INTEGRATION OF ARTIFICIAL INTELLIGENCE IN STEAM EDUCATION IN BULGARIA: AN ANALYSIS OF STRATEGIC VISION, PEDAGOGICAL PRACTICE, AND ETHICAL CHALLENGES

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Abstract: In the context of globalization and digitalization of public and social life, education is tasked with cultivating integrated practical knowledge and skills in adolescents. This creates the need to develop a STEM educational approach in combination with the capabilities of artificial intelligence (AI).
The aim of this study is to analyze the multifaceted integration of AI in STEAM education in Bulgaria by comparing the ambitious national strategic vision with the realities of pedagogical practice and institutional readiness.
The methodology used is a systematic synthesis and critical analysis of scientific literature and empirical data. The methodology is built on a triangulation of diverse sources, in order to achieve a holistic and objective view of the research problem. The analysis covers international and national strategies and documents, quantitative empirical data and academic and research literature. A synthesis of Bulgarian and international peer-reviewed articles, conference proceedings and research reports were carried out. These sources provide the theoretical framework for the pedagogical applications, transformational potential and ethical challenges associated with AI in STEAM education, allowing the Bulgarian case to be considered in a broader international context.
The results reveal a significant gap between this strategic vision and the on-the-ground reality. On the one hand, a national "top-down" strategy promotes the integration of AI, exemplified by the MES-INSAIT flagship project for sovereign educational AI and the foundational program for STEM centers. On the other hand, empirical data show widespread skepticism among teachers, low levels of adoption (41% have never used AI), a deep geographical digital divide, and a critical lack of support at the school level (82% of schools do not have a digitalization strategy). The results also identify a "three-speed" education system in which an elite academic ecosystem (INSAIT, leading universities) operates at a global standard, largely disconnected from the mainstream school system. The conclusions argue that the successful integration of AI in Bulgarian STEAM education depends not only on technological development, but on bridging the gap between policy and practice. The main obstacles are not technological, but systemic and pedagogical.
The research results in strategic recommendations that focus on a human-centered approach, focused on a large-scale national teacher training program that addresses the practical and ethical application of AI in the classroom, the development of robust mechanisms for knowledge transfer from academia to schools, and a pedagogical shift from perceiving AI as a tool for teacher effectiveness to a tool for student inquiry and creativity. The need for a change in curricula and assessment methods that prioritizes the development of critical thinking, creativity, and collaboration is highlighted.
Keywords: artificial intelligence, STEAM education, pedagogical transformation, ethical challenges, educational policy

1. INTRODUCTION

The integration of Artificial Intelligence (AI) into education, particularly within the interdisciplinary STEAM (Science, Technology, Engineering, Arts and Mathematics) model, represents not just a technological innovation but a fundamental paradigmatic shift in contemporary pedagogy (Baxarova, 2025). Global discourse positions AI as a driver for unprecedented personalization of learning, fostering creativity and developing key 21st century skills (Willie, 2024). In this context, each national education system is challenged to adapt its strategies to harness the potential of this transformative technology.
In the Bulgarian educational context, this transformation acquires concrete dimensions through the state's strategic commitment to modernization. A fundamental step in this direction is the National Programme "Building a School STEM Environment", launched around 2020. This programme focuses on the creation of physical infrastructure - modern STEM centers equipped with 3D printers, robotic kits and interactive displays - in order to promote "learning through experience" (Galabova, 2022; Kozhuharova & Zhelyazkova, 2021; Peykova & Garov, 2019). The chronological sequencing of policies - first investment in "hardware" and physical environments, and subsequently the development of an "intelligent" software layer - represents a strategic choice with significant long-term implications. This "hardware-first" strategy creates a certain inertia where technology is associated with specific physical spaces and tools. This challenges the future integration of intangible and pervasive AI to overcome this "siloed mentality" and become a universal pedagogical agent rather than just another tool in the STEM laboratory.

This paper aims to critically analyze the current state of AI integration in STEAM education in Bulgaria. The study focuses on the complex interaction between three key areas:

1. the ambitious top-down national vision driven by state institutions;
2. the bottom-up reality reflecting teacher attitudes, institutional capacity and deep inequalities in the school system; and
3. the role of the elite academic ecosystem as a driver of innovation, but also as a potential factor in deepening the educational divide.

2. MATERIALS AND METHODS

This study is a systematic synthesis and critical analysis of scientific literature and empirical data. The methodology is built on a triangulation of disparate sources in order to achieve a holistic and objective view of the problem under study. The analysis covers the following categories of materials:

- **Policy and government documents:** Key strategic texts that form the national framework were studied, such as the "Concept for the Development of Artificial Intelligence in Bulgaria by 2030" and the official "Guidelines for the Use of Artificial Intelligence in Schools" published by the Ministry of Education and Science (MES). These documents reveal the official vision and political intentions.
- **Quantitative empirical data:** the results of an online survey conducted in December 2023 by Education Without Backpacks were analyzed. The survey provides concrete quantitative indicators of levels of AI adoption, attitudes and institutional readiness among Bulgarian teachers and school administrators.
- **Academic and research literature:** a synthesis of Bulgarian and international peer-reviewed articles, conference papers and research reports. These sources provide the theoretical framework for the pedagogical applications, transformative potential and ethical challenges associated with AI in STEAM education, allowing the Bulgarian case to be considered in a broader international context.

3. RESULTS

The objective presentation of the data collected reveals a complex picture characterized by a stark contrast between strategic ambitions and reality on the ground.

3.1. NATIONAL VISION: STRATEGIC AMBITIONS AND FLAGSHIP INITIATIVES

At the state level, there is a clearly articulated top-down vision that positions AI as a strategic imperative for the nation's future competitiveness. This vision is set out in documents such as the "Concept for the Development of Artificial Intelligence in Bulgaria by 2030", which refers to the European model for building "reliable artificial intelligence", balancing technological progress with a sound ethical and legal framework.

In the education sector, this vision is made concrete through the recommended "Guidelines for the use of Artificial Intelligence in Schools" published by the Ministry of Education in February 2024. These guidelines define the role of AI primarily as a support tool whose purpose is to automate administrative and preparatory activities, thus freeing up teacher time for actual pedagogical work and individual attention to students.

The most ambitious and concrete initiative is the announced partnership between the Ministry of Education and Science (MES) and the Institute for Computer Science, Artificial Intelligence and Technology (INSAIT) for the development of a specialized AI application "just for education." This flagship project pursues a dual objective. On the one hand, the goal is educational: to provide teachers and students with a safe and powerful assistant, trained on verified and approved content (such as electronic textbooks), in order to eliminate the risk of disinformation and AI-generated "hallucinations." On the other hand, the project is an expression of the pursuit of technological sovereignty, by guaranteeing the security and confidentiality of student data, which will not be shared with external tech giants. The initiative is seen as a pilot testing ground for the wider application of BgGPT – the first open-source large language model for the Bulgarian language, developed by INSAIT.

3.2. ON-THE-GROUND REALITY: INSTITUTIONAL INERTIA AND A GEOGRAPHY OF INEQUALITY

In stark contrast to the ambitious national vision, the reality in Bulgarian schools reveals a picture of caution, significant inequalities, and deep structural deficits. Data from the December 2023 survey by the "Education Without Backpacks " Association provides a sobering perspective:

- **Low level of adoption:** 72% of teachers in Bulgaria still do not regularly use AI tools, with a full 41% having never resorted to them. These results are confirmed by other national surveys from the same period, according to which more than 80% of teachers do not use AI tools in their work (Kozhuharova & Kozhuharov, 2024). The assessment of AI's usefulness is moderate, with an average score of 3.57 on the six-point grading scale, which indicates a rather reserved attitude.

- **Disconnect between administration and teachers:** While 45% of administrative staff representatives use AI regularly, this share among teachers is merely 25%. This suggests the presence of a "performative digitalization" model, where technology is adopted at the administrative level for process optimization but fails to penetrate the core of the educational process.
- **Lack of systemic support:** The data indicates that 82% of schools do not have a written digitalization strategy, and 73% of them have not organized and are not planning AI training. Even more worrying is the communication vacuum: 43% of teachers do not know if their school has a digitalization strategy at all.
- **Geographical divide:** The disparities between the capital city and the rest of the country are stark. Only 7% of surveyed teachers from Sofia state that they have never used AI, while in villages and smaller towns, this share reaches 23-25%.

Table 1: Attitudes and Use of AI in Bulgarian Education (December 2023)

Indicator	Teachers (%)	Administrative teams (%)
Regular use of AI	25	45
Never used AI	41	16
The school has a digitalisation strategy	18 (43% unaware)	18
AI training conducted/planned	15 (25% unaware)	27

The data is based on a study by the Education Without Backpacks Association.

The ways in which the few innovating teachers use AI are also indicative. The technology is mostly applied to tasks that ease the teacher's work outside the classroom, such as "creating assignments, tests and other educational resources" (63%) and "creating lessons, lesson plans" (27%). This indicates that at this stage, AI is perceived as a tool to enhance teacher effectiveness rather than a learning tool to transform pedagogy.

3.3. THE ACADEMIC ECOSYSTEM.

While the mainstream school system struggles with structural deficits, academia in Bulgaria is emerging as a powerful driver of innovation, forming a "three-speed" education system.

- **First speed (The Global Elite):** At the center of this academic rise is INSAIT at Sofia University, which develops world-class technologies like BgGPT and attracts leading international scientists. Leading universities such as Sofia University "St. Kliment Ohridski" (through its Faculty of Mathematics and Informatics - FMI) and the Technical University – Sofia play a key role. The FMI at Sofia University provides fundamental training and, as early as 2018, introduced the pioneering for Bulgaria course "Responsible Artificial Intelligence." TU-Sofia stands out with its strong industry ties (a partnership with Bosch) and a unique model of vertical integration through the Technological School "Electronic Systems" (TUES), which offers a high school-level specialization in AI.
- **Second speed (The Innovators):** A small number of innovative schools, like the aforementioned TUES, which successfully integrate advanced concepts and serve as pilot centers.
- **Third speed (The Mainstream System):** The vast majority of Bulgarian schools, which remain largely unaffected by the innovations generated at the top of the pyramid.

Forums like the National Conference "SMART STEM Education and Innovations" play an important role in knowledge exchange, bringing together academics, teachers, and experts, and serving as a platform for disseminating good practices.

4. DISCUSSION

The synthesis of the findings reveals three main "fault lines" that hinder the effective transformation of the Bulgarian education system through AI. These fault lines are not technological in nature, but rather systemic, pedagogical, and cultural.

The first and most obvious is the fault line between **vision and reality**. The widespread skepticism and low adoption rates of AI among teachers should not be interpreted as irrational technophobia, but as a completely rational response to institutional uncertainty and the lack of systemic support. When 82% of schools lack a digitalization strategy and 73% do not plan any training, the teacher is left to navigate a powerful and potentially disruptive technology alone, without clear guidance or support. In this context, caution is a logical defensive reaction.

The second fault line is between **elite innovation and systemic fairness**. The creation of a "three-speed" system, where innovation is concentrated in an elite circle of academic institutions and a few pilot schools, carries a serious risk. Instead of reducing them, this concentration could deepen existing educational inequalities and widen the

digital divide, which is one of the main ethical concerns in AI implementation (Willie, 2024). There is a lack of sustainable mechanisms to "translate" the complex, world-class academic research conducted at INSAIT and the universities into accessible and scalable pedagogical resources for the average teacher. The MES-INSAIT project is a step in the right direction, but its success depends on building a comprehensive support ecosystem, not just on creating a technological product.

The third and perhaps deepest fault line is between the **technological focus and pedagogical transformation**. The debate in Bulgaria often centers on the technology itself—which model to use (BgGPT), what hardware to buy (STEM centers). This shifts the focus from the more important question: how can AI fundamentally change pedagogy? The data showing that teachers use AI primarily for preparing lessons and tests indicates that the technology is being applied to automate outdated pedagogical practices (the efficiency paradigm) rather than to inspire new ones (the knowledge and creativity paradigm). The proven effectiveness of Intelligent Tutoring Systems, for example, lies precisely in their ability to adapt the process to the learner rather than simply automating the teacher's tasks (Kulik & Fletcher, 2016; Ma et al., 2014). This contradicts the vision of transforming the teacher's role from a "transmitter of knowledge" to an "architect of the learning experience," who mentors and encourages critical thinking.

In this complex context, the ethical dimensions become critically important. Bulgaria's strategic choice to develop its own sovereign educational AI is a commendable and forward-thinking response to global concerns about the privacy of student data, which are at the core of the ethical framework for "trustworthy AI." However, serious questions remain. For example, how will it be ensured that the model, trained on "approved" Bulgarian content, will not reproduce and amplify existing cultural or social biases within it—one of the main risks known as algorithmic bias (Xie et al., 2025). Solving the problem of academic integrity (plagiarism) also requires not prohibitions, but a pedagogical evolution – a shift towards assessment that measures process, critical thinking, and creativity. This debate is especially relevant after the emergence of powerful language models such as ChatGPT (Rudolph et al., 2023). To avoid the risk of dehumanization, the application of the "human-in-the-loop" model is key, where technology assists but does not replace the final judgment and emotional connection provided by the teacher (Dang & Liu, 2025).

5. CONCLUSION

The integration of artificial intelligence into STEAM education in Bulgaria is not merely a technological upgrade but a fundamental paradigm shift with enormous yet unrealized potential. The analysis shows that the country possesses the key ingredients for success: a clear national vision, strategic investments, and a world-class academic core. However, this potential is hindered by a deep chasm between the ambitious vision and the reality in the mainstream school system, which is marked by systemic inertia, significant inequalities, and a focus on technology at the expense of pedagogy.

The path forward requires a fundamental shift in priorities. The challenge is not primarily technological; it is human, organizational, and pedagogical. Success depends on building bridges over the identified fault lines, especially the bridge between the "islands" of elite innovation and the "continent" of mainstream education. To this end, the following strategic recommendations can be formulated:

1. **Accelerate and Fund the National Strategy:** A shift is needed from general guidelines to a concrete, binding, and adequately funded national strategy for AI in education, with a clear roadmap and measurable goals.
2. **Invest in the Human Factor:** Establish a large-scale, mandatory, and continuous national program for teacher qualification that focuses on practical pedagogy and the ethical application of AI, not just on the technical skills for using tools.
3. **Establish Knowledge Transfer Mechanisms:** Develop and implement specific institutional mechanisms for knowledge transfer (e.g., educational technology centers, mentorship programs) that systematically translate academic research into ready-to-use, open, and easily adaptable educational resources for teachers.
4. **Redesign the Learning Process:** Encourage a national shift in curricula and assessment methods that prioritizes the development of critical thinking, creativity, and collaboration. The future of AI in education lies not in full automation, but in creating ecosystems of collaborative intelligence, where technology enhances, rather than replaces, the irreplaceable human qualities that are at the heart of true education.

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