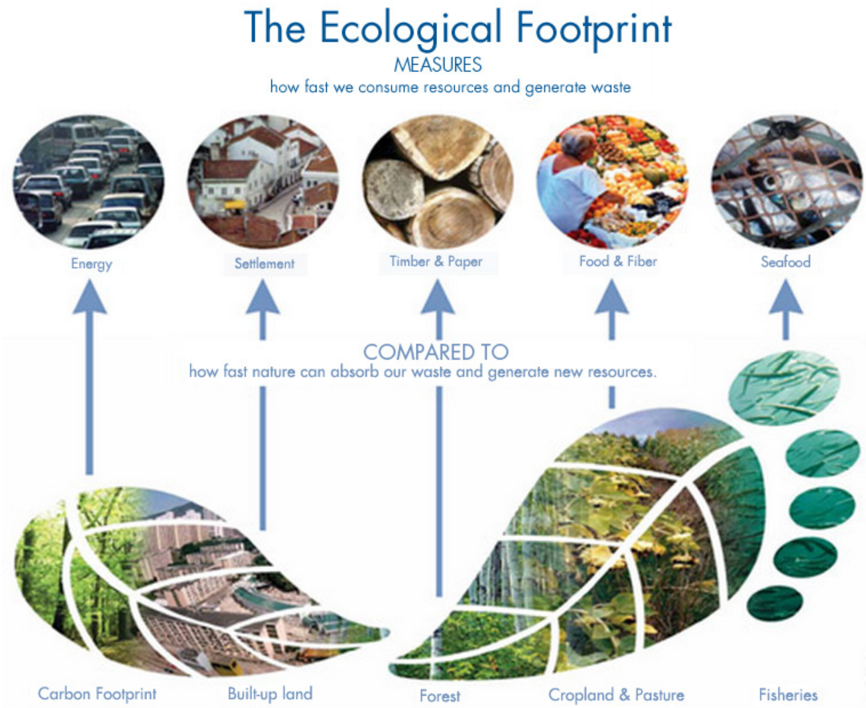


**Figure 4.** *Ecological Footprint*
Explanatory note. Adapted from Global Footprint Network (https://www.footprintnetwork.org/our-work/ecological-footprint/).

The concept of ecological footprint has also been addressed in the context of the global sustainable development goals. Recent studies have shown that humanity's demands on the biosphere have begun to exceed the resources provided by nature. This situation is explained by the concept of impact inequality, which emphasizes that the services provided by nature are not being used efficiently enough, especially within consumption-oriented economic models (Dasgupta et al., 2023).

Cordero et al. (2020) have shown that climate change-based education has a significant reducing effect on individuals' lifetime carbon footprint. In the research, it is emphasized that environmental education is not only limited to increasing the level of knowledge but also contributes to long-term behavioral transformations. Ecological footprint is not only theoretical, but also a behavioral transformation tool that can be shaped by education. As a matter of fact, the study conducted by Cordero et al. shows that this transformation is possible by showing that carbon footprints decrease in the long term if individuals are educated.

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### Carbon Footprint

Wiedmann and Minx (2008) define carbon footprint as "the measurement of the total carbon dioxide emissions directly and indirectly caused by an activity or accumulated over the life cycle of a product". Similarly, the Center for Sustainable Systems (n.d.) defines carbon footprint as *"total greenhouse gas emissions caused directly and indirectly by an individual, organization, activity, or product."* Accordingly, carbon footprint has become a widely used indicator in environmental and climate change policies, allowing quantitative calculation of climate impacts in tons of carbon dioxide equivalent (Peters, 2010, p. 1325).

When the literature is examined, this concept in Turkey is not only an environmental indicator but also turns into an important learning tool that supports individual awareness and behavior change in educational environments. As a matter of fact, academic studies carried out in recent years show that practices for carbon footprint are integrated into the education system. For example, Kurt and Çavuş-Güngören (2020) examined the carbon footprint knowledge levels and sustainability attitudes of secondary school students and revealed that awareness development varies according to grade level.

Studies comparing the effects of formal and distance education processes on carbon footprint provide meaningful data for the development of environmentally conscious education models (Güğül & Kılınç, 2022). It has been observed that environmental education practices implemented at the primary education level increase students' awareness of their carbon footprint. All these findings demonstrate that the carbon footprint has important potential in the context of education to increase environmental literacy, develop sustainable attitudes, and cultivate active individuals in the fight against climate change (Weidema et al., 2008).

### Water Footprint

The literature reveals that integrating environmental footprint concepts into education is becoming increasingly important in terms of understanding environmental issues and updating sustainable living skills (Galli et al., 2012; Hoekstra & Wiedmann, 2014; Matuštík & Kočí, 2021). In this context, the water footprint is discussed in educational environments as an important concept that supports both individual awareness and behavioral transformation. Matuštík and Kočí (2021) define water footprint as an environmental pressure indicator measured as the sum of blue, green, and gray water volumes used throughout the production chain and emphasize that this indicator has the potential to assess environmental impacts holistically. Because of this, water footprint offers a functional learning area not only for natural resource management but also for transforming individual consumption habits through education.

Various studies conducted in Turkey show that this concept is directly related to education. For example, a study conducted by Akbaş and Sünbül (2022) found that most middle school students could not define the concept of water footprint scientifically, generally providing superficial explanations such as “water pollution” or “wasting water”. This situation reveals that environmental concepts are not sufficiently included in teaching programs.

Scale-based applications developed to address this deficiency aim to raise awareness at different levels of education and encourage behavioral change. The Water Consumption Behavior Scale, developed by Çankaya and Filik İşçen (2014), was designed to assess the individual water usage habits of science teacher candidates and has been supported by validity and reliability analyses. Similarly, the Water Attitude Scale developed by Karslı and Tunca Güçlü (2023) is a reliable tool that assesses primary school students' attitudes toward water in three sub-dimensions and can serve as a basis for educational interventions. In addition, the Water Literacy Scale developed by Aytaç (2023) has been added to the literature as a unique tool that can comprehensively measure students' water knowledge, behavior and attitudes.

These studies show that it is not enough to teach environmental concepts such as water footprint only as content and that multifaceted teaching processes targeting the cognitive, affective and operational dimensions of learners are needed. The common feature of these scales should be to focus on individual attitudes and behaviors rather than conceptual knowledge.

In conclusion, these studies show that the reflection of environmental concepts on education should be structured not only at the cognitive but also at the attitudinal and behavioral level. As in the example of the water footprint, it is thought that social transformation that will support environmental sustainability will be possible through the systematic and practical transfer of these concepts into educational environments.

## New Generation Footprints

This section discusses the concepts of *technology footprint*, *digital footprint,* and *artificial intelligence footprint*, which we believe that new members of the Footprint Family. In short, the technology footprint refers to the amount of energy consumption, carbon emissions, and waste that occur from the production to the use of technological tools. Digital footprint refers to the data traces left by individuals on the internet and is related to privacy, security and ethical issues. The artificial intelligence footprint shows the energy consumed and the resulting carbon emissions during the design, training and operation of AI systems.

## Technology Footprint

With the widespread adoption of technology in daily life, the environmental impacts of digital tools have also become more pronounced. The technological footprint includes the environmental impacts caused directly or indirectly by individuals, organizations, or societies through digital tools, hardware, and technology-based organizations, such as energy consumption, carbon emissions, and electronic waste production ( e.g. **Figure 5**).This concept encompasses not only physical production and consumption processes but also the environmental burdens arising during data processing, automation systems and digital infrastructures (Dam et al., 2024; Gupta et al., 2021).

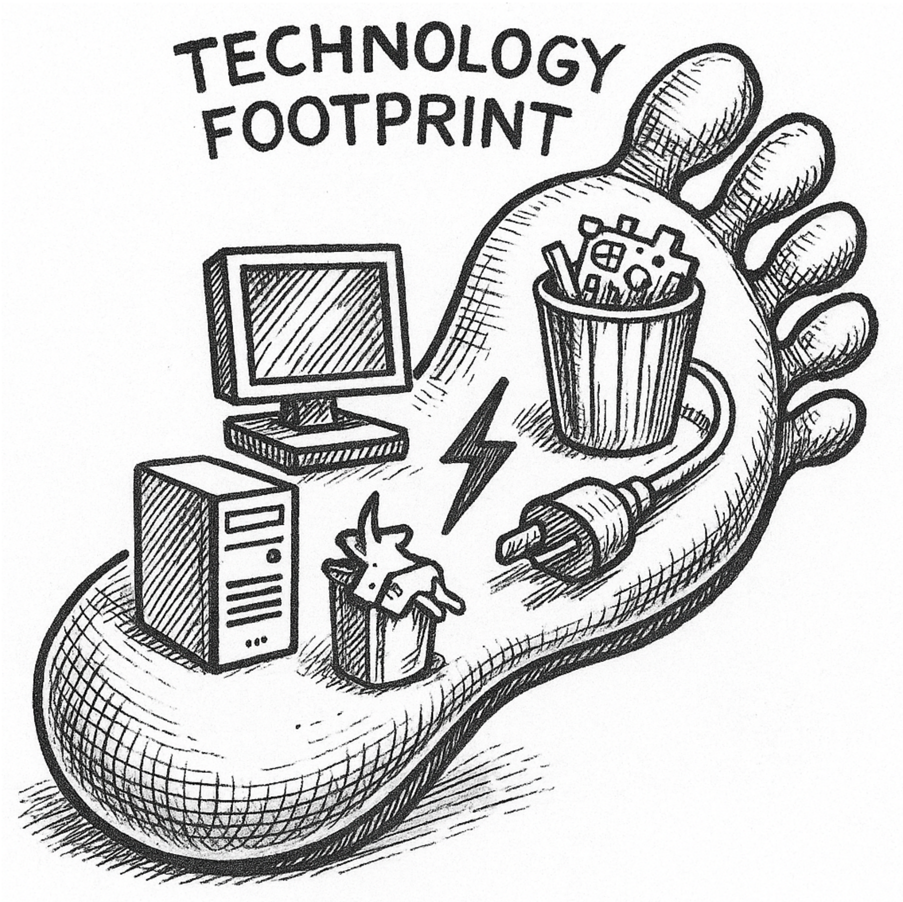


**Figure 5.** *Technology Footprint*
Explanatory note. This figure was created by the authors using ChatGPT (OpenAI), 2025.

Studies show that technological innovations can have a long-term effect of reducing the ecological footprint. For example, it has been found that technological innovations have long-term effects of reducing the ecological footprint in the E-7 countries, which consist of Brazil, China, India, Indonesia, Mexico, Russia, and Turkey. The study emphasizes that technological progress must be supported by renewable energy use and green innovation strategies to contribute to environmental sustainability. Furthermore, it has been observed that there is a unidirectional causality relationship between technological innovation and ecological footprint and that this effect becomes more pronounced in the long term (Dam et al., 2024).

The association of technological footprint with education has been supported in recent years by approaches such as computational sustainability (Gomes et al., 2019) and green computing in education (Murugesan, 2008).

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These frameworks highlight aspects such as low carbon emission targets, data saving strategies and eco-friendly digital tool selection for the sustainable use of educational technologies. For example, the annual carbon emissions of desktop computers are on average 50% higher than those of laptops (Strubell et al., 2020).

In Gupta et al. (2021), it was revealed that the environmental impacts of information technology are not limited to energy consumption during the usage phase. The study highlights that the production stages of technological devices and infrastructure also contribute significantly to the total carbon footprint. The environmental impact of data centers was examined in detail, noting that major technology companies such as Facebook and Google have taken significant steps to reduce their daily operational emissions by switching to renewable energy. However, despite this transformation, it was also stated that approximately 80% of emissions still originate from production-based processes such as server production, manufacturing of integrated circuits, data center construction and cooling systems. For example, it is stated that a mobile device or server must be used continuously for at least three years to balance the carbon emissions from production in an environmental sense.

These findings show that the technological footprint is not limited to the usage process but also creates environmental impacts throughout the entire life cycle of technological products, from their design to production, from the use of individuals to the process after that. Especially when the invisibility of carbon emissions from the production stage and production loads that are not visible in environmental sustainability analyses are ignored, incomplete or misleading results may occur. Therefore, energy consumption-oriented solutions alone are not enough but a holistic evaluation covering the entire life cycle of products is required. To analyze the environmental impacts of technological devices more accurately, it is important to report production processes transparently and include these impacts in decision-making processes (Dam et al., 2024; Gupta et al., 2021).

It is important for students to realize their environmental impact while using technological tools to develop sustainable digital habits. To gain this awareness, the following practices can be included in educational environments:

- Providing information about energy consumption helps students recognize the invisible environmental costs.

- Discussing the environmental impact of hardware choices fosters conscious device usage habits.

- Activities focused on electronic waste increase students' awareness of recycling and technology ethics.

- Calculating the school's technological footprint encourages students to question their consumption habits.

- Discussion and project-based applications develop the ability to evaluate technology critically and responsibly.

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- These approaches support students in becoming not only users of technology but also conscious individuals who question its environmental and ethical consequences.

**Digital Footprint**

With the acceleration of digitalization, the traces left by individuals in online environments have become an important research topic both technologically and sociologically. Digital footprint refers to the data traces formed because of individuals' interactions in digital environments and these traces shape the virtual identity of the individual; It is directly related to many critical issues such as data security, privacy, surveillance and ethical responsibility (McDermot, 2018; Zuboff, 2019). Digital footprints: It is obtained from various digital environments such as social media platforms (Facebook, Twitter), learning management systems (e.g. Moodle) and online learning environments (e.g. MOOCs) and allows for the systematic monitoring of individuals' online behaviors (Buitrago-Ropero et al., 2020).

The academic use of the concept was first used by Bailey and Caidi (2005) when discussing the privacy implications of smart card-based systems. In this context, the term has its origins in the study of surveillance and privacy. Witte (2006), emphasizing that social lives in digitalizing societies increasingly leave digital traces, drew attention to the importance of the concept of digital footprint in the social sciences (Schrenk, 2022).

In the early uses of the concept of digital footprint, some terminological variations are observed. According to Kligiené (2012), this concept was first expressed by Negroponte (1995) as “slug trail” and later defined by Tim O'Reilly as “data exhaust.” This concept refers to the traces left behind because of actions taken in the digital environment. A digital footprint is the trace left behind by individuals after their actions in the digital environment. All actions performed via television, mobile phones, the internet, and other digital devices contribute to these footprints. Moreover, digital footprints are not limited to individuals but also apply similarly to companies and institutions (Kligiené, 2012).

In the literature, the digital footprint is generally examined under two main headings. These active and passive digital footprints (Buitrago-Ropero et al., 2020; Kligiené, 2012; McDermot, 2018; Schrenk, 2022). These two basic classifications reveal how digital traces are shaped according to user awareness (e.g. **Table 1**).

**Table 1.** *Comparison of Active and Passive Digital Footprints*

| Feature | Active Digital Footprint | Passive Digital Footprint |
|---|---|---|
| Definition | Digital traces intentionally created by the user. | Digital traces collected without the user's awareness. |
| User Awareness | Conscious: the user is aware and produces content deliberately. | Unconscious: data are collected automatically in the background. |
| Examples | Social media posts, blogs, comments. | IP addresses, cookies, browsing history. |
| Collection Method | Through direct user actions. | Automatically by systems and algorithms. |
| Use in Education | Digital citizenship education, content creation activities. | Learning analytics, behavioral tracking. |
| Ethical Concern | Responsibility for sharing, digital identity management. | Privacy violation, surveillance capitalism. |

*Explanatory note.* Adapted from Schrenk (2022), Kligienė (2012), McDermot (2018), & Buitrago-Ropero et al. (2020).

- **Active Digital Footprint:** These are traces left by the user consciously. Social media posts, blog articles, and online comments fall into this category. These traces are usually created to reach a specific audience and directly reflect the individual's digital identity.

- **Passive Digital Footprint:** These are the traces created by the user without realizing it. Examples of this category include IP addresses, cookies, and browsing data collected in the background. This type of data is usually recorded automatically by systems and used to analyze user behavior.

Digital footprints are considered an important tool in education for tracking students' learning processes and predicting their success. In a study conducted by Shafiq et al. (2025), it was found that online interaction data obtained through Moodle was positively correlated with academic success. It was found that students who logged into the platform on weekends and at night had a 10% increase in their success scores. This finding provides strong evidence of how digital footprints can be used to evaluate student participation and academic success in education.

Digital footprints can be considered a two-way tool in educational settings:

1) **Teaching Tool:** Educators can use digital footprints to analyze students' digital behavior. User data obtained through the Learning Management System can be effective in predicting academic success (Shafiq et al., 2025).

2) **Critical Awareness Tool:** By learning what digital footprints are and how they are managed, students can develop critical 21st-century skills such as digital citizenship, data literacy, and digital ethics. In this context, teaching digital footprints is essential for students to protect their online privacy and become ethical individuals in the digital world (Livingstone and Third, 2017).

In the context of the digital economy, which Zuboff (2019) defines as "*surveillance capitalism*", digital footprints are not only an issue of individual privacy but are also entangled with multi-layered ethical issues such as global data exploitation, algorithmic biases, and digital inequalities. Therefore, digital footprint education should be approached as an interdisciplinary field of education that encompasses themes such as information ethics, cultural awareness, and responsible technology use (Emejulu & McGregor, 2016).

Finally, a recent study examining the environmental impacts of digital technologies has shown that elements such as digital infrastructure and industrial automation can reduce carbon emissions at the city level. This impact is felt positively not only at the local level but also in neighboring regions, demonstrating that digitalization can make indirect contributions to environmental sustainability (Shen et al., 2023).

### Artificial Intelligence Footprint

Recently, the use of AI has risen steeply, particularly through GenAI applications. While users may not realize it, these technologies are making significant impacts on environmental sustainability. The high processing power and data requirement of GenAI increase energy consumption, which causes carbon emissions. Therefore, each user unwittingly creates an environmental *artificial intelligence footprint* while using GenAI applications (e.g. **Figure 6**). However, most users are unaware of the environmental impact of GenAI.

Current research reveals that these models consume high amounts of energy in their training and release processes, and significantly consume environmental resources such as water. In the literature, the effects of GenAI on the environment are discussed with several examples, and suggestions are presented to lower these effects. The concept of artificial intelligence footprint can be defined as the totality of carbon emissions, energy consumption, data processing load and ethical-interactive consequences arising from the use and development of AI-based technologies.

The study by Strubell et al. (2020) is an important piece of research that draws attention to the environmental impacts of AI models. The study found that the carbon emissions generated during the training of LLMs such as BERT and GPT-2 are quite high and that this process requires a significant amount of energy consumption. This finding demonstrates that the efficiency and productivity offered by AI systems come at an invisible environmental cost. Therefore, the development of AI technologies must consider not only accuracy and processing power but also energy efficiency and environmental responsibility.

GenAI models place important pressure on environmental sustainability, particularly due to their high computational power and large data requirements. A study conducted by Ding et al. (2025) examined 369 GenAI models developed between 2018 and 2024 and found that the energy consumption and carbon emissions of these models are particularly high in countries with high carbon intensity. According to the research results, China and the US account for 99% of productive AI-related emissions. Carbon emissions were calculated at 6.76–8.98 million tons in China and 3.66–8.72 million tons in the

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US. In low-carbon intensity countries such as Sweden, these values are seen to be quite low. Furthermore, while the finance and healthcare sectors account for the highest energy consumption related to AI, the education sector poses a more limited burden in this regard.

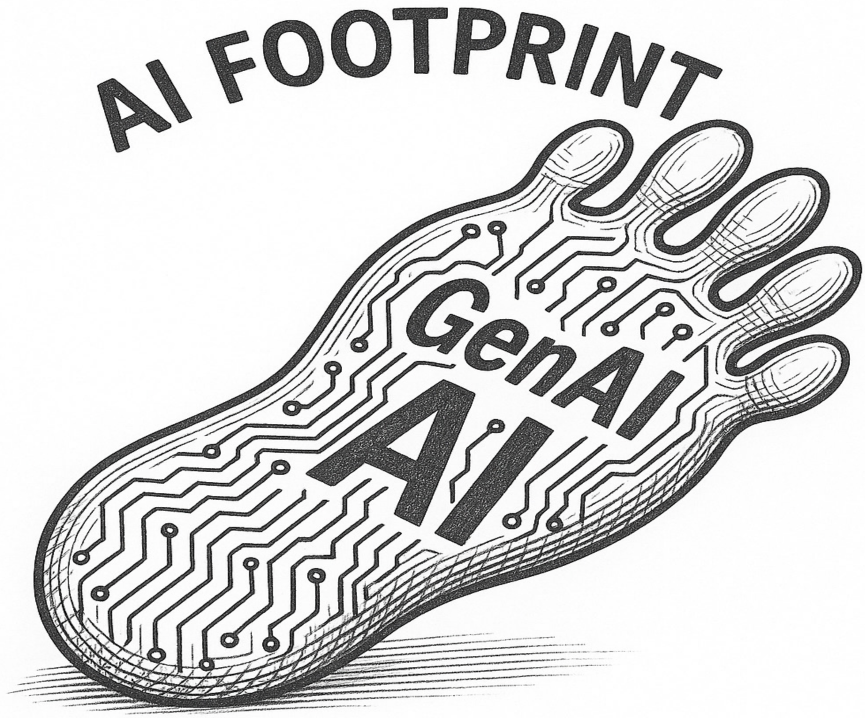


***Figure 6.*** *Artificial Intelligence Footprint*
*Explanatory note. This figure was created by the authors using ChatGPT (OpenAI), 2025.*

The environmental impacts of AI models are generally assessed through their carbon footprint. However, some studies also examine the effects of AI on water consumption. Water consumption arising during the training processes of AI applications, especially LLMs (e.g., GPT-3), presents a significant problem. In this context, a study found that about 5.4 million liters of water were consumed during the training of the GPT-3 model. This consumption stems from the cooling processes of data centers, and it has been observed that more water is required, especially during hot periods. The research results show that AI systems create sustainability problems not only in terms of carbon footprint but also in terms of water footprint. It is recommended that data centers be relocated to cooler regions and that renewable energy sources be used (Li et al., 2025).

Also, the environmental sustainability impacts of AI technologies have become an important research topic in recent years, particularly in the context of the energy consumption of large-scale models. It has been noted that AI models generate a major carbon footprint both in operational processes and through hardware-related factors. Research indicates that LLMs pose a high risk in terms of operational carbon footprint (Wu et al., 2022). In this context, it is emphasized that energy efficiency strategies need to be developed to reduce the environmental impact of AI models. Approaches such as model optimization and the use of low-energy hardware have the potential to significantly reduce carbon emissions. Furthermore, encouraging the use of renewable energy sources increases the sustainability level of AI applications.

The Green AI approach offers a comprehensive perspective aimed at minimizing the environmental impact of AI systems. This approach advocates for the development of AI models with a focus on environmental sustainability and promotes the adoption of green computing strategies to reduce energy consumption. Green AI is not just a technological preference but also a holistic and strategic approach that supports long-term environmental well-being. Ensuring that AI systems developed within this framework consider criteria such as energy efficiency and resource utilization is a fundamental requirement for sustainable digital transformation (Mitu and Mitu, 2024; Wang et al., 2024).

In contrast, the Red AI approach, commonly encountered in the field of AI, aims to maximize model accuracy while ignoring the major environmental and computational costs incurred in achieving this success. The development of LLMs, which involves using millions of parameters and training on massive datasets, often results in only very small increases in accuracy. For example, it is common for increasing a model's accuracy by 1% to require thousands of times more processing power and energy consumption. This situation leads to significant carbon emissions and energy consumption, while also creating barriers to access for low-resource research groups. Red AI inclines to prioritize computational power in this race, often at the expense of environmental sustainability, ethical concerns and principles of equitable access (Schwartz et al., 2020).

To reduce the environmental impacts of AI technologies, countries must develop long-term plans, integrate these technologies into their development strategies and express policies united with sustainability goals. Particularly in industrialized countries, it is crucial to direct AI applications in a manner that supports the energy transition. In this context, a study conducted in China compared 30 regions and found that AI usage meaningfully reduced the ecological footprint per capita in eastern and central regions, thanks to advanced technological infrastructure and environmentally friendly applications. In contrast, it was determined that a similar effect could not be achieved in Western regions due to infrastructure deficiencies and limited applications. The findings show that not only technology investments but also comprehensive strategies sensitive to regional conditions are necessary (Wang et al., 2024).

The fast-increasing use of AI and GenAI models also raises major problems in terms of environmental sustainability. A review of the literature reveals that AI applications requiring high processing power, particularly LLMs, have environmental impacts in terms of both carbon emissions and water consumption. In this context, the unconscious use of AI and GenAI models poses an even

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greater threat to our future. Some studies in the literature reveal that this environmental impact is closely related to model architecture. Sparse models consume much less energy than intensive models because they only run the necessary processing steps and can therefore significantly reduce carbon emissions (Patterson et al., 2021).

Therefore, it is crucial to increase users' awareness of the AI footprint they create when using AI models. To reduce the environmental impact of AI models, a Green AI approach needs to be adopted and individuals need to be made aware of this issue. It is very important for our future that not only the manufacturers and developers of these models, but also the users, take responsibility for making AI models more sustainable. It plays an important role for individuals to understand the concept of artificial intelligence footprint and use these models consciously, while also reducing environmental impacts. In this context, it is necessary to increase the awareness of individuals and society and it will affect the more conscious and sustainable use of AI models by individuals.

While the use of AI tools in education supports learning processes, students should also question the invisible effects of these technologies. AI footprint awareness in education can be developed in individuals by:

- Energy awareness should be instilled: The processing load and carbon footprints of tools such as ChatGPT and Midjourney can be explained.

- Data ethics education should be provided: Discussions should be held with students based on questions such as “Where did this system get my data?”

- Ethical usage protocols should be developed: It should be determined how, for what purpose, and within what limits AI systems will be used in schools.

## Conclusion

Artificial intelligence (AI) and generative artificial intelligence (GenAI) models are rapidly developing and becoming an indispensable part of daily life. AI and GenAI tools/models make it easier to think, write and produce. It saves users' time, speeds up work and maybe even makes its users more productive individuals. However, behind these conveniences, there are often invisible environmental effects. Every new content, every output, every line of data consumes energy, consumes water and emits carbon. In other words, these systems, where users get help, shape our future on the one hand and consume it on the other. It is no longer only important what we do and how fast, but also what trace we leave behind. Because every technological convenience leaves a mark on the future. So, how aware are we of this impact on the future?

When raising the next generation, it is essential to discuss this concept within educational programs and to raise our children, who are our future, with this awareness. Especially today, when rapidly developing technologies such as the Internet of Things have become part of everyday life, children and young people must be raised not only to use these tools but also to question

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their effects and think in terms of sustainability. This awareness begins at an early age. When teaching our children about technology, we must also teach them about its footprint.

As Galli et al. (2012) have demonstrated, the concepts of carbon, water, and ecological footprints should not be considered independently but rather addressed holistically under the term *"footprint family"*. In this study, we argue that new generation footprints, such as the digital footprint and artificial intelligence footprint, which have expanded this conceptual structure due to the impact of the digital age, should also be included in this family. When the literature is examined, we argue that the concept of footprint family has evolved with digitalization and in this context, new generation footprint types should be included in this structure.

The footprint of technology transforms not only the environment but also the individual. Sustainability has now become a multi-layered concept that includes not only environmental but also ethical, digital, social and pedagogical dimensions. Today's technological tools have multiple intertwined effects in areas such as energy use, data security, privacy and ethical responsibility.

Every trace we leave in digital environments affects not only today but also tomorrow. For this reason, it is important to not only understand how we use technology but also to be aware of and question its impacts. Educational environments are one of the most powerful grounds for this awareness to develop. Children and young people are not just consumers of information, but also carriers of data, energy and ethical decisions. Therefore, footprint awareness should be the cornerstone not only of science classes but also of digital citizenship, environmental ethics and social responsibility education.

The *footprint family* has now expanded. And recognizing, promoting and questioning this expanding structure is one of the most basic responsibilities of today. Because today's technological tools interact not only with environmental but also with multi-layered areas such as data security, energy use, ethical responsibility and privacy. Therefore, sustainability is no longer just an environmental issue but has become a multidimensional conceptual framework that requires an interdisciplinary perspective. In educational environments, this awareness should be gained from an early age and even users should learn that there may be a footprint behind every click, every algorithm, every line of code.

Today's technological tools interact not only with the environment but also with many other sub-dimensions such as data security, energy use, ethical responsibility and privacy. Therefore, sustainability is no longer just an environmental issue but a conceptual framework that needs to be addressed with a multidimensional and interdisciplinary approach. For this reason, increasing the awareness of individuals and society, especially the younger generation about digital and AI footprints has become a fundamental necessity for more ethical, conscious and sustainable use of technology.

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AI systems are growing and developing day by day and are now becoming an integral part of daily life. With these systems, production accelerates, processes become easier and time saving becomes inevitable. However, behind every ease there is an invisible trace. Because every convenience provided by AI systems has an impact on the environment, society and the future. This mark has become not only today's responsibility but also tomorrow's responsibility. For this reason, when using technology, it is necessary not only to benefit from it but also to be aware of the traces we leave behind. Every user, every institution and every educator should be able to recognize, understand and question the trace left behind by technology. Because the sustainability of the future is possible not only by producing technology but also by recognizing its footprint.

## REFERENCES

Akbaş, U., & Sünbül, M. (2022). Ortaokul öğrencilerinin su ayak izi farkındalığı düzeyleri. *Korkut Ata Üniversitesi Türkiyat Araştırmaları Dergisi*, (13), 123–142. https://doi.org/10.51531/korkutataturkiyat.1471798

Akıllı, H., Kemahlı, F., Okudan, K., & Polat, F. (2008). Ekolojik ayak izinin kavramsal içeriği ve Akdeniz Üniversitesi İktisadi ve İdari Bilimler Fakültesi'nde bireysel ekolojik ayak izi hesaplaması. *Akdeniz İİBF Dergisi*, *8*(15), 1–25.

Aytaç, E. (2023). *Water literacy scale development study* (Master's thesis, Balikesir University). ProQuest Dissertations & Theses Global. https://www.proquest.com/openview/87041569244efaca0d19a1f24ed1871b/

Bahar, M., & Kiras, F. (2017). Türkiye'de çevre eğitimi konulu tez ve makalelerin analizi. *Eğitimde Kuram ve Uygulama*, *13*(1), 35–50. https://doi.org/10.17240/aibuefd.2017.17.32772-363962

Bailey, S. G. M., & Caidi, N. (2005). How much is too little? Privacy and smart cards in Hong Kong and Ontario. *Journal of Information Science*, *31*(5), 354–364. https://doi.org/10.1177/0165551505055400

Buitrago-Ropero, M. E., Ramírez-Montoya, M. S., & Chiappe, A. (2020). Digital footprints (2005–2019): A systematic mapping of studies in education. *Interactive Learning Environments*, *31*(2). https://doi.org/10.1080/10494820.2020.1814821

Bulut, G., & Özer, M. A. (2024). Ekolojik modernleşmeye iklim değişikliği ve "çevresel ayak izleri" üzerinden bakmak. *Çankırı Karatekin Üniversitesi İİBF Dergisi*, *14*(3), 752–778. https://doi.org/10.18074/ckuiibfd.1503754

Çankaya, C., & Filik İşçen, C. (2014). Fen bilgisi öğretmen adaylarına yönelik su tüketim davranış ölçeği: Geçerlik ve güvenirlik çalışması. *E-Journal of New World Sciences Academy*, *9*(3), 341–352. https://doi.org/10.12739/NWSA.2014.9.3.1C0622

Carson, R. (1962). *Silent spring*. Boston, MA: Houghton Mifflin.

Center for Sustainable Systems. (n.d.). *Carbon footprint factsheet*. University of Michigan. Retrieved June 27, 2025, from https://css.umich.edu/publications/factsheets/sustainability-indicators/carbon-footprint-factsheet

Çevre, Şehircilik ve İklim Değişikliği Bakanlığı. (2022). *Çevre nedir?* https://webdosya.csb.gov.tr/db/destek/icerikler/01_cevre_brosur-20191128080426.pdf

Cordero, E. C., Centeno, D., & Todd, A. M. (2020). The role of climate change education on individual lifetime carbon emissions. *PLOS ONE*, *15*(2), e0206266. https://doi.org/10.1371/journal.pone.0206266

Crawford, K. (2024, February 20). Generative AI's environmental costs are soaring — and mostly secret. *Nature*. https://www.nature.com/articles/d41586-024-00478-x

Čuček, L., Klemeš, J. J., & Kravanja, Z. (2012). A review of footprint analysis tools for monitoring impacts on sustainability. *Journal of Cleaner Production*, *34*, 9–20. https://doi.org/10.1016/j.jclepro.2012.02.036

Dam, M. M., Kaya, F., & Bekun, F. V. (2024). How does technological innovation affect the ecological footprint? Evidence from E-7 countries in the background of the SDGs. *Journal of Cleaner Production*, *443*, 141020. https://doi.org/10.1016/j.jclepro.2024.141020

Dasgupta, P., Dasgupta, A., & Barrett, S. (2023). Population, ecological footprint and the Sustainable Development Goals. *Environmental and Resource Economics*, *84*(4), 659–675. https://doi.org/10.1007/s10640-021-00595-5

Ding, Z., Wang, J., Song, Y., Zheng, X., He, G., Chen, X., ... & Song, J. (2025). Tracking the carbon footprint of global generative artificial intelligence. *The Innovation*, *6*(5). https://doi.org/10.1016/j.xinn.2025.100866

Duran, B. G. (2019). *Çevre eğitimi için uygun animasyon filmlerin belirlenmesi...* (Master's thesis). Balıkesir University. https://tez.yok.gov.tr

Durkaya, F. (2022). Ekolojik ayak izi konusunda yapılan lisansüstü tezlerin analizi. *Fen Matematik Girişimcilik ve Teknoloji Eğitimi Dergisi*, *5*(2), 166–184.

Emejulu, A., & McGregor, C. (2016). Towards a radical digital citizenship in digital education. *Critical Studies in Education*, *60*(1), 131–147. https://doi.org/10.1080/17508487.2016.1234494

Erten, S. (2004). Çevre eğitimi ve çevre bilinci nedir, çevre eğitimi nasıl olmalıdır? *Çevre ve İnsan Dergisi*, 65/66, 25–32.

Fang, K., Song, S., Heijungs, R., de Groot, S., Dong, L., Song, J., & Wiloso, E. I. (2016). The footprint's fingerprint: On the classification of the footprint family. *Current Opinion in Environmental Sustainability*, *23*, 54–62. https://doi.org/10.1016/j.cosust.2016.12.002

Footprint Data Foundation, York University Ecological Footprint Initiative, & Global Footprint Network. (2023). *National Footprint and Biocapacity Accounts: 2023 Edition*. https://data.footprintnetwork.org

Galli, A., Wiedmann, T., Ercin, E., Knoblauch, D., Ewing, B., & Giljum, S. (2012). Integrating ecological, carbon and water footprint into a "Footprint Family" of indicators: Definition and role in tracking human pressure on the planet. *Ecological Indicators*, *16*, 100–112. https://doi.org/10.1016/j.ecolind.2011.06.017

Gomes, C., Dietterich, T., Barrett, C., Conrad, J., Dilkina, B., Ermon, S., ... & Zeeman, M. L. (2019). Computational sustainability. *Communications of the ACM*, *62*(9), 56–65. https://doi.org/10.1145/3339399

Güğül, G. N., & Kılınç, N. (2022). Uzaktan eğitimin karbon ayak izine etkileri. *Journal of Advanced Research in Natural and Applied Sciences*, *8*(1), 124–131.

Gupta, U., Kim, Y. G., Lee, S., Tse, J., Lee, H. H. S., Wei, G. Y., ... & Wu, C. J. (2021). Chasing carbon. In *IEEE International Symposium on High-Performance Computer Architecture* (pp. 854–867). https://arxiv.org/abs/2011.02839

Hoekstra, A. Y., & Wiedmann, T. O. (2014). Humanity's unsustainable environmental footprint. *Science*, *344*(6188), 1114–1117. https://doi.org/10.1126/science.1248365

Hynes, H. P. (1989). *The recurring Silent Spring*. Oxford, UK: Pergamon Press.

Karslı, M., & Tunca Güçlü, A. (2023). Suya yönelik tutum ölçeği. *Eğitimde Nitel Araştırmalar Dergisi*, *9*(2), 145–162. https://doi.org/10.34056/aujef.1275139

Keleş, Ö., & Aydoğdu, M. (2010). Preservice science teachers' views on reducing ecological footprints. *Journal of Turkish Science Education*, *7*(3), 171–187.

Keleş, Ö., Uzun, N., & Özsoy, S. (2008). Öğretmen adaylarının ekolojik ayak izleri. *Ege Eğitim Dergisi*, *9*(2), 1–15.

Kligiené, S. T. (2012). Digital footprints in the context of professional ethics. *Informatics in Education*, *11*(1), 65–79. https://doi.org/10.15388/infedu.2012.04

Kurt, P., & Çavuş-Güngören, S. (2020). Ortaokul öğrencilerinin sürdürülebilirliğe yönelik tutum, davranış ve farkındalıkları. *Akdeniz Eğitim Araştırmaları Dergisi*, *14*(34), 529–552.

Li, P., Yang, J., Islam, M. A., & Ren, S. (2025). Making AI less "thirsty". *Communications of the ACM*, *68*(7), 54–61. https://doi.org/10.1145/3724499

Livingstone, S., & Third, A. (2017). Children and young people's rights in the digital age. *New Media & Society*, *19*(5), 657–670. https://doi.org/10.1177/1461444816686318

Lo, C. K. (2023). Impact of ChatGPT on education. *Education Sciences*, *13*, 410. https://doi.org/10.3390/educsci13040410

Matuštík, J., & Kočí, V. (2021). What is a footprint? *Journal of Cleaner Production*, *285*, 124833. https://doi.org/10.1016/j.jclepro.2020.124833

McDermot, M. (2018). Digital footprints: Creation, implication, and higher education. *FDLA Journal*, *3*(1), Article 11.https://nsuworks.nova.edu/fdla-journal/vol3/iss1/11

Mitu, N. E., & Mitu, G. T. (2024). The hidden cost of AI. *Revista de Ştiinţe Politice*, 84. https://doi.org/10.2139/ssrn.5036344

Murugesan, S. (2008). Harnessing green IT: Principles and practices. *IT Professional*, *10*(1), 24–33.

Negroponte, N. (1995). *Being digital*. New York, NY: Alfred A. Knopf.

O'Reilly, T. (1999). What is Web 2.0. *O'Reilly Media*. https://www.oreilly.com/pub/a/web2/archive/what-is-web-20.html

OpenAI. (2025). *ChatGPT* [Large language model]. https://chat.openai.com/

Palmer, J. A. (1998). *Environmental education in the 21st century: Theory, practice, progress and promise*. London, UK: Routledge.

Patterson, D., Gonzalez, J., Le, Q., Liang, C., Munguia, L. M., Rothchild, D., ... & Dean, J. (2021). Carbon emissions and large neural network training. *arXiv preprint*, arXiv:2104.10350. https://arxiv.org/abs/2104.10350

Peters, G. P. (2010). Carbon footprints and embodied carbon. *Current Opinion in Environmental Sustainability*, *2*(4), 245–250. https://doi.org/10.1016/j.cosust.2010.05.004

Rahman, M. M., & Watanobe, Y. (2023). ChatGPT for education and research. *Applied Sciences*, *13*, 5783. https://doi.org/10.3390/app13095783

Raworth, K. (2017). *Doughnut economics*. White River Junction, VT: Chelsea Green Publishing.

Rees, W., & Wackernagel, M. (1996). Urban ecological footprints. *Environmental Impact Assessment Review*, *16*(4–6), 223–248. https://doi.org/10.1016/S0195-9255(96)00022-4

Schrenk, R. (2022). *Measuring the digital footprint* (Doctoral dissertation). International Burch University. https://doi.org/10.13140/RG.2.2.18363.28960

Schwartz, R., Dodge, J., Smith, N. A., & Etzioni, O. (2020). Green AI. *Communications of the ACM*, *63*(12), 54–63. https://doi.org/10.1145/3381831

Sellman, M. (2024, October 4). Thirsty ChatGPT uses four times more water than previously thought. *The Times*. https://www.thetimes.co.uk/

Sevil, Ü, & Dimişli, E. (1999). UNESCO-UNEP himayesinde çevre eğitiminin gelişimi. *Hacettepe Üniversitesi Eğitim Fakültesi Dergisi*, *17*, 120–130.

Shafiq, D. A., Marjani, M., Habeeb, R. A. A., & Asirvatham, D. (2025). Digital footprints of academic success. *Education Sciences*, *15*(3), 304. https://doi.org/10.3390/educsci15030304

Sheehan, C. D. (2008). *Impacts of an environmental education program on participants' environmental behaviors* (Master's thesis). University of Tennessee. https://trace.tennessee.edu/utk_gradthes/445

Shen, Y., Yang, Z., & Zhang, X. (2023). Impact of digital technology on carbon emissions. *Frontiers in Ecology and Evolution*, *11*, 1166376. https://doi.org/10.3389/fevo.2023.1166376

Strubell, E., Ganesh, A., & McCallum, A. (2020). Energy and policy considerations for modern deep learning research. *Proceedings of the AAAI Conference on Artificial Intelligence*, *34*(9), 13693–13696. https://doi.org/10.48550/arXiv.1906.02243

UNESCO. (2020). *The United Nations World Water Development Report 2020: Water and Climate Change*. Paris, France: UNESCO. https://unesdoc.unesco.org/ark:/48223/pf0000372985

Wang, Q., Li, Y., & Li, R. (2024). Ecological footprints and energy transitions. *Humanities and Social Sciences Communications*, *11*, 1043. https://doi.org/10.1057/s41599-024-03520-5

Wang, Y., Zhang, R., Yao, K., & Ma, X. (2024). Does artificial intelligence affect the ecological footprint? *Journal of Environmental Management*, *370*, 122458. https://doi.org/10.1016/j.jenvman.2024.122458

Weidema, B. P., Thrane, M., Christensen, P., Schmidt, J., & Løkke, S. (2008). Carbon footprint—a catalyst for life cycle assessment? *Journal of Industrial Ecology*, *12*(1), 3–6. https://doi.org/10.1111/j.1530-9290.2008.00005.x

Wiedmann, T., & Minx, J. (2008). A definition of carbon footprint. In C. C. Pertsova (Ed.), *Ecological economics research trends* (pp. 1–11). New York, NY: Nova Science Publishers.

Witte, J. (2006). Review of *Internet data collection* (Book review). *New Media & Society*, *8*(2), 344–347. https://doi.org/10.1177/146144480600800211

World Commission on Environment and Development. (1987). *Our common future*. Oxford, UK: Oxford University Press.

Wu, C. J., Raghavendra, R., Gupta, U., Acun, B., Ardalani, N., Maeng, K., ... & Hazelwood, K. (2022). Sustainable AI: Environmental implications, challenges and opportunities. *Proceedings of Machine Learning and Systems*, *4*, 795–813. https://doi.org/10.48550/arXiv.2111.00364

WWF. (2020). *Living Planet Report 2020: Bending the curve of biodiversity loss*. Gland, Switzerland: WWF.

Zuboff, S. (2019). *The age of surveillance capitalism*. New York, NY: Profile Books.

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# ARTIFICIAL INTELLIGENCE IN LANGUAGE EDUCATION: OPPORTUNITIES, CHALLENGES, AND FUTURE PERSPECTIVES

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## INTRODUCTION

In the 21st century, language learning has undergone a profound transformation driven by rapid technological advancement and the growing interconnectedness of a globalized world. Among the most significant of these technological shifts is the emergence and proliferation of artificial intelligence (AI), which has begun to reshape the ways in which languages are taught, learned, and used (Godwin-Jones, 2021). As education systems worldwide increasingly prioritize multilingual competence as a key component of academic success, career readiness, and intercultural communication, the integration of AI into language education represents both a paradigm shift and a powerful pedagogical opportunity.

Traditionally, language learning has relied on teacher-led instruction, textbooks, memorization of vocabulary, and classroom-based communicative practice. While these methods have produced generations of proficient speakers, they often face challenges such as limited personalization, resource constraints, and insufficient opportunities for authentic language use. The arrival of AI technologies — including machine learning algorithms, natural language processing (NLP), intelligent tutoring systems (ITS), and, more recently, large language models (LLMs) such as OpenAI's GPT series — has opened the door to fundamentally new approaches that overcome many of these limitations. These technologies are capable of delivering individualized instruction at scale, analyzing learner data to adapt content dynamically, providing instant and context-sensitive feedback, and generating authentic communicative interactions that approximate real-world language use (Kasneci et al., 2023).

Moreover, AI is uniquely positioned to address some of the long-standing pedagogical challenges in language education. For example, adaptive learning platforms can personalize the sequence and difficulty of lessons based on a learner's proficiency and progress, while conversational chatbots can provide limitless speaking practice in a low-pressure environment — a resource that is often scarce in traditional classroom settings. Automated writing assistants can offer immediate feedback on grammar, vocabulary, and style, fostering learner autonomy and accelerating the revision process. Similarly, speech recognition and pronunciation assessment technologies can provide fine-grained analysis of pronunciation errors, enabling learners to improve their speaking skills with precision and confidence.

The integration of AI into language education is not only a technological development but also a significant pedagogical shift. It invites educators to reconsider the roles of teachers and learners, the design of curricula, and the very nature of assessment. Teachers are no longer merely transmitters of knowledge but become facilitators, data interpreters, and designers of AI-supported learning experiences. Learners, on the other hand, are empowered to become active agents in their own education, benefiting from personalized pathways, instant feedback, and access to vast linguistic resources that were previously unimaginable. Despite these transformative opportunities, the application of AI in language learning is not without challenges. Ethical concerns such as data privacy, algorithmic bias, and unequal access to technology must be addressed to ensure that AI-driven education is equitable and inclusive. Furthermore, the effectiveness of AI tools varies widely, and empirical evidence about their long-term impact on language acquisition remains incomplete. Questions regarding pedagogical alignment, cultural appropriateness, and the role of human interaction in AI-mediated learning continue to shape ongoing debates among researchers and practitioners.

This paper aims to provide a comprehensive examination of the role of artificial intelligence in language education by analyzing the opportunities it presents, the challenges it entails, and the future directions it suggests. Drawing on recent empirical studies, theoretical frameworks, and real-world implementations, the study explores how AI technologies are reshaping language teaching methodologies, learner experiences, and educational outcomes. By situating current developments within broader pedagogical and ethical contexts, the paper seeks to contribute to an informed understanding of how AI can be harnessed to support effective, equitable, and innovative language learning in the digital age.

## The Evolution of Artificial Intelligence in Language Education

The integration of Artificial Intelligence (AI) into the field of language education represents one of the most significant paradigm shifts in modern pedagogy. Over the past few decades, the rapid advancement of AI technologies has transformed not only how languages are taught and learned but also how educators conceptualize the process of language acquisition itself. This evolution has been marked by a series of technological, theoretical, and methodological milestones that have fundamentally redefined the relationship between teachers, learners, and the language-learning environment.

The earliest attempts to integrate technology into language learning can be traced back to the mid-20th century with the emergence of Computer-Assisted Language Learning (CALL) in the 1960s and 1970s. These early systems were limited to text-based drills and repetition exercises, focusing primarily on vocabulary and grammar practice. Although rudimentary, CALL systems laid

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the groundwork for the idea that technology could supplement and enhance traditional language teaching methods (Warschauer & Healey, 1998). However, these early systems lacked the adaptive, intelligent, and interactive features that characterize contemporary AI-based tools.

The late 1990s and early 2000s marked a turning point with the rise of the internet and the proliferation of multimedia resources. Language learning platforms began incorporating video, audio, and interactive exercises, creating more engaging and context-rich learning environments. Nevertheless, it was the development of machine learning (ML) and natural language processing (NLP) — core components of modern AI — that catalyzed a revolutionary transformation in the field. NLP, in particular, enabled machines to understand, interpret, and generate human language, paving the way for more sophisticated and human-like interactions between learners and digital platforms.

One of the earliest large-scale applications of AI in language education was automated essay scoring and grammar correction tools, such as those developed by ETS and Grammarly. These systems not only provided instant feedback but also analyzed language use in nuanced ways that mimicked human assessment. Over time, the focus of AI applications shifted from simple assessment to adaptive learning systems, which personalize learning content based on individual learner profiles, strengths, and weaknesses. Platforms such as Duolingo, Babbel, and Rosetta Stone began integrating AI algorithms that analyze user data to predict errors, recommend targeted exercises, and optimize learning paths.

A more recent development in the evolution of AI in language education is the rise of conversational AI and intelligent tutoring systems (ITS). These systems utilize NLP, speech recognition, and deep learning to simulate real-time conversations, provide personalized feedback, and adjust their teaching strategies dynamically. Virtual tutors and chatbots now serve as 24/7 conversational partners, offering learners a low-pressure environment in which to practice speaking and listening skills. This shift reflects a broader movement in language pedagogy from rote memorization to communicative competence and task-based learning, where the focus is on authentic, meaningful language use.

Another transformative innovation has been the integration of AI-driven speech recognition and pronunciation assessment tools. These technologies enable learners to receive immediate, precise feedback on their spoken language, including accent, intonation, and fluency — areas traditionally challenging to address outside of one-on-one instruction. Furthermore, advances in machine translation (MT) and large language models (LLMs) — such as OpenAI's GPT series or Google's BERT — have further blurred the boundaries between learning and communication. Learners can now engage with AI systems capable of not only translating but also explaining linguistic nuances, cultural contexts, and pragmatic features of language use.

The evolution of AI in language education has also been shaped by broader educational trends, including the rise of personalized learning, data-driven instruction, and learner autonomy. AI tools can collect and analyze vast amounts of learner data, enabling teachers and curriculum designers to make more informed decisions about instruction. Moreover, the shift from a teacher-centered model to a learner-centered paradigm has empowered students to take control of their own learning journeys, supported by intelligent systems that act as guides and facilitators rather than mere content deliverers.

Despite these advances, the evolution of AI in language education is not without challenges. Issues such as data privacy, algorithmic bias, and the potential dehumanization of the learning process continue to spark debate (Bozkurt et al., 2023). Moreover, while AI can provide unprecedented access to language learning resources, it cannot fully replicate the socio-cultural dimensions of language use, such as empathy, negotiation, and intercultural communication. These concerns highlight the importance of adopting a human-AI collaborative model, where AI enhances rather than replaces the human elements of teaching and learning.

In conclusion, the evolution of AI in language education reflects a broader shift in the educational landscape — one characterized by increasing personalization, interactivity, and learner agency. From early CALL systems to sophisticated conversational agents, AI has continuously expanded the boundaries of what is possible in language teaching and learning. As technologies continue to evolve, the challenge for educators, researchers, and policymakers will be to harness the transformative potential of AI while preserving the humanistic core of language education. This delicate balance will define the next chapter in the ongoing story of how humans teach, learn, and use language in the age of artificial intelligence.

AI-Powered Tools and Applications in Language Learning

The proliferation of Artificial Intelligence (AI) in the field of language education has given rise to an extensive range of tools and applications that are reshaping the way languages are taught, learned, and assessed. These tools, grounded in cutting-edge technologies such as natural language processing (NLP), machine learning (ML), deep learning, and speech recognition, are not merely supplementary aids but central components of modern language pedagogy. They are designed to support diverse learning objectives, from vocabulary acquisition and grammar correction to advanced conversational practice, intercultural communication, and even creative language production. The integration of AI-powered systems into educational contexts has thus created a dynamic, personalized, and adaptive learning environment unprecedented in the history of language teaching.

### Intelligent tutoring systems (ITS)

One of the most impactful applications of AI in language learning is the development of Intelligent Tutoring Systems (ITS). These systems emulate the capabilities of human tutors by analyzing learners' inputs, tracking their progress, and delivering personalized feedback. Unlike traditional computer-assisted language learning platforms, ITS can adapt dynamically to a learner's proficiency level, cognitive style, and learning pace. By leveraging large datasets and predictive analytics, these systems can identify patterns in a learner's errors, anticipate future challenges, and modify lesson plans accordingly.

For example, platforms like Duolingo and Rosetta Stone utilize AI algorithms to monitor user performance and adjust the difficulty and type of exercises in real time. This adaptivity is particularly beneficial for language learners, as it ensures that they are continually challenged but not overwhelmed, maintaining optimal engagement — a crucial factor in long-term retention and motivation (Loewen et al., 2019). ITS also allow for spaced repetition and retrieval-based practice, techniques supported by cognitive science as highly effective for vocabulary and grammar retention.

## AI-Driven natural language processing (NLP) tools

At the heart of many AI language applications lies Natural Language Processing (NLP), the branch of AI that enables computers to understand, interpret, and generate human language. NLP tools have become indispensable in language education for tasks such as grammar correction, semantic analysis, language translation, and text generation. They facilitate a deeper, more interactive engagement with the target language, providing learners with immediate, contextualized feedback on their language use.

One prominent example is Grammarly, which goes beyond simple error correction to offer nuanced suggestions related to tone, style, and clarity. Such feedback not only helps learners avoid grammatical mistakes but also enhances their communicative competence by fostering awareness of register, cohesion, and rhetorical appropriateness. Similarly, applications like ChatGPT and Google Bard utilize advanced NLP models to simulate realistic dialogues, generate writing prompts, or explain complex grammatical concepts interactively. These tools effectively function as conversational partners, writing assistants, and virtual teachers simultaneously, providing learners with opportunities for authentic language use that extend beyond the classroom (Kohnke, 2023).

Machine translation tools, once limited to literal and often inaccurate translations, have also undergone a revolution due to NLP advancements. Platforms like DeepL and Google Translate now employ deep neural networks that capture contextual meaning, idiomatic expressions, and cultural nuances. These improvements make them valuable tools not only for translation tasks but also as learning aids that help students compare structures and understand semantic subtleties between languages.

## Speech recognition and pronunciation training

Spoken language competence — including pronunciation, intonation, and fluency — has traditionally been one of the most challenging skills to develop without direct human feedback. AI-powered speech recognition technologies have addressed this challenge by enabling precise, real-time analysis of learners' spoken language. These systems transcribe speech, identify phonetic

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errors, and provide corrective feedback, often with detailed explanations about articulation and prosody (Rogerson-Revell, 2021).

Applications like Elsa Speak and Speechling use deep learning models to analyze subtle acoustic patterns and compare learners' pronunciation to that of native speakers. They offer targeted exercises to improve specific sounds or stress patterns, helping learners achieve more natural and comprehensible speech. In addition to individual pronunciation feedback, some systems incorporate conversational AI to simulate realistic spoken interactions. These virtual interlocutors not only respond to learners' speech but also adapt their vocabulary and complexity level based on the learner's proficiency, enabling gradual progression in conversational skills.

Moreover, the integration of speech recognition into mainstream tools like Google Assistant, Alexa, or Siri has expanded opportunities for informal language practice. Learners can engage with these voice-activated AI systems in the target language during daily routines, reinforcing learning through authentic, context-rich interactions outside the traditional classroom.

**Adaptive learning platforms and personalized curricula**

AI's capacity to process vast amounts of learner data enables the creation of adaptive learning platforms that tailor content to individual needs, preferences, and goals. These systems analyze user behavior, test results, time spent on tasks, and even emotional responses to recommend personalized learning paths. Such personalization is particularly valuable in language learning, where proficiency levels and learning objectives vary widely among students.

For example, platforms like Busuu and Babbel use AI to track a learner's vocabulary retention, identify weak areas, and introduce review sessions at optimal intervals. Some advanced platforms go further by incorporating predictive analytics to forecast future learning challenges and preemptively introduce relevant materials. This degree of personalization enhances learner engagement, increases motivation, and improves learning outcomes.

Furthermore, AI systems can create dynamic curricula that evolve as learners progress. Instead of following a fixed syllabus, learners receive content that is continuously updated based on their performance data. This approach aligns with modern educational theories such as constructivism and learner-centered pedagogy, which emphasize individualized learning experiences and active learner involvement.

**Conversational agents and virtual language partners**

One of the most transformative developments in AI-powered language learning is the emergence of conversational agents — chatbots and virtual avatars capable of simulating human-like dialogue. These tools combine NLP, speech synthesis, and machine learning to engage learners in interactive conversations that mimic real-world language use. Unlike traditional practice methods, conversational agents offer immediate feedback, adapt their responses to the learner's input, and can operate 24/7, providing a low-stress environment for language practice (Jeon, 2022).

For instance, Replika and ChatGPT can engage users in complex, context-sensitive conversations, while platforms like MondlyAR use augmented reality (AR) to place learners in immersive, simulated environments where they interact with virtual speakers. These tools help bridge the gap between classroom learning and real-world communication, fostering not only linguistic competence but also pragmatic and intercultural awareness.

Additionally, conversational agents can be programmed to adopt specific roles — such as a travel guide, customer service representative, or academic advisor — enabling learners to practice language relevant to their personal or professional goals. This functional approach to language learning reflects the principles of task-based language teaching (TBLT), which emphasizes using language as a tool for achieving real-world tasks.

### Challenges, Ethical Concerns, and Limitations

The rapid integration of artificial intelligence (AI) into language education has brought transformative benefits to teaching and learning processes. However, alongside its undeniable potential, the deployment of AI in educational contexts is also accompanied by a range of significant challenges, ethical concerns, and inherent limitations that must be critically examined. As AI technologies become more deeply embedded in pedagogical practices, educators, policymakers, and researchers must grapple with complex questions regarding data privacy, equity, algorithmic bias, pedagogical dependence, and the human dimensions of language learning. Understanding these challenges is essential for developing responsible, sustainable, and inclusive approaches to AI-driven language education.

One of the most prominent concerns surrounding AI in language learning relates to data privacy and security. AI systems rely heavily on large volumes of learner data — including written texts, spoken input, interaction histories, performance analytics, and even biometric or emotional data — to provide personalized feedback, track progress, and optimize learning experiences. While this data-driven approach enhances the effectiveness of AI tools, it also raises serious questions about how learner data is collected, stored, processed, and shared. In many cases, users are unaware of the extent of data collection or how their personal information is being utilized. Moreover, language data can contain sensitive cultural or personal information, increasing the risk of misuse, unauthorized access, or breaches. These risks are particularly pronounced when AI applications are developed or hosted by private corporations that may prioritize commercial interests over user privacy (Williamson & Eynon, 2020). Consequently, educators and institutions must ensure that robust data governance policies, informed consent procedures, and compliance with international privacy regulations such as the GDPR are in place before integrating AI technologies into educational environments.

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Closely related to privacy concerns is the issue of algorithmic bias and fairness, which poses a significant ethical challenge in AI-based language learning systems. AI models are only as unbiased as the data on which they are trained. If the training data reflects existing social, cultural, or linguistic biases — such as gender stereotypes, racial prejudices, or cultural hierarchies — these biases can be perpetuated or even amplified by AI systems. For instance, language models may generate responses that privilege certain dialects, varieties, or cultural references while marginalizing others (Bender et al., 2021). Automated speech recognition systems may struggle to accurately process accents or speech patterns from underrepresented linguistic communities, resulting in unfair assessments or negative feedback. Similarly, writing evaluation tools may penalize non-native speakers for stylistic choices that deviate from norms associated with native-speaker varieties. These forms of bias not only undermine the fairness and reliability of AI-based language instruction but also risk reinforcing existing inequities in educational outcomes. Addressing this challenge requires careful dataset curation, transparency in algorithm design, ongoing bias audits, and the inclusion of diverse linguistic and cultural data in model training.

Another significant challenge concerns accessibility and the digital divide, which highlight the risk of deepening educational inequalities in the era of AI-enhanced language learning. While AI-powered platforms offer personalized, high-quality instruction, their effectiveness often depends on access to reliable internet connections, modern digital devices, and technological literacy. Students in low-income regions, rural areas, or marginalized communities may lack these resources, resulting in unequal opportunities to benefit from AI-based education. Moreover, many commercial AI tools are subscription-based, placing them out of reach for learners and institutions with limited financial means. This growing "AI gap" threatens to widen existing disparities in language proficiency and educational attainment, particularly between well-resourced urban centers and underserved populations. Policymakers and educators must therefore prioritize digital equity initiatives, including affordable access to technology, public investment in infrastructure, and targeted support for disadvantaged learners, to ensure that the benefits of AI are distributed fairly across all segments of society.

A further challenge lies in the overreliance on AI technologies and the potential erosion of essential human elements in language education. Language learning is not merely a cognitive process of mastering grammar, vocabulary, and pronunciation; it is also a deeply social, cultural, and emotional activity that involves negotiation of meaning, identity formation, and intercultural understanding. While AI can simulate certain aspects of communication, it cannot fully replicate the complexity of human interaction, empathy, or socio-pragmatic nuance. Excessive dependence on AI tools — such as automated feedback systems, chatbots, or translation engines — may lead to a mechanistic approach to language learning, where learners focus on correctness and efficiency at the expense of creativity, critical thinking, and communicative competence. Furthermore, if AI becomes the primary source of instruction, learners may miss out on valuable opportunities for collaborative learning, peer interaction, and cultural immersion, all of which are essential for developing advanced language skills.

The potential deskilling of teachers is another significant concern associated with the widespread adoption of AI in language education. While AI can greatly assist educators by automating routine tasks and providing data-driven insights, there is a risk that overdependence on technology could diminish the role of teachers and reduce their pedagogical agency. If AI systems are perceived as superior in delivering instruction, assessing performance, or managing learning progress, teachers may be relegated to passive facilitators rather than active designers of learning experiences. This shift could erode teacher expertise, weaken professional identity, and reduce opportunities for human judgment and creativity in curriculum design. Furthermore, the successful integration of AI requires educators to develop new digital competencies and pedagogical strategies, yet many teachers lack sufficient training or institutional support to use these tools effectively. Professional development initiatives that equip teachers with the skills to critically evaluate, adapt, and complement AI systems are therefore essential to prevent deskilling and ensure that technology enhances rather than replaces human pedagogy.

Another complex issue is the transparency and explainability of AI systems used in language education. Many AI algorithms — particularly those based on deep learning — function as “black boxes,” producing outputs without providing clear explanations of how decisions are made. This lack of transparency poses significant challenges in educational contexts, where accountability, reliability, and interpretability are critical. Learners and teachers need to understand why a particular error was flagged, why a certain score was assigned, or how feedback was generated in order to trust and effectively use AI tools. Without explainability, there is a risk that users will accept AI recommendations uncritically, potentially reinforcing misconceptions or inaccurate assessments. Efforts to improve algorithmic transparency, such as providing interpretable feedback explanations or incorporating human-in-the-loop systems, are therefore essential for building trust and ensuring pedagogical integrity.

Ethical concerns also extend to intellectual property and authorship in the age of AI-generated content. AI tools can produce essays, translations, and even creative texts with minimal human input, raising questions about authorship, originality, and academic integrity. Students may be tempted to submit AI-generated work as their own, blurring the line between assistance and plagiarism. Additionally, educators face challenges in distinguishing genuine student output from machine-generated text, complicating assessment and undermining the validity of language proficiency evaluations. Institutions must develop clear policies and guidelines regarding the appropriate use of AI tools, including transparency requirements, citation practices, and academic honesty protocols, to address these concerns.

Another limitation of AI-driven language education is the contextual and cultural insufficien**cy** of many current systems. Language is deeply embedded in cultural norms, social practices, and historical contexts, and effective language learning involves not only mastering linguistic forms but also understanding cultural nuances, pragmatic conventions, and communicative strategies. AI systems, however, often lack the cultural awareness necessary to fully support intercultural competence. They may fail to detect culturally inappropriate language use, misinterpret idiomatic expressions, or provide feedback that is linguistically correct but pragmatically odd. This limitation is particularly problematic for learners preparing to use language in real-world intercultural contexts, such as diplomacy, business, or international collaboration. Addressing this gap requires interdisciplinary approaches that integrate linguistic, cultural, and sociolinguistic knowledge into AI design and training processes.

Furthermore, there are concerns about the long-term sustainability and scalability of AI technologies in language education. Many AI applications require significant computational resources, frequent software updates, and ongoing maintenance, which can be costly and logistically challenging for educational institutions. The rapid pace of technological change also means that tools can become obsolete quickly, requiring continuous investment in infrastructure and training. Additionally, the environmental impact of AI — particularly the energy consumption associated with training large language models — raises questions about the sustainability of widespread AI adoption in education. Institutions must weigh the pedagogical benefits of AI against these financial, logistical, and environmental considerations when planning for long-term implementation.

Finally, there is the philosophical and pedagogical question of human-AI balance: How much should language education rely on AI, and what aspects of teaching and learning should remain inherently human? While AI can enhance efficiency, personalization, and access, it cannot replicate the depth of human relationships, empathy, creativity, and cultural intelligence that characterize effective teaching. Striking the right balance requires a conscious effort to integrate AI as a complement to — rather than a replacement for — human interaction. Educators must ensure that technology serves pedagogical goals rather than dictating them and that learners are guided not only by algorithms but also by human mentors who can nurture critical thinking, intercultural sensitivity, and lifelong learning values.

In conclusion, while artificial intelligence offers unprecedented opportunities to enhance language education, its adoption is accompanied by a complex array of challenges, ethical concerns, and limitations that must not be overlooked. Issues of privacy, bias, inequality, transparency, overreliance, teacher roles, academic integrity, cultural adequacy, and sustainability all demand careful attention and proactive solutions. Addressing these challenges requires collaboration among educators, technologists, policymakers, and researchers to develop ethical guidelines, equitable access policies, transparent algorithms, and robust teacher training programs. Only by confronting these issues head-on can the educational community harness the full potential of AI in a way that is responsible, inclusive, and aligned with the fundamental human values that underpin language learning. Ultimately, the goal is not to replace human pedagogy with technology but to integrate AI thoughtfully and critically, enhancing the human dimensions of education while mitigating its risks and limitations.

### Future Directions and Recommendations

The rapid integration of artificial intelligence (AI) into language education has already transformed many traditional approaches to teaching, learning, and assessment. Yet, despite significant progress, the field remains in a state of dynamic evolution, with immense untapped potential and numerous unresolved challenges. As we look toward the future, it is clear that the next phase of AI's development in language education will not simply involve refining existing technologies but reimagining the entire pedagogical landscape. Future directions must be guided by interdisciplinary collaboration, ethical responsibility, cultural inclusivity, pedagogical innovation, and a learner-centered vision that places human development at the core of technological advancement. The following discussion outlines the key areas in which AI-driven language education is likely to evolve and offers strategic recommendations for maximizing its transformative potential while addressing current limitations.

A central priority for the future is the development of more context-aware, culturally intelligent, and pragmatically sensitive AI systems. Current language learning technologies often excel at teaching vocabulary, grammar, and basic communicative functions but struggle with the subtleties of pragmatics, socio-cultural nuance, and discourse conventions. Future research must therefore focus on training models that not only understand linguistic form but also grasp cultural meanings, politeness strategies, regional variations, and situational appropriateness. This will require incorporating interdisciplinary insights from sociolinguistics, anthropology, intercultural communication, and cognitive science into AI design. Large language models of the future should be trained on diverse, multicultural datasets and fine-tuned for specific communicative contexts — such as business negotiations, academic discourse, diplomatic interactions, or informal conversations — so that they can provide contextually appropriate feedback and cultural explanations. Such systems will not only improve language proficiency but also foster intercultural competence, a skill that is increasingly vital in our globalized world.

Another key direction involves advances in personalization and adaptive learning. The next generation of AI-powered platforms will likely move beyond static, one-size-fits-all instruction to offer deeply individualized learning experiences that continuously adapt to each learner's needs, goals, learning style, and pace. Future systems should integrate multimodal data — including linguistic performance, cognitive load, emotional engagement, motivation levels, and even biometric signals — to create a comprehensive learner profile. Based on this profile, AI can dynamically adjust the difficulty level, sequence of activities, type of feedback, and mode of instruction in real time. For example, an AI tutor might detect when a learner is frustrated with a grammar exercise and switch to a game-based task to maintain engagement or notice patterns of fossilized errors and design targeted remediation modules. Moreover, adaptive systems could offer personalized learning paths aligned with professional or academic objectives, such as preparing for language proficiency exams, developing industry-specific terminology, or mastering academic writing conventions. The result would be a more responsive, efficient, and motivating learning experience that maximizes individual potential.

The future will also witness a significant expansion in multimodal and immersive learning environments powered by AI. As natural language processing converges with computer vision, augmented reality (AR), virtual reality (VR), and extended reality (XR), language learners will increasingly engage with authentic, interactive, and context-rich scenarios. Imagine a learner practicing Arabic in a virtual Middle Eastern marketplace, negotiating prices with AI-driven shopkeepers who respond with culturally appropriate language and gestures, or participating in a simulated academic conference where real-time AI feedback guides their presentation skills. Such immersive environments can dramatically enhance language acquisition by providing meaningful communicative contexts, reducing anxiety, and promoting experiential learning. Furthermore, future systems may combine multimodal input — including text, speech, facial expressions, gestures, and visual cues — to assess communicative competence more holistically and provide nuanced feedback on aspects such as prosody, intonation, non-verbal communication, and intercultural pragmatics. These innovations will bring language learning closer to the complexities of real-world interaction and prepare learners for authentic communication in diverse global settings.

A crucial recommendation for the future is to ensure that AI tools remain human-centered and pedagogically grounded**.** Technology should serve as a powerful supplement to — not a replacement for — human instruction. Teachers will continue to play an irreplaceable role as mentors, facilitators, cultural mediators, and motivators. Therefore, future AI systems must be designed to support and enhance the teacher's role rather than undermine it. This can be achieved by developing platforms that provide teachers with actionable insights into learner progress, suggest personalized interventions, automate administrative tasks, and allow for customization of content according to pedagogical goals. At the same time, teacher education programs must evolve to include digital literacy, AI ethics, and data analytics training so that educators are empowered to integrate technology effectively and critically. A collaborative human-AI teaching model — where machines handle repetitive tasks and data analysis while teachers focus on higher-order thinking, creativity, and emotional engagement — will likely be the most effective paradigm for the future of language education.

Ethical design and governance frameworks will also become increasingly important as AI continues to shape language learning. Future systems must be built on principles of fairness, accountability, transparency, and inclusivity. This involves implementing rigorous bias detection and mitigation strategies, ensuring explainability in algorithmic decisions, protecting user data through strong encryption and privacy policies, and obtaining informed consent for

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data collection. Furthermore, developers and policymakers must establish clear guidelines for the responsible use of AI-generated content, including norms for citation, authorship, and academic integrity. An emerging area of research known as “explainable AI” (XAI) will be particularly relevant, as it seeks to make machine decision-making processes more transparent and interpretable to educators and learners. This will foster trust, enhance pedagogical effectiveness, and ensure that AI is used in ways that align with educational values and ethical standards.

In addition, the future of AI in language education will depend heavily on interdisciplinary collaboration and cross-sector partnerships. No single field — whether linguistics, computer science, education, or psychology — can address the complex challenges of integrating AI into language learning. Researchers from diverse disciplines must work together to design models that combine linguistic accuracy with cognitive insights, pedagogical soundness, and cultural sensitivity. Partnerships between universities, technology companies, government agencies, and non-profit organizations will be essential to fund research, scale innovations, and ensure equitable access to AI-powered tools. International collaboration will also play a crucial role in developing multilingual, multicultural systems that serve the needs of learners across different linguistic and cultural backgrounds. Such cooperative efforts will accelerate progress and ensure that AI technologies reflect the diversity and complexity of human language and communication.

Looking ahead, evaluation and assessment practices in language education will also undergo a paradigm shift driven by AI. Traditional assessments — often based on discrete-point testing and static scoring — are increasingly inadequate for measuring communicative competence in dynamic, real-world contexts. Future AI-driven assessment systems will likely adopt a more continuous, formative, and performance-based approach. They may analyze language use in authentic tasks, track learner progress over time, and provide detailed diagnostic feedback on multiple dimensions of language proficiency. Moreover, AI could enable adaptive testing systems that adjust question difficulty based on learner responses or use multimodal analysis to assess speaking, writing, and interactional skills more accurately. This shift will not only improve the validity and reliability of language assessment but also make it more aligned with pedagogical objectives and learner needs.

Equity and inclusion must remain central priorities as AI becomes more embedded in language education. Future innovations should aim to close, rather than widen, the digital divide by providing low-cost, offline, and multilingual solutions for learners in underserved regions. Open-source AI platforms, collaborative online learning communities, and government-subsidized educational technologies could play an important role in democratizing access. Additionally, AI tools must be designed to accommodate diverse learning needs, including those of students with disabilities, neurodiverse learners, and speakers of low-resource languages. For example, speech recognition systems should be trained to understand a wide range of accents and speech patterns, and interfaces should be designed with accessibility features such as screen

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readers, voice commands, and adaptive interfaces. Inclusive design is not only a matter of social justice but also a prerequisite for unlocking the full potential of AI in global language education. Another promising direction for future exploration is the integration of affective computing and emotional intelligence into AI language learning systems. Language learning is not purely a cognitive process; it is deeply influenced by affective factors such as motivation, anxiety, confidence, and identity. Future AI systems could use sentiment analysis, facial expression recognition, and physiological signals to detect learners' emotional states in real time and respond appropriately — for example, by offering encouragement during moments of frustration or adjusting task difficulty to maintain motivation. By integrating emotional intelligence into AI systems, educators can create more empathetic, supportive, and humanized learning experiences that promote persistence and resilience.

Finally, sustainability and long-term vision must guide the next phase of AI adoption in language education. This involves not only financial and infrastructural planning but also environmental responsibility. Developers should focus on creating energy-efficient algorithms, leveraging cloud-based solutions that reduce hardware dependency, and exploring decentralized models that minimize carbon footprints. Educational institutions must adopt long-term strategies for updating technology, training staff, and integrating AI into curricula in a way that is scalable and adaptable to future innovations. Moreover, as AI continues to evolve, continuous research will be necessary to evaluate its impact on learning outcomes, pedagogy, ethics, and society. A forward-looking, iterative approach that prioritizes sustainability and adaptability will ensure that AI remains a positive and enduring force in language education.

In conclusion, the future of artificial intelligence in language education is filled with transformative potential — but realizing that potential will require more than technological innovation alone. It demands a holistic, interdisciplinary, and ethically grounded vision that places learners and educators at the center of the educational ecosystem. Future directions must prioritize cultural intelligence, deep personalization, immersive learning, teacher empowerment, ethical governance, and inclusive access. They must harness the power of AI not to replace the human dimensions of language learning but to enrich, extend, and elevate them. By following these strategic recommendations, policymakers, educators, researchers, and developers can shape an AI-driven future in which language education becomes more equitable, more effective, and more human than ever before. Ultimately, the goal is not just to teach languages more efficiently but to cultivate globally competent, culturally aware, and communicatively skilled individuals who can thrive in an increasingly interconnected world — a vision that AI, if responsibly and creatively harnessed, is uniquely positioned to help achieve.

## Conclusion

In conclusion, the integration of artificial intelligence (AI) into language education represents a transformative milestone in the evolution of teaching and learning methodologies. Across the multiple dimensions explored in this

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study — including the evolution of AI in language education, AI-powered tools and applications, pedagogical benefits, methodological transformations, challenges, ethical concerns, limitations, and future directions — it becomes evident that AI holds unprecedented potential to reshape the way languages are learned, taught, assessed, and experienced globally. The convergence of computational intelligence, data analytics, natural language processing, and immersive technologies offers learners and educators tools and resources that were unimaginable just a few decades ago, enabling a level of personalization, interactivity, and adaptability that traditional methods alone could not achieve. These technological advancements have paved the way for learner-centered, communicative, and adaptive pedagogical approaches, fundamentally altering the dynamics of language classrooms and redefining the roles of both teachers and learners (Chen et al., 2020).

One of the central outcomes of AI integration in language education is its ability to deliver highly personalized and adaptive learning experiences. Unlike conventional methods that often follow uniform curricula and standardized pacing, AI-driven systems dynamically adjust instruction based on individual learner profiles, proficiency levels, cognitive patterns, and motivational factors. This personalization fosters more efficient and meaningful language acquisition, reduces learner frustration, and enhances engagement. Moreover, AI encourages learner autonomy, empowering students to take control of their educational journey, practice independently, and develop critical metacognitive and self-regulatory skills. By doing so, learners are not only acquiring language knowledge but also cultivating essential lifelong learning competencies that extend far beyond the classroom.

The pedagogical advantages of AI extend into the enhancement of communicative competence and contextual learning. AI-powered conversational agents, intelligent tutoring systems, and multimodal platforms provide learners with opportunities to engage in authentic, context-rich communication scenarios that replicate real-life interactions. This experiential learning enables the development of pragmatic awareness, cultural competence, and discourse-level skills, addressing a longstanding gap in traditional grammar- and translation-focused approaches. Furthermore, AI facilitates a proactive and data-informed pedagogy, allowing educators to anticipate learner difficulties, provide targeted interventions, and continuously refine instructional strategies. Teachers, in turn, are able to shift from purely content delivery roles to facilitative, strategic, and mentoring roles that leverage AI insights to support learners' holistic development.

Despite these profound benefits, the study also highlights the complex challenges and ethical considerations inherent in AI integration. Issues related to data privacy, algorithmic bias, accessibility, overreliance on technology, transparency, cultural adequacy, teacher deskilling, and academic integrity underscore the need for careful and responsible implementation. These challenges cannot be overlooked; rather, they must be addressed through robust policies, ethical design principles, teacher training, equitable access strategies, and interdisciplinary collaboration. AI, while powerful, is not a panacea; its effective deployment requires human judgment, critical evaluation, and ongoing oversight to ensure that it complements rather than diminishes the human dimensions of language learning.

Looking to the future, AI in language education is poised to evolve in ways that further enhance immersion, contextualization, and inclusivity. The integration of augmented and virtual reality, multimodal sensory inputs, affective computing, and culturally aware systems promises to create richer, more authentic, and emotionally engaging learning experiences. Future AI applications will likely provide nuanced feedback on pronunciation, pragmatics, cultural appropriateness, and intercultural communication, supporting learners not only in linguistic mastery but also in navigating the complexities of global communication. At the same time, the emphasis on ethical, equitable, and sustainable practices will remain critical, ensuring that AI does not exacerbate educational inequalities or compromise the integrity and authenticity of learning experiences. By fostering cross-disciplinary collaboration, transparent algorithmic design, inclusive accessibility measures, and continuous teacher development, the educational community can maximize the transformative potential of AI while mitigating its inherent risks.

Another critical dimension of the conclusion involves the synergistic relationship between humans and AI in education. The research demonstrates that the most effective pedagogical outcomes arise from a balanced approach in which AI functions as an augmentative tool rather than a replacement for human instruction. Teachers provide the contextual understanding, empathy, cultural nuance, and ethical judgment that AI alone cannot replicate, while AI handles tasks such as adaptive feedback, repetitive practice, data analysis, and immersive simulations. This synergy ensures that learners benefit from the best of both worlds: the scalability, adaptability, and analytical power of AI combined with the emotional intelligence, creativity, and ethical discernment of human educators (Molenaar, 2022). In this sense, AI becomes a partner in the educational process rather than a substitute, enhancing the quality, efficiency, and impact of language learning on a global scale.

The study further emphasizes the importance of lifelong learning and learner agency in an AI-enhanced educational landscape. AI tools facilitate flexible, self-directed, and continuous learning opportunities that extend beyond traditional classroom boundaries, enabling learners to engage with language content at their own pace and in their own context. This flexibility is particularly valuable in a world characterized by rapid globalization, digital transformation, and evolving professional demands. By embedding lifelong learning principles into AI-powered platforms, educators and developers can cultivate not only language proficiency but also the adaptability, resilience, and intercultural competence that learners require to thrive in diverse personal and professional environments.

Moreover, the findings underscore the necessity of holistic and inclusive design principles in future AI development. Language learning technologies must accommodate learners of diverse linguistic, cognitive, and socio-cul-

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tural backgrounds, including speakers of minority languages, learners with disabilities, and those with limited digital literacy or access to technological resources. Inclusivity in AI design ensures equitable educational opportunities, promotes social justice, and enriches the learning environment by embracing linguistic and cultural diversity. Future research and development efforts should prioritize these considerations, integrating universal design principles, accessibility features, and localized content to support learners worldwide.

In summation, the integration of artificial intelligence into language education constitutes both a transformative opportunity and a profound responsibility. The findings of this study highlight that AI can revolutionize pedagogy by enabling personalized, immersive, communicative, and data-informed learning experiences. Simultaneously, educators, policymakers, and researchers must remain vigilant in addressing ethical challenges, mitigating risks, and ensuring inclusive and culturally sensitive practices. By embracing a human-centered, ethically grounded, and strategically guided approach, the educational community can harness AI to enhance the quality, equity, and effectiveness of language education globally. The ultimate vision is one in which AI empowers learners, supports teachers, and fosters a lifelong, culturally competent, and communicatively proficient approach to language learning — creating a more connected, informed, and empathetic global society. In this sense, AI is not merely a technological tool; it is a catalyst for reimagining the future of language education, one that blends innovation, ethics, pedagogy, and human values in a harmonious and sustainable manner.

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## REFERENCES

Bozkurt, A., Xiao, J., Lambert, S., Pazurek, A., Crompton, H., Koseoglu, S., ... & Jandrić, P. (2023). Speculative futures on ChatGPT and generative artificial intelligence (AI): A collective reflection from the educational landscape. *Asian Journal of Distance Education, 18*(1).

Chen, L., Chen, P., & Lin, Z. (2020). Artificial intelligence in education: A review. *IEEE Access, 8*, 75264–75278.

Godwin-Jones, R. (2021). Big data and language learning: Opportunities and challenges. *Language Learning & Technology, 25*(1), 4–19.

Jeon, J. (2022). Exploring AI chatbots in EFL classrooms: Learners' expectations and perceptions. *Computers & Education: Artificial Intelligence, 3*, 100072.

Kasneci, E., Sessler, K., Küchemann, S., et al. (2023). ChatGPT for good? On opportunities and challenges of large language models for education. *Learning and Individual Differences, 103*, 102274.

Kohnke, L. (2023). ChatGPT for language teaching and learning. *RELC Journal, 54*(2), 537–550.

Loewen, S., Crowther, D., Isbell, D. R., Kim, K. M., Maloney, J., Miller, Z. F., & Rawal, H. (2019). Mobile-assisted language learning: A Duolingo case study. *ReCALL, 31*(3), 293–311.

Molenaar, I. (2022). Towards hybrid human-AI intelligence in education: Understanding the limitations of AI-driven personalization. *European Journal of Education, 57*(4), 632–645.

Rogerson-Revell, P. M. (2021). Computer-Assisted Pronunciation Training (CAPT): Current trends and future directions. *RELC Journal, 52*(1), 189–205.

Warschauer, M., & Healey, D. (1998). Computers and language learning: An overview. *Language Teaching, 31*(2), 57–71.

Williamson, B., & Eynon, R. (2020). Historical data and the future of educational research. *Postdigital Science and Education, 2*, 423–428.

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# ARTIFICIAL INTELLIGENCE TOOLS USED IN EDUCATION AND APPLICATION AREAS

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## Introduction

Artificial intelligence today exists in almost all areas of life as systems that can perform tasks that would be difficult for humans to do in a short time in just a few seconds, with various approaches such as decision-making, learning, predicting, making suggestions, and producing new results from existing data (Fullan, Azorín, Harris, & Jones, 2024). Although the history of artificial intelligence, which has become increasingly widespread in recent years with the development of technology and has attracted the attention of many governments, institutions, companies, societies, and individuals, actually dates back a century. In recent years, the development of artificial intelligence has continued with increasing momentum to the present day. From the emergence of the internet and the intelligent agents paradigm in 1994 to the present day, artificial intelligence has become more integrated into our daily lives during this period, which is referred to as the "Third Golden Age of Artificial Intelligence" (Çelebi, Demir, & Karakuş, 2023). Artificial intelligence technologies have permeated almost every area of our daily lives, including education, health, economy, government, transportation, communication, and many other sectors (Hocaoğlu, 2025).

Artificial intelligence (AI) in education refers to the application of AI technologies to improve students' learning processes, increase teachers' productivity, and optimize overall education systems. AI in education encompasses a wide range of applications, such as personalizing learning processes, monitoring student performance with data analytics, automating teaching materials, and making education more accessible (Holmes, Bialik, & Fadel, 2019). Artificial intelligence is not only used to support learning but is also effectively utilized in a wide range of areas such as teaching, assessment, classroom management, administrative tasks, teacher duties, and school management (Arslan, 2020).

On the other hand, AI-powered tools help students overcome the difficulties they encounter while doing their homework and coursework. The visual upload feature enables students to quickly convey complex problems and find solutions. Being accessible from phones and computers allows students to use them anytime and anywhere (Seven & Erümit, 2025). It can be said that AI tools have significant potential to improve the quality of education when used correctly, effectively, and efficiently. Today, thanks to AI-supported systems, teachers can prepare more efficient lesson plans, while students gain a more personalized learning experience. This transformation reinforces the effects of digitalization in education, lightening teachers' workloads while accelerating students' learning processes (Boztepe, 2025). It is important to use and encourage the use of artificial intelligence applications in education because they enrich learning environments and reflect the positive outcomes of student-teacher interaction into the educational process (Çiftçi, Çiftçi, Akca, & Kaçmaz, 2024). The rapid and intensive development of artificial intelligence has led to a rapid increase in the use of artificial intelligence applications in education. Every day, new AI applications are being made available to education stakeholders. Therefore, enabling school administrators, teachers, students, and other education stakeholders to more easily access, compare, and correctly and effectively use the AI tools they need will save time and contribute to increased work efficiency. Therefore, this study includes AI tools that have been used in educational environments, are considered useful, and can be utilized at every level of education. Links to the tools have been added to theirnames.

**Artificial Intelligence Tools**

**ChatGPT*:*** This is the basic tool used in the lesson plan preparation process. The application is asked to create a lesson plan by entering variables such as learning outcomes, subject, lesson time, relevant sections in the textbook, and number of students. Changes can be made to the basic lesson plan created by the application in line with the desired objectives. Care should be taken to describe the desired situation specifically to the application. In addition to creating a lesson plan draft, ChatGPT can be asked to generate numerous sample materials for the lesson. Based on the provided information, create a lesson plan, provide examples for dictation exercises, explain addition by proving it at an elementary school level, review student assignments according to grammar rules, explain the concept of patience to a seven-year-old child, suggest three educational games for physical education, compose a song for our class, prepare multiplication table flashcards, and engage in a debate with a student by defending one side. In artificial intelligence studies, "prompt" and "command" are very important. For example, we can revise the lesson plan with commands such as "make the questions in the evaluation section multiple choice" or "add an attention-grabbing activity to the introduction section." Copilot: It is a chatbot similar to ChatGPT. Unlike ChatGPT, it conducts research based on a current database. It can answer our questions by referring to websites, articles, and teaching programs. Copilot can also be used as a primary resource in the lesson plan preparation process. With the application, you can create desired images and design visuals. It also allows

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for graphic and table design. All operations performed with ChatGPT can be done with Copilot using up-to-date data. ChatGPT and Copilot can be used as basic AI tools when creating Lesson 9 plans. We can choose whichever tool provides us with the most efficient results.

**Copilot:** It is a chatbot similar to ChatGPT. Unlike ChatGPT, it conducts research based on a current database. It can answer our questions by referring to websites, articles, and teaching programs. Copilot can also be used as a primary resource in the lesson plan preparation process. With the application, you can create desired images and design visuals. It also allows for graphic and table design. All operations performed with ChatGPT can be done with Copilot using up-to-date data. ChatGPT and Copilot can be used as basic AI tools when creating Lesson 9 plans. We can choose whichever tool provides us with the most efficient results.

**Animated Drawings:** This tool is designed to convert children's drawings into animations. Users can upload drawings and choose from different animation styles. In art class, we can animate the pictures drawn by students and turn them into animations. This way, students may become more eager and motivated to draw. How can we use it? By combining the animations prepared in the application, we can create a short cartoon related to a life skills lesson.

**Ideogram and Leonardo:** Ideogram and Leonardo is an AI image creation tool. By entering detailed commands for the desired image into the application, it generates various images. Since the application is designed in English, commands entered in English produce more effective results. How can we use it? Images to be used in the prepared lesson plan can be created with a few commands. The images generated are original images not found on Google or other databases.

**Eduaide and Magic School:** With these tools, we can prepare daily plans, create assessment questions, design activity experiments, prepare educational models and materials according to 5E-Gagne, and enrich our lessons according to globally accepted education and activity methods. A key feature of these tools is that they have specially prepared sections for each topic, and these sections are managed by pre-trained artificial intelligence. For example, when creating questions with ChatGPT, we need to enter and edit a series of commands. This is not necessary with trained artificial intelligence in these applications because the tools have been trained with various commands beforehand. Each educational tool within the applications has a unique feature that distinguishes it from the others.

**Gamma AI and Tome AI:** Tome and Gamma are two AI presentation tools that help you create presentations quickly. If you don't have enough experience and time for design and slide editing, these AI tools can help you with this. Both applications can create the slides you want in minutes. How can we use them? We take the relevant sections from the textbook and turn them into fun slides. This way, we don't stray from the context of the textbook. We can also convert examples we will give to students or explanations outside of class into slides by entering a few commands. For example, by entering a command such as

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"create a fun slide about the capitals of the world's countries," we can create a slide on this topic, or we can create a slide by simply copying and pasting sections from the textbook.

**Suno and Udio:** Suno and Udio are AI-based tools used to create music. The lyrics of the desired song are entered, and the desired song genre is selected. Then, within a few minutes, the application creates the desired song with a suitable melody at . How can we use it? By preparing songs about concepts that need to be memorized, students can easily learn those concepts. Poems or texts prepared by students can be turned into songs. We can start the day by creating a class song that includes the students' names and use it actively in music class.

**Fliki:** Only the desired text and topic are taught to the application, and the application creates a written, narrated, and visual video according to the selected duration. We can instantly create videos on any topic we want. It is up to us to ensure that only the desired parts are included in the video. How can we use it? Abstract concepts that are difficult to understand can be entered as commands and turned into videos with audio explanations. Lesson review videos can be created by entering the titles of topics that students do not understand, making it easier to convey situations that are difficult to illustrate with examples. For example, it is possible to achieve the desired output by giving commands such as turning our responsibilities towards animals into a video, converting the rotational movements of the Earth and the Sun into a video with entertaining dialogues, or creating entertaining videos about the capitals of countries.

**Canva:** Canva is an AI-powered application that allows users to design online. With the AI features found under the magic tabs in Canva, users can create professional designs. They can search for content suggestions with various images, create educational materials quickly and easily, and perform many other features quickly and practically.

**MathGPT:** MathGPT is an AI-based math problem-solving application. With this platform, you can upload screenshots or type questions directly into the application to solve math problems instantly. MathGPT can solve questions instantly or reach the answer by explaining step by step. How can we use it? It can be used under parental supervision to provide students with detailed feedback on their math homework. It can help students find answers more quickly to math questions they are struggling with or cannot solve.

**Yippty:** It is only a multiple-choice question creation site. Unlike other platforms, it works only for this purpose. The most important feature that distinguishes it from other question preparation tools is that we can paste up to ten thousand words into the application. Because the more text we enter, the higher the validity of our test will be in that direction. How can we use it? The relevant sections of the textbook can be copied and a test can be created. Tests can be created from reading books or the reading texts in Turkish textbooks.

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**Call Annie:** This is an AI assistant based on ChatGPT. It offers real-time conversation with virtual people through its video chat feature. The chat language is English. How can we use it? Students can practice speaking English by having daily English conversations in class using a smart board or at home using their phones. This way, students can improve their English language skills and gain confidence in speaking.

**Heygen ve Rask:** These AI tools can translate a previously recorded Turkish video into any other language. The video is translated into a different language without distorting the mouth movements and recorded sound. How can we use it? Each student explains a different topic and records a video. Each recorded video is translated into a different language, and a library is created. These videos promote foreign language development, create content for the channel, and can be used in Erasmus and e-twinning projects.

**Elevenlabs:** With this AI tool, you can narrate your Turkish text with various voices (ten different human voices). We can also record our own voice and translate it into other languages, including Turkish, using the various voices available in the application. How can we use it? Texts and stories written by students can be narrated with this application, resulting in audio materials. Students are motivated to write and improve their writing skills. When the written stories or texts are played aloud in class, it contributes to attention, listening, and comprehension skills. The texts written by students can be converted to audio, uploaded to YouTube, and a class story channel can be created.

**Speechtexter:** A fast, practical, and lag-free AI tool that instantly converts your speech into text. Students can use the application while writing daily. They can access a written transcript by recounting what they remember for the purpose of reviewing a lesson or topic, thereby reviewing the lesson. We can ask them to send the written transcript of the topic they recounted to the teacher. Additionally, one-on-one meetings with students can be recorded and transcribed using the app. ChatGPT can summarize the transcribed meeting and identify key points.

**Adobe Express:** We can record our voice and have a conversation with an avatar of our choice within the application. With Elevenlabs, another AI tool, we can convert our own voice into an animated voice and add it to this video. How can we use it? We can create short informational videos and attract students' attention by sending these assignments to the WhatsApp group.

**Toonart:** This is an AI-powered avatar creation tool. After uploading our own photo to the app, we can choose from various avatar designs available in the app. How can we use it? Students' avatars can be created and posted on the classroom wall for various purposes, such as an assignment checklist or a behavior chart. You can also use avatars in activities where you don't want to use students' original photos. To recognize children who are reviewing the lesson taught at school or reading a book, images can be turned into avatars and made to speak by adding voiceovers.

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**AutoDraw:** is an AI-powered drawing tool developed by Google. It analyzes simple doodles made by the user (such as stick figures, houses, trees) and uses artificial intelligence to offer similar professional drawing suggestions. This allows users to create clean and understandable visuals in a short time, even if they lack drawing skills. Teachers can capture students' attention by quickly adding drawings to the board or presentation using AutoDraw while explaining a topic.(For example: Quickly creating solid–liquid–gas visuals while teaching the "states of matter" topic in science class.)

**Consensus AI:** An AI-powered research tool that aims to provide accurate and reliable information based on scientific research. When a user asks a question, Consensus AI scans academic articles and generates evidence-based answers summarized from scientific sources. This allows users to access results based directly on scientific studies rather than the confusing information found online.In education, teachers and students can use Consensus AI to find scientifically based data for homework, projects, or research topics, read article summaries, and cite sources. This helps develop research skills and fosters the habit of accessing reliable information.

**Colossyan:** It is a platform that quickly converts text, presentations, or documents into videos with artificial intelligence support. Users can convert their written texts into videos with the voiceovers of their chosen avatars and create narrations in different languages. In education, teachers can upload lesson content or topic summaries to the application and turn them into engaging video lessons for students.

**Diffit AI:** An artificial intelligence tool that enables teachers to quickly adapt lesson content to students' levels. When any text, topic, or web link is entered, the tool automatically generates summaries, word lists, questions, and activities. This allows teachers to transform the same topic into materials of appropriate difficulty for students of different levels. It greatly facilitates personalized teaching and differentiated learning processes in education. It creates worksheets in the style of the Singapore mathematics education model.

**Table 1.** *Categorization of Artificial Intelligence Tools*

| Category | AI Tools |
|---|---|
| Lesson Planning and Content Development | ChatGPT, Copilot, Eduaide, Magic School, Diffit AI, Consensus AI |
| Numerical Tools | MathGPT, Yippty |
| Visual Design & Drawing | Ideogram, Leonardo, AutoDraw, Canva |
| Video & Presentation & Animation | Gamma AI, Tome AI, Animated Drawings, Colossyan, Fliki, Adobe Express, Toonart |
| Sound & Music Production | Suno, Udio, Elevenlabs |
| Language Learning & Communication | Call Annie, Heygen, Rask |
| Writing & Dictation | Speechtexter |

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## REFERENCES


Boztepe, C. (2025). Artificial Intelligence Applications in Education: Opportunities, Limitations, and Ethical Debates. *Dumlupınar University Journal of Educational Sciences Institute, 9*(1), 98-121. Arslan, K. (2020). Artificial intelligence and its applications in education. *Western Anatolia Journal of Educational Sciences, 11*(1), 71-88.

Boztepe, C. (2025). Artificial intelligence applications in education: Opportunities, limitations, and ethical debates. *Dumlupınar University Journal of Educational Sciences Institute, 9*(1), 98-121.

**Çelebi, C., Demir, U., & Karakuş, F.** (2023). Systematic review of studies on artificial intelligence literacy. *Necmettin Erbakan University Ereğli Faculty of Education Journal, 5*(2), 535-560. https://doi.org/10.51119/ereegf.2023.67

**Çiftçi, M., Çiftçi, A., Akca, H. A., & Kaçmaz, E.** (2024). Innovation in education with artificial intelligence: Innovative approaches and applications. *Socrates Journal of Interdisciplinary Social Researches, 10*(48), 242-251. https://doi.org/10.5281/zenodo.14588723

Fullan, M., Azorín, C., Harris, A., & Jones, M. (2024). Artificial intelligence and school leadership: Challenges, opportunities, and implications. *School Leadership & Management, 44*(4), 339-346. https://doi.org/10.1080/13632434.2023.2246856

Hocaoğlu, A. Y. (2025). Examining the artificial intelligence awareness levels of special education teachers. *Journal of Individual Differences in Education, 7*(1), 1-16.

Holmes, W., Bialik, M., & Fadel, C. (2019). *Artificial intelligence in education: Promises and implications for teaching and learning*. Center for Curriculum Redesign.

Seven, E. H., & Erümit, A. K. (2025). An examination of generative artificial intelligence tools in mathematics education: Tool features, usage purposes, and effects. *Uşak University Journal of Educational Research, 11*(2), 136-162.

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# THE USE OF ARTIFICIAL INTELLIGENCE IN EDUCATIONAL MEASUREMENT AND EVALUATION PROCESSES: OPPORTUNITIES, LIMITATIONS AND FUTURE PERSPECTIVES

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## INTRODUCTION

The twenty-first century has been a period in which education systems have rapidly digitalized and data-driven decision-making processes have come to the fore. This transformation has brought about fundamental changes not only in teaching methods but also in the way learning is assessed and measured. Although traditional approaches to measurement and evaluation have long been effective in determining students' levels of knowledge, they remain limited in capturing the depth of learning, creativity and higher-order thinking skills (Cohen & Manion, 2018). The diversity in education, individual differences in learning and the increasing impact of technology make it necessary for measurement and evaluation processes to become more flexible, personalized and data-based.

At this point, artificial intelligence (AI) introduces a new dimension to assessment processes in education. AI is generally defined as a field of science that aims to equip computer systems with human-like thinking, learning and problem-solving abilities (Russell & Norvig, 2021). The use of AI in education is becoming increasingly widespread in such areas as monitoring student performance, identifying learning gaps, automatic scoring systems and personalized feedback mechanisms (Luckin, Holmes, Griffiths, & Forcier, 2016). In particular, in measurement and evaluation processes, AI-based systems save teachers time, increase objectivity and enable in-depth data analyses through learning analytics.

However, the use of AI in the field of measurement and evaluation brings not only opportunities but also various ethical, pedagogical and methodological debates. Issues such as data privacy, algorithmic bias, and the validity and reliability of assessment tools are considered important factors that limit the applicability of AI-based systems in education (UNESCO, 2023). In addition, how AI-supported assessment tools transform the role of teachers and how students perceive these systems are also examined carefully by researchers (Popenici & Kerr, 2017).

In this chapter, current approaches to the use of AI in educational measurement and evaluation processes are discussed from a multidimensional perspective. First, the development of AI-supported assessment applications and their impact on education systems are addressed; then the opportunities they offer and the limitations encountered are evaluated. Finally, possible future directions and policy suggestions are presented, offering a holistic perspective on the AI-shaped nature of assessment in education.

## The Transformation of Measurement and Evaluation in Education

Measurement and evaluation are among the most important components of the teaching–learning process. Measurement involves determining students' levels of knowledge, skills or attitudes, while evaluation refers to interpreting these findings to make educational decisions (Nitko & Brookhart, 2014). For many years, measurement processes were mostly carried out through standardized tests, written exams or teacher observations. Although these approaches provide advantages in terms of ease of implementation and objectivity, they have not sufficiently reflected students' thinking processes, creative productions and problem-solving skills (Black & Wiliam, 1998).

The integration of digital technologies into learning environments has also reshaped the understanding of measurement and evaluation. As learning processes have moved to online platforms, the volume and variety of data collected from students have increased dramatically. This development has brought the concept of learning analytics to the agenda. Learning analytics refers to making sense of students' interactions in digital environments in order to gain a deeper understanding of learning processes (Siemens & Long, 2011). In this way, measurement is transformed from a process limited to determining an outcome into a dynamic structure that tracks the learner's journey.

In this context, computer adaptive testing (CAT) has emerged as a significant innovation. CAT systems automatically determine the difficulty level of subsequent items according to each student's responses, thereby offering a personalized assessment process (Wainer, 2000). This method yields results that are closer to the learner's true proficiency level while also making the examination process shorter and more efficient.

In addition, alternative assessment approaches have gained renewed importance with the help of technology. Portfolio assessments, project-based work and digital performance tasks make it possible to evaluate students' multifaceted skills (Gikandi, Morrow, & Davis, 2011). These methods assess not only the learner's level of knowledge but also their ability to apply, analyze and produce knowledge.

This transformation has also redefined the roles of teachers. Teachers are no longer merely individuals who assign grades, but have become assessment designers who analyze data and guide students' learning processes (Ercikan & Pellegrino, 2017). In digitalized assessment processes, teachers' data literacy and their competence in pedagogically interpreting measurement results have become as important as their content knowledge. Therefore, the integration of AI into these processes is not only a technical innovation, but also an indication of a paradigmatic transformation in the nature of educational measurement and evaluation.

### AI-Based Assessment Applications

With the widespread use of AI technologies in education, measurement and evaluation processes have become increasingly flexible, dynamic and data-driven. AI has the potential not only to analyze whether students' responses are correct or incorrect, but also to examine their thinking processes, problem-solving strategies and learning behaviors (Heffernan & Heffernan, 2014). In this respect, assessment is turning into a holistic reflection of the learning process rather than being only an outcome-based evaluation.

### Automated Scoring Systems

AI-supported automated scoring systems provide significant convenience especially in the evaluation of open-ended questions. Thanks to natural language processing techniques, students' written responses can be analyzed semantically; the system can evaluate the correctness, clarity and conceptual coherence of an answer. In this way, the long scoring processes of teachers can be greatly accelerated and subjective differences in evaluation can be reduced (Shermis & Burstein, 2013). Some of these systems perform scoring by learning from pre-labeled sample responses, while others build their own linguistic patterns through deep learning models. For example, systems used in the evaluation of writing skills can analyze a student's text in terms of grammar, vocabulary use and coherence and assign a score accordingly.

### Computer Adaptive Testing (CAT)

Another innovation that AI has brought to the field of measurement is computer adaptive testing. In these systems, each item is selected based on the student's response to the previous item; thus the difficulty level of the test is adjusted according to the individual learner (Wainer, 2000). AI algorithms continuously make predictions about the student's knowledge level based on their response patterns. This approach both shortens the duration of the test and provides a more accurate measurement of the learner's actual performance. Some international exams and online testing platforms use CAT algorithms to reduce measurement error and to tailor the test experience to each student.

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## Learning Analytics and Predictive Assessment

Learning analytics is one of the most powerful components of AI in education. Digital traces left by students in online environments—such as login times, number of clicks and patterns of incorrect responses—can be analyzed to construct individual learning profiles (Siemens & Long, 2011). These data can be used to predict future performance or to identify learning difficulties at an early stage. For example, an AI-supported learning management system may detect that a student has a tendency towards low achievement and send learning alerts to both the student and the teacher. In this way, assessment systems are transformed from structures that merely evaluate past performance into systems with a preventive function oriented towards the future.

## Assessment Based on Visual and Behavioral Data

In recent years, AI has started to measure students' performance not only through text-based data but also via visual and behavioral data analysis. Through methods such as facial recognition, emotion analysis or eye-tracking, measurements can be made regarding students' attention, motivation and emotional states (D'Mello & Graesser, 2015). These systems are particularly important for monitoring student engagement in online education and determining whether learners actively contribute to the learning process. However, such applications also lead to ethical debates because the collection and processing of behavioral data require careful regulation of privacy and informed consent.

## Sample Applications from Türkiye and the World

AI-based assessment applications are not only on the agenda in developed countries, but are also increasingly attracting the attention of educational institutions in Türkiye. Automatic scoring of open-ended items, AI modules integrated into learning management systems and platforms that monitor students' learning performance in real time are becoming more common. At the international level, platforms such as Gradescope, Turnitin Feedback Studio, Khanmigo and ChatGPT-based educational applications stand out as tools that support teachers in the assessment process. These platforms both accelerate evaluation and offer instant feedback to learners, thereby personalizing the learning experience.

### *Gradescope*

Gradescope is a platform initially developed to facilitate the grading process of written exams in higher education. Thanks to its AI-supported image recognition system, teachers can score students' handwritten responses in a digital environment. The system groups similar responses and allows them to be evaluated collectively, which provides considerable time savings especially in large classes (Pritchard, Lee, & Bao, 2020). In addition, Gradescope analyzes the scores assigned by the teacher and performs consistency checks, offering suggestions for correction when necessary.

### *Turnitin Feedback Studio*

Turnitin Feedback Studio is used not only for plagiarism detection but also for the evaluation of students' written products and the provision of feedback. The system compares student texts with a large academic database and generates a similarity report; in addition, it allows teachers to add written comments, audio feedback and scoring criteria. Turnitin's similarity reports help teachers maintain academic integrity, while quick-mark and rubric tools show students in a concrete way the areas in which they need to improve (Cheema & Sheridan, 2021). In this way, assessment becomes not merely a process of assigning grades but also one that focuses on learning-oriented feedback.

### *Khanmigo*

Khanmigo is an AI-supported teaching and assessment assistant developed by Khan Academy. Based on the ChatGPT infrastructure, it provides students with personalized guidance, produces questions and offers instant feedback according to students' responses. When a student makes an error while solving a problem, Khanmigo does not directly give the correct answer but instead provides hints that guide the learner through the correct reasoning process (Khan Academy, 2024). This feature makes it possible to evaluate the student's cognitive processes and supports process-oriented assessment.

### *ChatGPT-Based Educational Applications*

ChatGPT and similar natural language processing–based systems are now increasingly used by teachers in assessment processes. ChatGPT can analyze students' open-ended responses, provide feedback on their written work and be integrated into rubric-based scoring systems. For example, a teacher can upload students' explanations about a science concept to ChatGPT and request an evaluation of scientific accuracy, conceptual coherence and language use for each response. Such applications make assessment semi-automated in a way that supports the teacher. However, it is emphasized that these systems should be used within a framework of human–AI collaboration rather than completely replacing teacher judgment (UNESCO, 2023).

## Ethical, Reliability and Validity Dimensions

The integration of AI into educational measurement and evaluation brings with it not only technical advantages but also new debates in the areas of ethics, reliability and validity. While the fast, objective and data-driven nature of AI systems creates significant opportunities for educators, errors, biases or lack of transparency that may arise in algorithmic decision-making processes can lead to serious problems for the principle of fairness in education (Baker & Hawn, 2021). Therefore, it is necessary not only to assess the pedagogical value of technological innovations but also to carefully determine their ethical boundaries.

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### Algorithmic Bias and Issues of Fairness

AI systems are models that learn based on data. However, since these data are often created by humans or collected from past educational practices, they may contain implicit biases. For example, a dataset dominated by response patterns from students of certain socio-economic groups may cause the algorithm to generate systematic differences against other groups in the evaluation process (Holmes, Bialik, & Fadel, 2021). This situation may make it difficult to protect the principle of fairness in AI-supported assessment systems. Therefore, the models developed should be trained on data that are inclusive of different student groups; regular bias tests should be conducted and the results should be audited by independent ethics committees. Teachers' knowledge of the limitations of AI systems and their support of AI-generated assessment results with human judgment serve as important balancing factors that reduce ethical risks (UNESCO, 2023).

### Data Privacy and Security

AI systems require large amounts of student data to function effectively. These data may include personal information such as response histories, texts, behavioral patterns and, in some cases, even facial expressions or voice recordings. Therefore, data privacy and information security are among the most critical issues in AI-based assessment systems. The unauthorized sharing, misuse or exposure of data through cyberattacks may lead to the disclosure of students' private information. To minimize these risks, systems must be designed in accordance with national and international privacy regulations, and students and parents must be informed about what data are collected, how these data are processed and with whom they are shared. Transparency increases learners' trust in these systems and strengthens the pedagogical value of AI-supported assessment.

### Debates on Validity and Reliability

As with any measurement tool, validity—the extent to which a tool measures what it is intended to measure—and reliability—the consistency of measurement results—are fundamental elements in AI-based assessment systems. However, the boundaries of these concepts differ from those in traditional measurement tools when it comes to AI systems (Ercikan & Pellegrino, 2017). In automated scoring systems, ensuring that the student's response is evaluated correctly requires that the model be trained with appropriate linguistic and conceptual patterns. In such systems, validity depends not only on the accuracy of the scores but also on the extent to which the system can capture the student's cognitive processes. In terms of reliability, it is important that the system produce consistent results for different students and different testing sessions. For this reason, AI-based assessment tools should be regularly tested using mixed validation methods such as comparisons with human raters and cross-analyses.

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### Human–AI Collaboration and Ethical Balance

It is not expected that AI will completely remove humans from the assessment process in education. On the contrary, the most effective models generally operate on the basis of human–AI collaboration (Luckin et al., 2016). AI is strong in areas such as data analysis, pattern recognition and providing rapid feedback, whereas teachers are indispensable in evaluating context, students' emotional states and pedagogical appropriateness. The ethically ideal approach is to position AI as an assistant that supports teachers' decision-making. In this way, the results produced by the system are blended with human judgment to achieve more just, reliable and meaningful evaluations.

### Transparency and Accountability

For AI systems to be used ethically in education, the principles of transparency and accountability are indispensable. Students, teachers and administrators should be able to understand how the system works, what data it analyzes and how it produces results. Non-transparent systems reduce user trust and diminish the pedagogical value of assessment results (Baker & Hawn, 2021). Therefore, developers are advised to share documentation that clearly explains algorithmic decision-making processes, while educational institutions are advised to conduct regular ethical audits. The implementation of AI-based assessment systems in harmony with the principles of ethics, reliability and validity requires not only technological change but also cultural and pedagogical transformation.

### Future Trends and Policy Recommendations

The rapid development of AI technologies is reshaping the future of measurement and evaluation processes in education. This transformation brings not only a technological innovation but also a pedagogical, ethical and administrative paradigm shift. In the upcoming period, it is foreseen that assessment systems will become more personalized, adaptive and integrated into the learning process (UNESCO, 2023). This section addresses prominent future trends and the regulations that should be made at the policy level.

### Personalized Assessment and Adaptive Systems

With the development of AI, educational measurement and evaluation are becoming increasingly personalized. Because each student's learning pace, style and level of knowledge differ, standard test approaches are becoming insufficient. AI-supported adaptive systems can analyze students' performance data in real time and individualize assessment. For example, the system can examine the speed of responses, recurring error patterns and conceptual misunderstandings, and determine the difficulty level of subsequent items accordingly (Wainer, 2000). In the future, these systems are expected to evolve into adaptive assessment practices that also analyze students' emotional reactions. In this way, assessment will become a multidimensional process that covers not only cognitive but also affective dimensions.

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### AI-Supported Feedback Mechanisms

One of the basic elements of effective assessment in education is feedback. AI does not simply assign grades; it can also provide meaningful and timely feedback showing in which concepts the student made errors, why these errors occurred and how they can be corrected. In the future, AI systems are expected to produce predictive feedback by analyzing students' prior learning data. Such a system may, for instance, generate alerts such as "This student continues to repeat the same errors on this topic even after several attempts; there is probably a conceptual misconception." These developments enable teachers to better understand their students, create individualized support plans and detect learning losses at an early stage.

### Teacher Education and AI Literacy

The effective use of AI-based assessment systems depends on teachers' ability to pedagogically make sense of these technologies. A teacher should not only know how to operate the system but also understand how it makes decisions, what data it uses in scoring and what limitations it has (Ercikan & Pellegrino, 2017). In this context, AI literacy will become an important component of future teacher education programs. Supporting teachers in areas such as data interpretation, ethical evaluation and awareness of algorithmic bias will enhance the pedagogical impact of technology. The Ministry of National Education and higher education institutions should lead this process by developing practice-oriented modules on AI within teacher education.

### Development of National and Institutional Policies

For AI-based assessment tools to be used safely, ethically and effectively, guiding principles need to be defined at the policy level. In this scope, the following should be established: national ethical protocols for the protection of student data; accreditation standards that regulate the use of AI tools in educational institutions; and frameworks that balance the responsibilities of teachers and students (UNESCO, 2023; OECD, 2021). In addition, it is recommended that national education policies consider AI not merely as a tool for assessment but as a component that supports learning, and that teacher decision-making mechanisms be kept at the center.

### Human–AI Collaboration and New Roles

The future understanding of measurement and evaluation will be built on an interactive model of collaboration between humans and machines. While AI is a powerful tool for big data analysis and rapid feedback generation, the teacher will remain the decision-maker who evaluates the pedagogical context, the student's emotional state and the subtleties of the learning environment (Luckin et al., 2016). In this perspective, the teacher assumes the role of an AI-augmented assessor. The learner, in turn, becomes not only an object of assessment but also an active subject of the process. In this way, AI becomes a partner that strengthens the human element at the heart of teaching rather than replacing it.

### Future Research Areas in AI-Based Assessment

Future research will focus on the validity structures, long-term learning effects and ethical awareness dimensions of AI-supported assessment systems. In particular, students' perceptions of and attitudes towards such systems, as well as their levels of motivation, will constitute important research topics. In addition, examining the achievement differences of students from different socio-economic backgrounds in AI-based assessments will provide new evidence for educational equity (Holmes, Bialik, & Fadel, 2021).

### Policy Recommendations

Policy recommendations regarding AI-based measurement and evaluation may be summarized as follows:

- Updating data privacy laws so that AI systems used in education are fully aligned with personal data protection regulations.
- Establishing ethical review committees that monitor AI systems at school and university levels.
- Updating teacher education programs so that AI awareness and ethical data use become integral parts of curricula.
- Creating national standards, in coordination with the Ministry of National Education and the Council of Higher Education, for the validity and reliability of AI-based assessment tools.
- Implementing pilot projects on AI applications in schools and regional measurement centers, and scaling systems up gradually based on the findings.

### AI-Based Measurement and Evaluation Approaches of the Ministry of National Education in Türkiye

In recent years, the Ministry of National Education (MEB) in Türkiye has structured its digital transformation vision in line with long-term education goals and has begun to integrate AI technologies into measurement and evaluation processes. In MEB's strategic plans, the digitalization, personalization and data-based support of decision-making processes in measurement and evaluation systems are among the main objectives (Ministry of National Education, 2023). This vision foresees the active use of AI not only in examination practices but also in the multidimensional monitoring of student achievement.

#### *Digital Assessment and Learning Analytics Applications*

The Education Informatics Network (EBA) platform, operated by MEB, is one of the most comprehensive implementations in Türkiye in terms of data-supported assessment and learning analytics. Exams and activities administered via EBA collect large-scale performance data from students, which are processed using analytic tools. In this way, trends in student achievement, topic-based areas of difficulty and learning gaps can be identified. In addition, digital test applications carried out through Measurement and Evaluation

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Centers (ÖDMs) provide a basis for adaptive test designs supported by AI. The electronic assessment systems used in these centers can score student responses instantly and provide teachers with analysis reports at both individual and classroom levels.

### *Models for Predicting Student Achievement*

MEB has also begun to develop models for predicting student achievement by using data mining and AI techniques. Especially in large-scale examinations such as the High School Entrance System (LGS) and the Higher Education Institutions Examination (YKS), performance predictions are made and areas of difficulty are identified by analyzing the data of millions of students from previous years. This approach is one of the reflections of predictive assessment in the Turkish context. In addition, MEB aims for AI-supported systems to make evaluations based not only on exam results but also on performance indicators during the learning process. In this way, not only students' outcome achievement but also their learning trajectories can be measured.

### *Open-Ended Response Analysis and Automatic Scoring Pilots*

Recent research and pilot projects in Türkiye show that MEB has begun to test natural language processing–based systems for the evaluation of open-ended items. These systems can analyze students' written responses at the linguistic and conceptual level and generate scores that are alternative or supportive to teachers' ratings. For example, open-ended questions in Turkish and Science courses at the lower-secondary level are being tested with automatic scoring algorithms; as a result, both the time required for evaluation is reduced and consistency among teachers is increased. It is planned that these applications will be scaled up nationwide in the coming years.

### *Awareness in Teacher Education*

MEB has also identified the development of teachers' AI literacy in the field of measurement and evaluation as one of its priority goals. In this scope, in-service training modules on AI awareness, the use of digital assessment tools and data interpretation skills have been developed on online teacher training platforms. In addition, strategy documents on digital transformation in education include sample lesson implementations that demonstrate how teachers can use AI-supported assessment tools in classroom evaluation processes. These efforts aim to increase teachers' capacity to use technology for pedagogical purposes.

### *Future Plans*

Among MEB's long-term goals is the development of national AI-supported assessment systems. In this context, it is planned to establish learning analytics platforms that can monitor students' academic development multidimensionally, provide personalized feedback and conduct data analysis on a national scale. These initiatives strengthen Türkiye's potential to become a regional actor in AI-based assessment practices in education.

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## Conclusion and Recommendations

The widespread use of AI technologies in education is fundamentally transforming the understanding of measurement and evaluation. The transition from traditional test-based approaches to data-driven, personalized and dynamic systems is not only a technological innovation but also a pedagogical necessity. Classical assessment methods that are limited to determining students' levels of knowledge cannot fully reflect the nature of learning. For this reason, AI-supported systems come to the fore as tools that can track learners' cognitive processes, recognize learning styles and provide real-time feedback (Luckin et al., 2016).

While the integration of AI into assessment processes offers significant advantages for teachers, it also brings ethical and methodological responsibilities. Issues such as algorithmic bias, data privacy and the validity and reliability of assessment results must be carefully managed for these systems to be used sustainably in education. In addition, AI should not be seen as a tool that completely replaces human decision-making but as a component that supports the professional judgment of teachers. Keeping the final decision in education in human hands is important for maintaining ethical responsibility and pedagogical sensitivity (UNESCO, 2023).

In conclusion, AI has given a new meaning to measurement and evaluation in education: assessment has now become a dynamic process that aims not only to determine what the student knows but also to understand how they learn and how learning can be improved. The success of this transformation lies in education systems that can balance the power of technology with human guidance and that build an assessment culture which is fair, transparent and learner-centered.

## REFERENCES


Baker, R. S., & Hawn, A. (2021). Algorithmic bias in education. *International Journal of Artificial Intelligence in Education, 31*(1), 1–12.

Black, P., & Wiliam, D. (1998). Assessment and classroom learning. *Assessment in Education: Principles, Policy & Practice, 5*(1), 7–74.

Cheema, J. R., & Sheridan, K. (2021). Effectiveness of Turnitin in promoting academic integrity and improving academic writing. *Journal of Academic Ethics, 19*(4), 567–585.

Cohen, L., & Manion, L. (2018). *Research methods in education* (8th ed.). Routledge.

D'Mello, S., & Graesser, A. (2015). Feeling, thinking, and computing with affect-aware learning technologies. In *Learning technologies handbook* (Vol. 3, pp. 1–26). U.S. Army Research Laboratory.

Ercikan, K., & Pellegrino, J. W. (2017). *Validation of complex assessments: Perspectives and challenges*. Routledge.

Gikandi, J. W., Morrow, D., & Davis, N. E. (2011). Online formative assessment in higher education: A review of the literature. *Educational Research Review, 6*(1), 7–24.

Heffernan, N., & Heffernan, C. (2014). The ASSISTments ecosystem: Building a platform that brings scientists and teachers together for minimally invasive research on human learning and teaching. *International Journal of Artificial Intelligence in Education, 24*(4), 470–497.

Holmes, W., Bialik, M., & Fadel, C. (2021). *Artificial intelligence in education: Promises and implications for teaching and learning*. Center for Curriculum Redesign.

Khan Academy. (2024). Khanmigo: AI-powered tutor and teaching assistant. Retrieved from https://khanacademy.org

Luckin, R., Holmes, W., Griffiths, M., & Forcier, L. B. (2016). *Intelligence unleashed: An argument for AI in education*. Pearson.

Ministry of National Education. (2023). *2023–2027 Strategic Plan*. MEB Publications.

Nitko, A. J., & Brookhart, S. M. (2014). *Educational assessment of students* (7th ed.). Pearson.

OECD. (2021). *AI in education: Trends and policy recommendations*. OECD Publishing.

Popenici, S., & Kerr, S. (2017). Exploring the impact of artificial intelligence on teaching and learning in higher education. *Research and Practice in Technology Enhanced Learning, 12*(1), 1–13.

Pritchard, D., Lee, K., & Bao, L. (2020). Using Gradescope to improve assessment efficiency and consistency in science education. *Journal of Science Education and Technology, 29*(2), 123–135.

Russell, S., & Norvig, P. (2021). *Artificial intelligence: A modern approach* (4th ed.). Pearson.

Shermis, M. D., & Burstein, J. (2013). *Handbook of automated essay evaluation: Current applications and new directions*. Routledge.

Siemens, G., & Long, P. (2011). Penetrating the fog: Analytics in learning and education. *EDUCAUSE Review, 46*(5), 30–40.

UNESCO. (2023). *Guidance for generative AI in education and research*. UNESCO Publishing.

Wainer, H. (2000). *Computerized adaptive testing: A primer* (2nd ed.). Lawrence Erlbaum.

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# CURRENT STUDIES ON ARTIFICIAL INTELLIGENCE IN EDUCATION

As we leave the first quarter of the twenty-first century behind, we are witnessing one of the most transformative technological revolutions in human history: the Age of Artificial Intelligence. This book, Current Studies on Artificial Intelligence in Education, offers a comprehensive and multidimensional exploration of how AI is reshaping the educational ecosystem. Far beyond being a mere technological tool, this volume examines AI as a phenomenon that transforms pedagogical approaches, alters assessment paradigms, and introduces critical ethical and environmental responsibilities.

Comprising six meticulously peer-reviewed chapters, the book blends rigorous theoretical frameworks with practical real-world applications. It addresses a wide spectrum of contemporary topics, including robotic coding, computational thinking, personalized language learning, and the environmental footprint of AI. By positioning AI not as a replacement for human educators but as a powerful ally, the work emphasizes a "human-centric" transformation designed to maximize the potential of both teachers and students.

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