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INTRODUCTION

Technical Faculty “Mihajlo Pupin” in Zrenjanin, University of Novi Sad, Republic of Serbia, is proud to organize the XVI International Scientific Professional Conference “Information Technologies and Development of Education 2026” (ITRO 2026). The Conference is held on May 14th, 2026, at the Technical Faculty “Mihajlo Pupin” in Zrenjanin, Serbia.

The ITRO 2026 conference is established to bridge the gap between scientific research, professional practice, and education. With a long-standing tradition spanning sixteen years, the conference serves as a valuable platform for tracking the continuous evolution of education, particularly when viewed through the perspective of information and communication technologies. Its thematic core focuses primarily on the teaching process as the foundational cornerstone of the modern information society. Current global trends closely align with UNESCO's ongoing efforts to enhance this field, addressing the evolving demands of life and work in the 21st century. It is essential for competent professionals, researchers, and educators to assess the current state of education, identify underlying challenges, and outline future perspectives, while recognizing its profound impact on the development of society as a whole.

While the central pillar of the conference remains the model of dual education as a vehicle for building a strong foundation for industrial growth, recent global dynamics have highlighted a critical, overarching shift in pedagogical reality. Consequently, the primary focus and dominant theme of this year's conference is: AI in Education - Advantage, Problem or Something in Between.

The integration of Artificial Intelligence as a central theme is both deliberate and inevitable. As AI technologies rapidly reshape every aspect of professional and daily life, education stands at a historic crossroads. We are no longer merely discussing new digital tools, but a fundamental paradigm shift in how knowledge is acquired, processed, and evaluated. By examining whether AI acts as an advantage, a challenge, or a complex space in between, this Proceedings volume aims to provide a balanced, scientifically grounded perspective. It explores how intelligent systems can personalize learning, support educators, and optimize educational frameworks, while simultaneously addressing critical questions regarding ethics, data privacy, and the preservation of authentic human critical thinking.

The conference brings together university professors, researchers, directors of grammar and secondary vocational schools, members of the wider academic community, and other professionals dedicated to driving educational innovation forward. To capture the full scope of these contemporary educational challenges, the conference covers a diverse range of thematic fields, including:

- Digitalization of education
- Education in crisis situations
- Contemporary educational challenges
- Theoretical and methodological issues in modern pedagogy
- Digital didactics and media education
- Modern communication strategies in teaching
- Curriculum development for contemporary education
- E-learning advancements and trends
- Educational management practices
- Methodological approaches to teaching natural and technical sciences
- The integration of information and communication technologies (ICT) in education

- The concept and implementation of dual education
- Development and application of interactive e-books

Demonstrating strong international interest and geographical diversity, a total of 110 authors from 11 countries and 2 continents contributed to the conference. This includes 75 authors from the Republic of Serbia and international authors representing countries such as North Macedonia, Bulgaria, Slovakia, Hungary, India, Bosnia and Herzegovina, Croatia, Kyrgyzstan, United Kingdom and Romania.

This volume of the Proceedings contains 44 peer-reviewed papers, published entirely in the English language. We firmly believe that the research presented herein will offer valuable insights, spark meaningful dialogue, and contribute significantly to shaping the future of education in the AI era.

Chairman of the Organizing Committee

Dragana Glušac, Ph.D, Professor

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PLENARY PAPERS

AI Model For Assessment Of Drivers' Situational Awareness In Micromobility

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Abstract. This paper presents the implementation of an AI-based system for assessing situational awareness among micromobility drivers, focusing on electric scooter and bicycle users in urban traffic. The model employs the Mamdani fuzzy inference method with input parameters such as reaction time, decision accuracy, and error frequency to generate a situational awareness score ranging from 0 to 1. Based on this score, the system delivers personalized educational content adapted to the driver's current level of awareness. The automatic synthesis of IF–THEN rules enables the creation of realistic traffic scenarios that integrate expert knowledge and simulate typical urban risks. Results indicate that personalized training contributes to progressive competence development, reflected in fewer errors and faster decision-making. The study confirms that adaptive AI systems can enhance safety in micromobility by providing individualized training that traditional methods often overlook.

Key words and phrases: Artificial Intelligence (AI), Situational Awareness (SA), Micromobility, Fuzzy Inference, Mamdani Method, Rough Set Theory.

1 INTRODUCTION

Urban micromobility, especially electric bicycles and scooters, has rapidly expanded in recent years as a sustainable and flexible mode of transportation. However, this growth has introduced new challenges in traffic safety, especially regarding drivers' situational awareness – their ability to perceive, understand and anticipate events in dynamic urban environments. Situational awareness is a key factor influencing decision-making and accident prevention, and its improvement is increasingly recognized as a priority in intelligent transportation systems.

The primary objective of this research is to develop an intelligent system designed to assess the situational awareness of individual drivers and, through this process, improve the overall awareness among micromobility users. However, it is important to note that the situational awareness assessment in this work is carried out with the explicit purpose of generating and providing personalized training materials to drivers. The proposed model integrates fuzzy inference (Mamdani method), rough set theory, and adaptive algorithms to assess situational awareness and provide customized educational content. By simulating different urban scenarios within a micromobility driver training framework, the study shows that training based on individualized situational awareness assessment can significantly improve drivers' attention and awareness in different traffic conditions, ultimately contributing to safer urban micromobility.

This paper is organized into five interconnected chapters that systematically detail the development and implementation of an AI-driven micromobility safety system. The **Introduction** establishes the context by highlighting the rapid growth of urban electric scooters and bicycles and the critical need for assessing driver situational awareness through an AI-based model. This is followed by a section on **Related Works**, which provides a comprehensive literature review on the theoretical foundations of Fuzzy Logic and Rough Set Theory, while also examining current advances in V2X communication and machine learning for predicting risky behaviors. The core of the study is presented in the chapter **AI Model for Assessing Driver Situational Awareness**, which outlines a conceptual shift towards adaptive training systems. This chapter contains two subchapters. A subchapter describing the architecture of the **Architecture of the AI Model for Assessment and Enhancement of Drivers' Situational Awareness**, and a subchapter describing the modular **Object-Oriented Design of the AI Model for Assessment of Drivers' Situational Awareness**. This is further

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detailed in the chapter that explains the **implementation of an AI model for drivers' situational awareness assessment** as a closed-loop interaction between the Driver, Inference Engine, and Tutor components. The chapter focuses on the technical performance of the Mamdani Fuzzy Logic Controller in generating a numerical awareness score. Finally, the **Conclusion** synthesizes the findings, confirming the synergy of integrated AI methods and suggesting future research directions such as deep learning for fatigue detection and reinforcement learning for adaptive teaching.

2 Related Work

Recent research emphasizes the integration of fuzzy logic, Rough Sets, machine learning, V2X communication, and simulation platforms to improve situational awareness (SA) and traffic safety, particularly in micromobility and intelligent transportation systems.

Fuzzy logic has been widely applied to model uncertainty in perception and decision-making. D'Aniello (2023) provides a systematic review of fuzzy logic in SA, while Ronquillo-Cana et al. (2022) propose a multidisciplinary fuzzy system to assess dangerous driving. Belohlavek (2015) revisits Pavelka-style fuzzy logic, highlighting its interpretive flexibility, and Pawlak (1982) introduces Rough Set Theory, which remains foundational for rule reduction and diagnostic accuracy.

Machine learning techniques are increasingly used to predict SA and detect risky behaviors. Chen et al. (2021) present fine-grained detection of driver distraction using neural architecture search. Yan et al. (2025) provide a systematic review of datasets and applications of machine learning in micromobility, while Li et al. (2025) survey federated learning in human sensing, emphasizing privacy-preserving approaches.

Narri et al. (2023) explore shared SA through V2X communication and set-membership estimation. Mansouri and Asklany (2025) propose fuzzy logic-based priority resource allocation for V2X networks. Li et al. (2026) investigate drivers' acceptance of cooperative vehicle-infrastructure systems, integrating trust and distraction perception into TAM and UTAUT frameworks.

AI applications in micromobility are gaining traction. Alp (2025) discusses AI's role in micromobility safety and education. Fong et al. (2023) highlight sustainable micromobility management in smart cities. Wu et al. (2025a, 2025b) introduce embodied AI simulation platforms (Metaurban) and scalable urban simulation for autonomous micromobility. Hassanin et al. (2025) review perception, planning, and control in intelligent two-wheelers, pointing toward autonomous riding.

Yannis et al. (2024) provide a technical background report on safer micromobility. Sudhakaran et al. (2025) examine safety issues for vulnerable road users through a world café approach. Spota et al. (2024) conduct a systematic review of e-scooter injury patterns, while Li, Iryo-Asano, and Alhajyaseen (2025) analyze drivers' risk perception toward e-scooters and bicycles. Useche et al. (2025) explore predictors of digital distractions in motorcycle commuting, emphasizing behavioral risks. De Zwart et al. (2025) assess expert opinions on SA evaluation methods in relation to safe driving.

3 AI Model For Assessment Of Drivers' Situational Awareness

The AI model for assessment of drivers' situational awareness starts from the need to increase the safety of micromobility drivers in complex urban conditions. Electric bicycles and scooters are becoming more and more present in cities, but their vulnerability in traffic requires new approaches to education and attention assessment. Traditional training methods often do not take into account individual differences among drivers, while personalized systems based on artificial intelligence enable content and assessments to be adjusted in real time. The proposed model integrates the driver's profile, analysis mechanisms and an adaptive educational module into a unique cycle of interaction, where behavioral data is processed through AI techniques, and the results are returned in the form of educational interventions. In this way, the system not only assesses the current level of situational awareness of drivers of electric scooters and bicycles, but actively contributes to its improvement, which creates the basis for safer and more responsible driving in an urban environment.

Architecture Of The AI Model For Assessment And Enhancement Of Drivers' Situational Awareness

The proposed architecture of the AI model is based on the concept of closed interaction between the driver and the system, enabling continuous data collection, analysis, and feedback with the aim of improving safety in urban traffic. The driver is represented in the system through the Driver component, which includes his profile and behavioral parameters, while the central part – the Inference Engine – applies artificial intelligence

methods, including fuzzy logic, rough set theory, and the Alpha algorithm, to assess the level of situational awareness. The results of these analyses are forwarded to the Tutor component, which uses them to create personalized educational content tailored to the driver's current needs. In this way, a dynamic cycle is formed in which the driver continuously provides input data, the system processes them, and education is returned in the form of targeted interventions that contribute to increased attention, awareness, and safer driving in urban conditions.

The Figure 1. illustrates an AI model for assessment and enhancement of driver situational awareness based on a closed-loop interaction between three main components: Driver, Inference Mechanism, and Tutor.

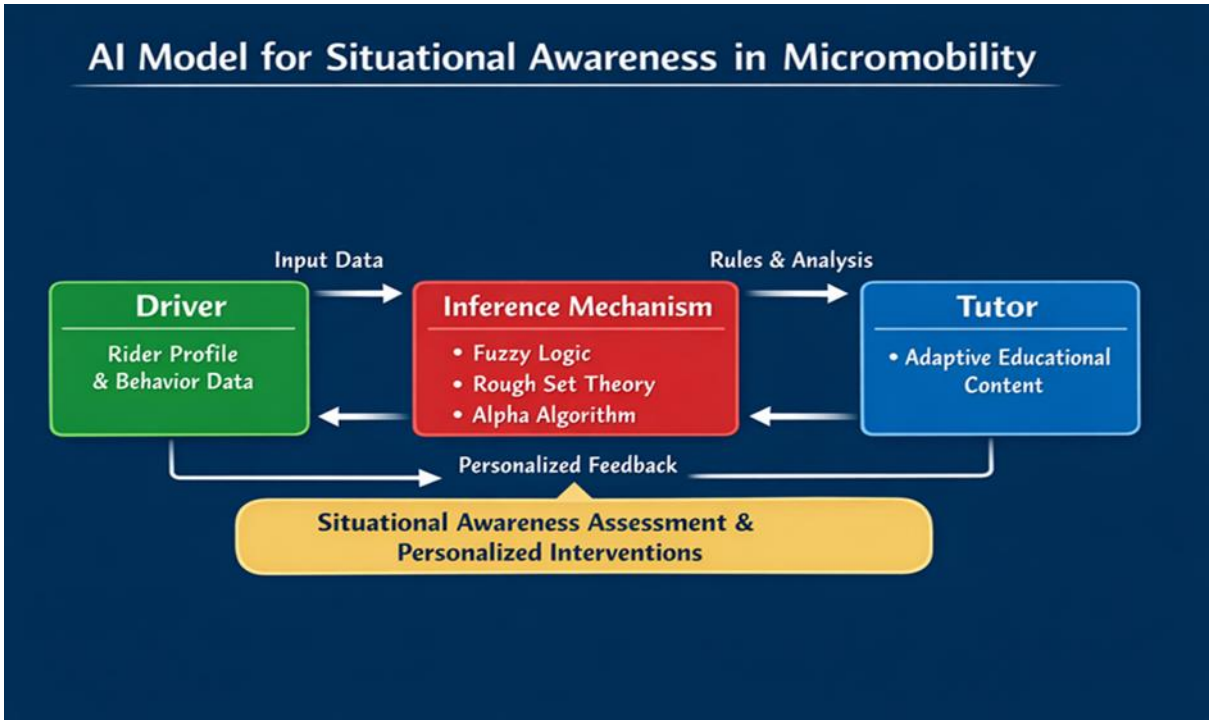


Figure. 1. AI model for assessment and enhancement of driver situational awareness

The AI model for assessment and enhancement of driver situational awareness in micromobility consists of three functional elements:

1. **Driver**
   - ✓ **Function:** Represents the driver's profile and behavioral parameters.
   - ✓ **Connection:** Linked to the Inference Mechanism (provides input data about the driver).
2. **Inference Mechanism**
   - ✓ **Function:** Applies AI techniques (fuzzy logic, Rough Set Theory, Alpha algorithm).
   - ✓ **Connection:** Connects the Tutor and Driver.
   - ✓ **Output:** Assessment of situational awareness + personalized educational interventions.
3. **Tutor**
   - ✓ **Function:** Delivers adaptive educational content.
   - ✓ **Connection:** Linked to the Inference Mechanism (receives rules and analysis results).

The **Driver** block represents the rider or driver profile, including behavioral parameters and input data related to the user's actions, reactions, and awareness during movement. These data are sent to the Inference Mechanism, which acts as the core analytical component of the system. This module applies artificial intelligence techniques such as fuzzy logic, Rough Set Theory, and the Alpha algorithm to evaluate the driver's situational awareness and identify potential weaknesses or risky behavior patterns.

Based on this analysis, the **Inference Mechanism** sends rules, assessments, and decision outputs to the Tutor module. The Tutor is responsible for delivering adaptive educational content, personalized feedback, and training recommendations tailored to the specific needs of the driver. In this way, the system does not only assess awareness, but also supports its continuous improvement through customized educational intervention.

The arrows in the diagram show a closed-loop cycle of interaction: The Driver provides input data, the AI system analyzes these data through the Inference Mechanism, and the **Tutor** returns personalized educational guidance to the driver. This process enables ongoing learning and improvement, ultimately leading to better situational awareness and safer behavior in micromobility environments.

Modular Object-Oriented Design Of AI Model For Assessment Of Drivers' Situational Awareness

The AI model for assessment of drivers' situational awareness is built on a modular, object-oriented architecture, enabling efficient implementation of closed-loop interaction between the driver and the educational module. The main strength of this structure lies in the synergy of three different AI methods: Fuzzy Logic enables modeling of subjective driver parameters; Rough Set Theory optimizes the rule base by eliminating inconsistencies; and Alpha Algorithm, through the α-cut method, ensures precise filtering of relevant information for decision-making.

This organizational structure directly supports a dynamic learning cycle, where the system processes data on driver behavior in real time to generate personalized content via the Tutor component. This establishes a robust technical foundation for a system that is not only reactive, but highly adaptive to the specific needs of an individual in an urban traffic environment.

The class diagram in Figure 2 represents the main classes involved in the fuzzy logic system for situational awareness assessment, showing its structural organization that includes a central controller, fuzzy variables, fuzzy terms, fuzzy rules, and a test execution class.

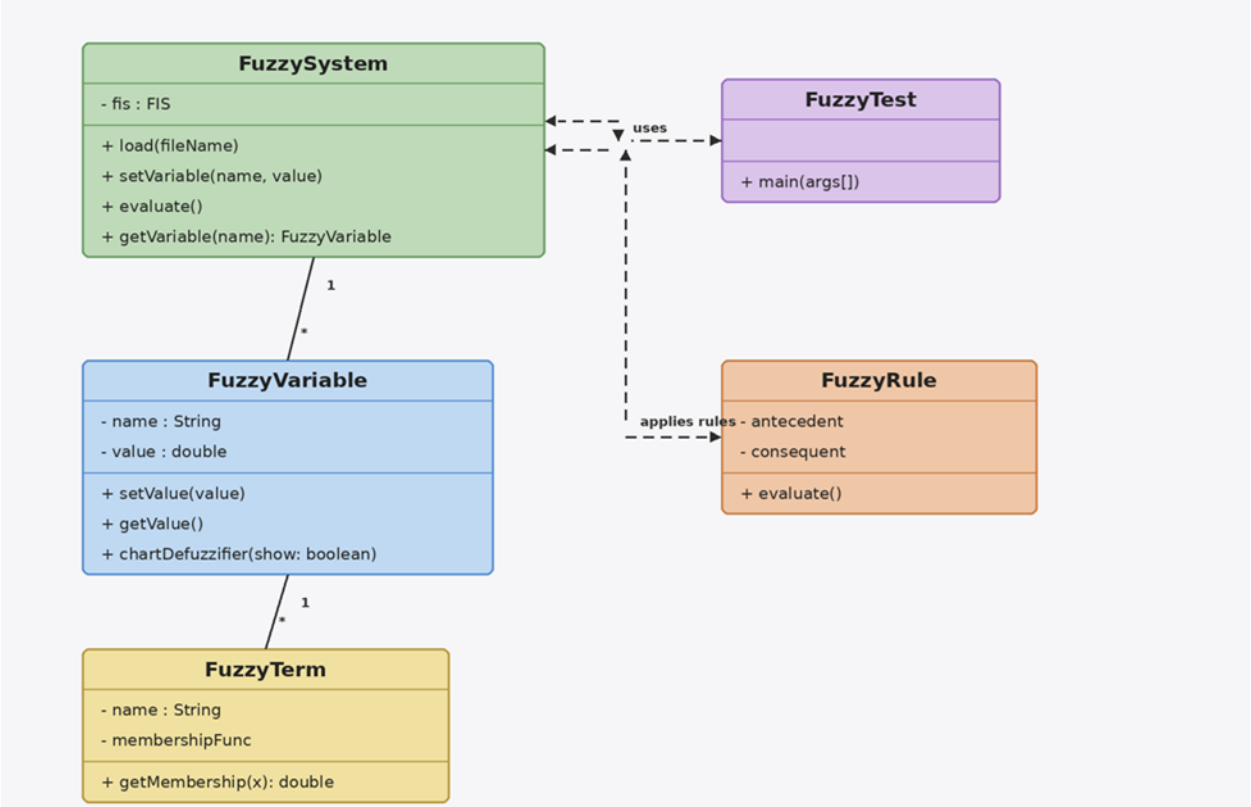


Figure. 2. Class diagram- fuzzy logic system for assessment of drivers' situational awareness

The **FuzzySystem** class represents the main control component. It contains an object of type **FIS**, which is responsible for loading the fuzzy inference system, assigning input values, executing the inference process, and retrieving output variables. Its operations include load(fileName), setVariable(name, value), evaluate(), and getVariable(name): **FuzzyVariable**. This class acts as the main interface for interacting with the fuzzy logic engine.

The **FuzzyVariable** class represents an individual fuzzy variable used in the system. Each variable has two main attributes: name, which identifies the variable, and value, which stores its numerical value. The class provides operations for assigning and reading values via setValue(value) and getValue(). In addition, it includes the chartDefuzzifier(show: boolean) method, which can be used to visualize the defuzzification process or the output membership function.

The **FuzzyTerm** class defines linguistic terms associated with a fuzzy variable. Each term has a name and a membership function (membershipFunc), which describes the membership function used to determine the degree to which an input belongs to that term. The getMembership(x): double method calculates the membership value for a given input. The set shown in the diagram indicates that a single **FuzzyVariable** can contain multiple **FuzzyTerm** objects.

The **FuzzyRule** class represents a single fuzzy rule in the inference process. It contains two essential components: an antecedent, which defines the conditional part of the rule, and a consequent, which defines the result or action. The evaluate() operation is used to process the rule during inference. The relationship between **FuzzySystem** and **FuzzyRule** indicates that the system applies these rules as part of the decision-making mechanism.

The **FuzzyTest** class contains a main(args[]) method and serves as the starting point for program execution. It uses the **FuzzySystem** class to initialize the fuzzy model, assign input values, and run the inference procedure. In this way, **FuzzyTest** acts as the execution or test layer of the application.

Overall, the class diagram illustrates the modular object-oriented design of a fuzzy logic system, where **FuzzySystem** coordinates the inference process, **FuzzyVariable** and **FuzzyTerm** define the fuzzy input/output structure, **FuzzyRule** encodes the inference logic, and **FuzzyTest** provides the execution framework.

4 Implementation Of The AI Model For Assessment Of Drivers' Situational Awareness

The implementation of the proposed AI model for assessing drivers' situational awareness was carried out with the aim of delivering personalized educational content for micromobility driver training. The model is based on the Mamdani fuzzy inference method, where the input parameters included reaction time, decision accuracy, and error frequency. Based on these data, the system generates an assessment of the driver's situational awareness on a scale from 0 to 1, thereby enabling quantitative monitoring of attention and awareness levels during simulated traffic scenarios.

Furthermore, through the automatic synthesis of IF–THEN rules for typical traffic situations, the model integrates expert knowledge into the process of risk evaluation and driver behavior assessment. The analysis of membership function shifts demonstrated that personalized training contributes to a progressive increase in competencies, manifested through a reduction in errors and faster decision-making.

The Mamdani Fuzzy Logic Controller (FLC) is presented in detail as the central mechanism for transforming input performance indicators into a single situational awareness metric. In this way, the implementation of the model provides a structured and intelligent method for assessing driver awareness, as well as a foundation for creating personalized educational interventions that contribute to safer driving in urban conditions.

The Figure 3. presents a Mamdani Fuzzy Logic Controller (FLC) designed to evaluate the situational awareness rating of micromobility drivers and deliver personalized content for further training.

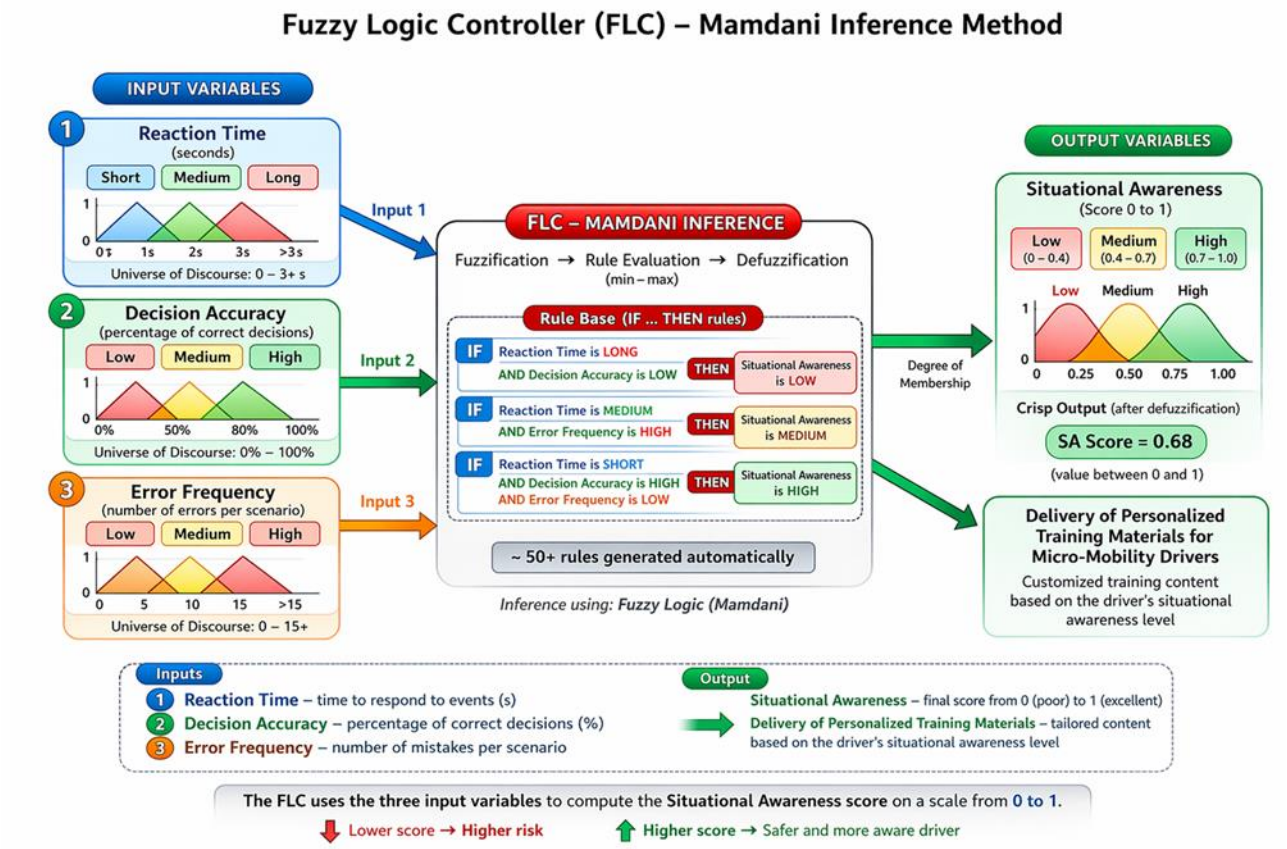


Figure. 3. Mamdani Fuzzy Logic Controller (FLC) designed to evaluate the situational awareness

The model transforms several behavioral performance indicators into a single awareness score through the main stages of fuzzy inference.

Figure 3 shows the input variables used by the system: Reaction Time, Decision Accuracy, and Error Frequency. These variables represent the driver's performance during simulated traffic situations. Reaction Time reflects how quickly the driver reacts to events, Decision Accuracy shows how correct the driver's actions are, and Error Frequency represents the number of errors made during the driving scenario.

The central part of Figure 3 illustrates the Fuzzy Inference System, which is the core of the controller. The first stage is Distinction, where clear numerical input values are converted into fuzzy linguistic terms such as low, medium, or high. After that, the Rule Base applies a set of IF-THEN rules to model expert knowledge and interpret driver behavior. The inference engine then processes these rules and combines their results, while Defuzziness converts the fuzzy output back into a single numerical value.

The output variables are shown on the right side of Figure 3, which are the situational awareness (SA) score and Delivery of personalized training materials for micro-mobility drivers. The situational awareness score is expressed on a scale from 0 to 1 and can be interpreted through three qualitative levels: Low, Medium and High. In this way, the controller provides a structured and intelligent method to assess the situational awareness of drivers and support personalized training or educational interventions. Delivery of personalized training materials for micro-mobility drivers depends on the level of situational awareness of drivers and is designed to meet the current needs of the individual. When awareness is low, the materials are focused on basic education and correcting the most critical errors, thus laying the foundation for the development of safe traffic behavior. For drivers with a medium level of awareness, the content focuses on improving existing skills and consistency in decision-making, through more complex scenarios and analysis of typical errors. For drivers with a high level of awareness, the system provides advanced educational interventions that develop the ability to anticipate the behavior of other participants and maintain attention in complex traffic conditions. In this way, personalized training becomes a dynamic process that progressively leads to a higher level of competence and contributes to safer micromobility in urban traffic.

5 CONCLUSION

The implementation of the proposed AI model has demonstrated that artificial intelligence can provide a structured and intelligent method for assessing the situational awareness of micromobility drivers, such as electric scooter and bicycle users. By applying the Mamdani fuzzy inference method with input parameters including reaction time, decision accuracy, and error frequency, the system generates a quantitative awareness score on a scale from 0 to 1. This enables continuous monitoring of driver performance and supports the delivery of personalized educational content tailored to individual needs. Drivers with low situational awareness receive basic training aimed at correcting critical errors, those with medium awareness are guided through more complex scenarios to strengthen decision-making consistency, while drivers with high awareness are challenged with advanced interventions that foster anticipation and sustained attention in demanding traffic conditions.

A key advantage of the model lies in its ability to automatically synthesize IF–THEN rules, which allows the creation of realistic scenarios typical of urban traffic. This integration of expert knowledge into the training process places drivers in situations that simulate real risks, thereby improving their understanding and responsiveness. The analysis of membership function shifts further confirmed that personalized training contributes to progressive competence development, manifested through fewer errors and faster decision-making.

Nevertheless, certain limitations remain. The realism of simulations depends on the technological platform, highlighting the need for integration with advanced VR/AR environments. Sustaining driver motivation to engage with the system is another challenge, opening opportunities for gamification and reward mechanisms. Additionally, technical resources such as simulator availability and computational capacity may influence the scalability of the system.

In a broader perspective, the application of such AI-based systems can significantly enhance safety in micromobility, particularly in urban areas where the number of users is rapidly increasing. Personalized education grounded in situational awareness assessment can become a vital component of strategies aimed at reducing accidents and improving the safety of all road users. Future development should explore the integration of deep learning for automatic recognition of fatigue-related parameters, the extension of the model through V2X communication, and the incorporation of reinforcement learning within the Tutor component. These advancements would enable the system to autonomously identify the most effective interventions for maintaining driver attention, thereby elevating traffic safety to a substantially higher level.

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Digital Technologies and Fine Tuning of Educational Outcomes

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Abstract. The digital transformation of education has generated unprecedented opportunities for personalizing learning experiences, yet a persistent challenge lies in aligning technological capabilities with established pedagogical theory. Drawing on recent advances in educational technology, including knowledge graph-based learning pathways, intelligent recommendation systems, and cognitive process modeling, this paper proposes a conceptual framework integrating nomology networks and knowledge graphs within the structure of digital Bloom's taxonomy to refine educational outcomes. The framework addresses the fundamental disjuncture between static curricular design and dynamically adaptive learning environments responsive to individual student needs. Knowledge graphs offer structural representations of domain content, capturing granular concepts, prerequisite relationships, and learning resources in machine-readable form. Nomology networks complement these by encoding principles of learning itself, including cognitive biases, common misconceptions, pedagogical strategies, and motivational factors shaping student engagement. Digital Bloom's taxonomy serves as the organizing architecture, ensuring content representation and learning process modeling correspond appropriately to the cognitive demands of diverse objectives across hierarchical levels: memorizing, understanding, applying, analysing, evaluating, and creating. This integration facilitates real-time diagnosis of student cognitive states, identification of root causes for learning difficulties, and deployment of targeted pedagogical interventions aligned with specific taxonomic levels. Ultimately, the framework transforms education from a broadcast medium into an intelligent, responsive dialogue between learners and pedagogical science, offering a comprehensive pathway toward genuinely personalized and cognitively-aware instruction in the digital age.

Key words and phrases: knowledge graphs, nomology, digital Bloom's taxonomy, educational technology

1 INTRODUCTION

The contemporary educational landscape marks a critical convergence of technological capability and pedagogical necessity. The shift from traditional classrooms to digitally mediated learning, accelerated by global online education trends, presents both opportunities and challenges. While digital and AI technologies are restructuring pedagogical frameworks, assessment methods, and administrative processes, the resulting abundance of resources often leads to information and cognitive overload, leaving students disoriented in pursuit of optimal outcomes. According to the OECD's Digital Education Outlook 2026, students using general-purpose AI tools improved short-term task performance by forty-eight percent but performed seventeen percent worse once access was removed. This confirms that learning gains are unsustainable when technology replaces cognitive effort rather than supporting it. Thus, technology improves learning only when explicitly designed to foster skill development, not as a shortcut, validating the nomological network approach that models learning processes over mere content delivery.

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Consequently, these challenges demand solutions beyond simple content organization or progress tracking. Current research identifies three primary AI applications in education: adaptive learning systems personalizing instruction, automated assessment tools offering immediate feedback, and administrative analytics optimizing operations. Although AI enhances e-learning platforms through adaptive educational systems, what is truly required are systems that understand complex relationships between knowledge concepts, the cognitive processes of student learning, and the most effective pedagogical strategies for individual learners—integrating structure, process, and personalization.

Therefore, we propose integrating nomology networks and knowledge graphs to capture the interconnected, hierarchical, and logical dependencies of educational content, thereby defining effective learning sequences. Framed by digital Bloom's taxonomy, this approach enables educational systems to move beyond simple content delivery. Our central thesis is that merging structural knowledge representations with process-oriented learning models allows dynamically adaptive, cognitively-aware instruction. This comprehensive approach fine-tunes educational outcomes by ensuring technology supports cognitive development rather than replacing it, offering a pathway toward more intelligent, responsive learning environments.

2 BLOOM'S TAXONOMY AND ITS DIGITAL ADAPTATION

Bloom's taxonomy (1956) classifies cognitive skills into six hierarchical levels—remembering, understanding, applying, analyzing, evaluating, and creating—providing structured guidance for learning objectives that develop critical thinking. Its digital adaptation acknowledges that cognitive processes operate differently within digitally-mediated learning environments (Churches, 2009). Research demonstrates that knowledge graph-based approaches enhance digital Bloom's taxonomy levels through structured activities including spaced retrieval practice, reading, and collaborative note-taking (Yeckeh Zaare, 2024).

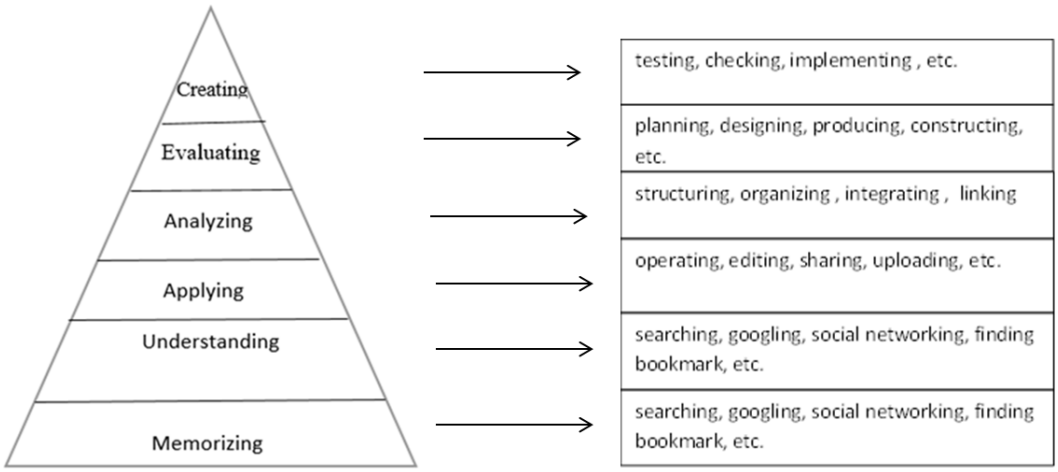


Figure 1. Bloom's taxonomy and digital adaptation

Integrating nomological networks with knowledge graphs represents a further advancement. Nomological networks encode abstract principles, cognitive biases, pedagogical strategies, and learning mechanisms that govern how students acquire information, enabling systems to diagnose not only what students know but why learning difficulties occur (Paul & Kurian, 2024). Knowledge graphs capture inherent connections and hierarchies within domains, enabling intelligent, context-aware question generation appropriate for different taxonomic levels (Abdelmagied et al., 2025). When combined with nomological networks that model misconceptions and pedagogical interventions, these approaches identify root causes of learning difficulties and deploy targeted instructional responses. This synthesis ensures a spectrum of complexity matching the full range of cognitive skills while modernizing assessment practices to align with real-world problem-solving scenarios (A Survey of Knowledge Graph Approaches, 2024). Thus, Bloom's framework combined with

knowledge representation and nomological modeling advances personalized, cognitively-aware educational practice.

3 THE EMERGING CONCEPT OF NOMOLOGY NETWORKS IN LEARNING

Nomology, the science of laws integrating objective rules with subjective reasoning, aligns with data science in education by enabling discovery and validation of generalizable patterns in learning data. Data science provides computational tools to operationalize nomological networks, enhancing educational models' validity and applicability. Through predictive analytics, personalized learning paths, and performance optimization, data science transforms education by analyzing student engagement, grades, and interactions. Databases play a crucial role in storing and analyzing this data, enabling personalization, adaptive systems, and improved learning outcomes. They support everything from basic record-keeping to advanced AI-driven models like knowledge graphs, aligning with interests in educational AI and graph-based modeling for next-generation learning environments.

Nomological networks map theoretical constructs, empirical measures, and their interrelationships to establish construct validity. In education, they validate assessments and learning models by linking abstract concepts like "motivation to learn" or "teaching presence" to observable outcomes. Unlike traditional curriculum maps that focus on structural overviews such as content sequencing, nomological networks emphasize theoretical validity through interconnected constructs, measures, and empirical relations. They add causal hypotheses and validation metrics for dynamic analysis. In AI-driven education, nomological networks validate models by graphing observations—like test scores—to concepts such as learning agility, aiding construct validity for adaptive systems. When used together with knowledge graphs, they structure cognitive constructs like creativity, linking neuroscience insights to measurable educational outcomes and enabling more intelligent, personalized learning environments.

4 EDUCATIONAL KNOWLWDGE GRAPHS

A knowledge graph is a specialized graph structure that represents relationships between real-world entities using nodes and edges. This graphical representation reduces misclassification and ambiguity while enabling contextualized searching and the application of AI-driven tools for deep analytics. Unlike simple databases that store raw data, knowledge graphs organize information as well-structured knowledge, fundamentally transforming how data is stored and utilized. They capture domain connections and hierarchies, enabling intelligent, context-aware question generation for different taxonomic levels. In learning processes, knowledge graphs prove extraordinarily helpful. They contain information about necessary prior knowledge required to understand specific material. A dynamic, tunable knowledge graph allows both teachers and students to adapt learning material to individual capabilities, needs, interests, and learning objectives. For example, mathematical theories, though axiomatically structured, are rarely taught axiomatically. Such presentation is unnatural, counterintuitive, and pedagogically unjustified except for advanced mathematics or engineering students. Instead, mathematical theories are taught intuitively—certain concepts are presented as obvious or self-evident. Consider the ordered pair (a, b). It is rarely introduced using set-theoretic definitions like {a, {a, b}}. Rather, it is accepted intuitively as a pair defined not only by its objects but also by their order. For most students, this intuitive understanding suffices, enabling them to grasp derivative notions such as relations and functions. Even the concept of a function can be introduced alternatively—not as a relation with specific properties, but intuitively as a rule assigning a single value to each member of a set, thereby bypassing the relation concept entirely. This flexibility demonstrates how knowledge graphs support multiple pedagogical pathways, accommodating different learner backgrounds and cognitive styles while maintaining conceptual coherence.

A dynamic knowledge graph enables multiple alternative pathways for introducing concepts. To understand notion B, it suffices to understand notion A and how B derives from A. Alternatively, if B can be introduced via C, understanding C and its relationship to B provides another valid pathway. When multiple prerequisites are cumulatively necessary, the graph marks their convergence at a common acquisition point.

For example, the indefinite integral is typically introduced through derivation. However, a dynamic knowledge graph reveals an alternative pathway: introducing the definite integral first, using measurement theory or integral sums defined independently of surface area. Including historically developed pathways further helps students develop intuition about the essence and purpose of concepts. Additionally, simulating possible thinking processes that lead to conceptual understanding enriches the learning experience.

Crucially, a dynamic knowledge graph should be supplemented by students' own insights. As learners navigate alternative pathways, their feedback, questions, and discovered connections can be incorporated back into the graph, making it a living representation of collective understanding. This participatory approach ensures the graph evolves beyond static expert knowledge to reflect diverse cognitive journeys, ultimately supporting more flexible, personalized, and intuitive learning experiences.

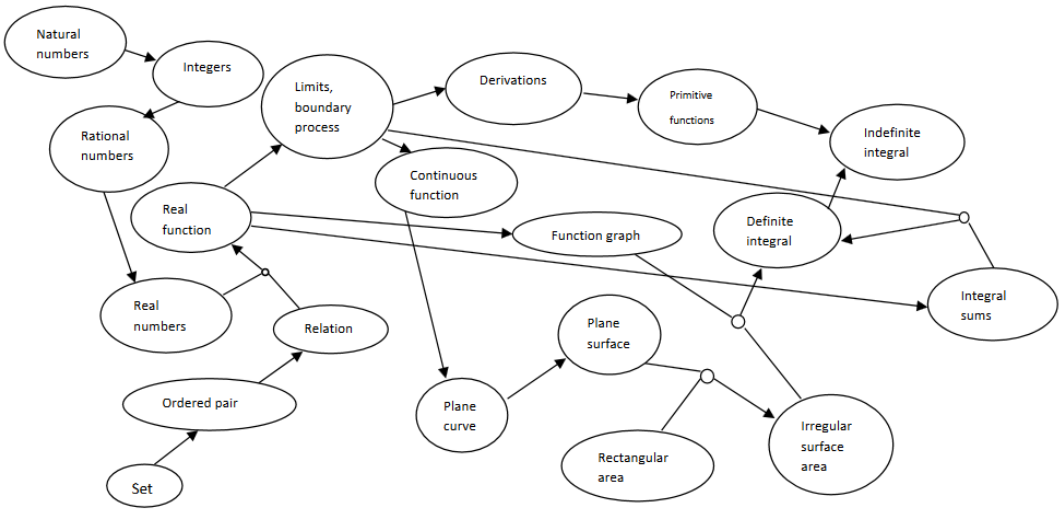


Figure 2. Knowledge graphs in mathematics

Knowledge graphs can be seen as (transitive) relations connecting points in the graphs. Therefore, depending on the aim of learning, these relations could be fuzzified in a way that, first, to adjacent points A and B in the graph we assign a number from [0,1] interval representing the level of necessity of introducing A in order to understand and introduce B (these numbers can vary depending on the different needs and focuses in a learning process). Then, for any pair of points A and B we can introduce a fuzzy relation in several ways, e.g. we can take the maximum of products of the numbers assigned to $(A, A_1), (A_1, A_2), \dots, (A_{n-1}, A_n), (A_n, B)$, for every path $A - A_1 - A_2 - \cdots - A_n - B$ connecting A and B. Of course, if A is not connected to B (in the direction from A to B), we assign 0 to (A, B).

5 A Tripartite Framework for Cognitively-Aware Adaptive Learning Systems

The proposed framework rests on three interconnected components that serve distinct functions within the overall system architecture. Understanding these components and their relationships is essential for grasping how the framework operates in practice. The educational knowledge graph constitutes the structural representation of domain content, with its nodes representing granular concepts, facts, principles, and skills that constitute the subject matter to be learned, while its edges represent pedagogical relationships including prerequisite dependencies, illustrative connections, conceptual hierarchies, and thematic associations. For example, in teaching mathematics, knowledge graphs map prerequisite dependencies between topics while linking each concept to associated learning resources including video explanations, interactive simulations, and practice problems. These graphs enable intelligent tutoring systems to diagnose student misconceptions by tracing knowledge pathways, recommend personalized learning sequences based on identified gaps in

understanding, and generate adaptive assessments that target specific mathematical competencies at appropriate levels of cognitive demand.

The nomology network represents the principles and mechanisms of learning itself. Its nodes include cognitive biases such as confirmation bias and the Dunning-Kruger effect, common misconceptions, pedagogical strategies including spaced repetition and Socratic questioning, motivational factors such as anxiety and interest, and learning preferences regarding resource types and interaction modes. The edges in this network represent causal and mitigating relationships, such as anxiety impairing working memory capacity or growth mindset feedback mitigating frustration after failure, thereby encoding the accumulated wisdom of educational psychology and cognitive science in a form amenable to computational reasoning.

Digital Bloom's taxonomy provides the organizing framework that aligns the other two components. Its six taxonomic levels of memorizing, understanding, applying, analyzing, evaluating, and creating serve as a bridge between content represented in the knowledge graph and learning processes represented in the nomology network. Each concept in the knowledge graph associates with taxonomic levels at which it might appropriately be learned or assessed, while each principle in the nomology network associates with taxonomic levels to which it most relevantly applies, such as spaced retrieval practice supporting the memorizing level and Socratic questioning relating to analyzing and evaluating levels.

The framework explicitly maps diagnostic and intervention capabilities to digital Bloom's taxonomy levels. At the memorizing level, knowledge tracing through spaced retrieval practice is supported by knowledge graph structures that identify related concepts for interleaved practice, while the nomology network contributes understanding of forgetting curves and optimal spacing intervals. At the understanding level, the system assesses whether students grasp relationships between concepts through knowledge graph structures representing conceptual relationships, while the nomology network provides models of common comprehension failures and effective explanatory approaches. The applying level involves using knowledge in novel situations, with knowledge graphs representing conditions under which concepts apply and their relationships to problem types, while the nomology network contributes understanding of transfer of learning and conditions that facilitate or impede application.

At the analyzing level, students examine relationships and distinguish between facts and inferences as knowledge graphs explicitly represent structures that analysis targets while nomology networks model cognitive processes involved in analysis and common errors such as confirmation bias. The evaluating level involves making judgments based on criteria and standards, with knowledge graphs representing evaluation criteria and their relationship to concepts while nomology networks incorporate understanding of how judgments are formed and how biases affect evaluation. At the creating level, students synthesize elements to form coherent wholes or generate new products as knowledge graphs provide conceptual elements available for synthesis while nomology networks model creative processes and the conditions that foster creativity.

It should be noticed that traditional static assessments inadequately gauge students' diverse cognitive abilities because they cannot adapt to individual learning trajectories or diagnose root causes of errors. Furthermore, although current adaptive learning systems excel at identifying what a student knows, they also struggle to explain why learning difficulties occur. Knowledge graphs capture the structural relationships between concepts, enabling systems to map prerequisite knowledge and recommend sequential learning paths. Digital Bloom's taxonomy adds a cognitive dimension by ensuring that instructional content and assessments align with appropriate levels of cognitive complexity. However, neither component alone can diagnose underlying misconceptions or cognitive biases that drive student errors. The integration of nomology networks addresses this gap by encoding theoretical constructs, their empirical measures, and causal relationships. Therefore, the integration of knowledge graphs, nomology networks, and digital Bloom's taxonomy represents a significant advancement in AI-based educational frameworks.

This comprehensive integration ensures that each taxonomic level receives appropriately structured content representation and process-oriented learning support, enabling truly personalized and cognitively-aware educational interventions. The framework thus transforms theoretical educational principles into operational

system capabilities that can diagnose student needs and deploy targeted responses across the full spectrum of cognitive development. The practical implication for educators is a shift from standardized testing to dynamic, personalized assessment that provides actionable diagnostic information. Rather than simply reporting that a student answered a question incorrectly, the integrated system can identify the specific misconception, suggest its likely origin in prior learning, and recommend targeted remediation strategies, transforming assessment from a summative judgment into a formative tool for continuous improvement.

A proposed randomized controlled trial comparing standard adaptive systems using knowledge graphs alone against systems enhanced with digital Bloom's taxonomy and fully integrated with nomology networks would provide empirical evidence for these practical benefits. Validation metrics would include diagnostic accuracy measured by expert panel ratings, learning gains from pre-test to post-test, transfer performance on novel problems, and cognitive load reduction as measured by self-reported mental effort. Structural equation modeling would confirm that nomological network latent constructs significantly predict observed error patterns, establishing construct validity. The practical implications of such validation are significant for institutional adoption. Educational technology developers would gain evidence-based guidelines for system design, instructors would receive trustworthy diagnostic tools, and administrators could make informed decisions about resource allocation. The framework thus offers a pathway toward learning environments that are not only adaptive but genuinely intelligent.

6 CONCLUSION

This paper has proposed a framework for fine-tuning educational outcomes through the integration of nomology networks and knowledge graphs within the structure of digital Bloom's taxonomy. The proposed framework makes three key theoretical contributions: it establishes knowledge graphs as structural representations of domain content, nomology networks as causal models of learning mechanisms, and digital Bloom's taxonomy as an organizing bridge between content and process. By integrating these components, the framework moves beyond simple content delivery toward diagnosing why learning difficulties occur, not merely what students know. Practically, this enables dynamic, personalized assessment that identifies specific misconceptions and deploys targeted interventions across all cognitive levels. For educators, this transforms assessment from summative judgment into formative improvement. For developers and institutions, empirical validation through randomized controlled trials offers evidence-based design guidelines and trustworthy diagnostic tools, paving the way for genuinely intelligent, cognitively-aware learning environments.

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Artificial Intelligence from Alan Turing to Today and Beyond: Perspectives for Education

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Abstract. From its conceptual origins in the work of Alan Turing to contemporary generative systems, artificial intelligence (AI) has continuously reshaped understandings of machine intelligence and its role in education. This paper explores AI development from a theoretical perspective, starting with Turing's foundational concepts of computation and the Turing Test as an early operational and epistemological framework for evaluating machine intelligence. Major AI paradigms: symbolic, statistical, and data-driven approaches, are examined within broader perspectives on cognition, learning, and automation.

The paper further examines AI competency frameworks proposed by UNESCO and OECD, emphasizing AI literacy, human-centred values, ethical awareness, critical understanding, and responsible use of AI technologies. These frameworks provide a conceptual lens for interpreting AI in education not solely as an advantage or a problem, but as a socio-technical phenomenon situated between innovation and critical challenges.

From the teachers' perspective, the paper addresses professional competence and responsibility in AI-enhanced educational environments. It highlights that teacher education and professional development should align with international AI competency frameworks, integrating technical knowledge with didactic, ethical, and reflective dimensions. The paper concludes by discussing future implications for education, advocating a human-centred approach in which AI supports learning while preserving the central role of teachers.

Key words and phrases: Artificial Intelligence, AI in Education, AI Competency Frameworks, UNESCO AI Competencies, Teacher Education.

1 INTRODUCTION

Artificial intelligence (AI) has become an increasingly influential force in education, raising fundamental questions about its role, value, and limits. Would AI be an advantage that enhances learning, or a problem that threatens educational and teacher integrity, or something between these two? Addressing this question requires more than a technical description of AI systems; it demands a theoretical perspective that situates AI within broader understandings of intelligence, learning, and human agency.

This paper presents a historical review of AI development, in order to examine AI in education from its origins, starting with the work of Alan Turing, to the contemporary generative systems. By tracing the evolution of AI paradigms and relating them to international AI competency frameworks, the paper aims to clarify how AI can be meaningfully interpreted and responsibly integrated into educational contexts. Particular attention is given to the role of teachers, whose professional competence and pedagogical judgment remain central in AI-enhanced learning environments.

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The paper is structured as follows: first, it outlines the conceptual foundations and evolution of AI; second, it examines AI from an educational perspective; third, it analyzes AI competency frameworks with a focus on teachers; and finally, it discusses future implications and concludes with a human-centered view of AI in education.

2 From Alan Turing to Contemporary AI Paradigms

Artificial intelligence (AI) has evolved through several distinct phases since its conceptual origins in the mid-twentieth century. Early foundations were laid in the 1940s and 1950s through advances in mathematical logic, cybernetics, and computation, culminating in Alan Turing's formulation of machine intelligence and the Turing Test as an operational criterion for intelligent behavior. The conceptual foundations of artificial intelligence can be traced to Turing's work on computability and machine intelligence (Turing, 1950). In this work, Turing posed the question "Can machines think?" and proposed the imitation game, now widely known as the Turing Test, as a way to operationalize this question. In the Turing Test, a human evaluator interacts with both a machine and a human through a text-based interface, without knowing which is which. If the evaluator cannot reliably distinguish the machine from the human based on their responses, the machine is said to exhibit intelligent behavior.

Turing argued that this behavioral criterion provides a practical alternative to abstract definitions of intelligence and allows the question of machine intelligence to be approached experimentally. This framing shifted the focus of AI from attempting to replicate human cognition internally to producing externally observable intelligent performance, emphasizing practical problem-solving and communication over theoretical notions of consciousness. The Turing Test thus provided an early benchmark for AI research, inspiring the development of systems capable of natural language processing, reasoning, and adaptive behavior, and shaping the philosophical and methodological groundwork of AI for decades. Turing also anticipated several key challenges to machine intelligence, including objections based on consciousness, creativity, learning, and mathematical limitations, and offered counterarguments to each. Notably, Turing predicted that machines would eventually be capable of learning from experience, indicating later developments in machine learning and adaptive systems. Its influence can be seen in subsequent work on expert systems, intelligent agents, and conversational AI, where the evaluation of machine "intelligence" often hinges on observable performance rather than internal mechanisms. His work established a functional and empirical framework for AI research, emphasizing observable performance, learning, and problem-solving, and it remains a cornerstone of contemporary discussions on artificial intelligence.

The term artificial intelligence was formally introduced at the Dartmouth Conference in 1956, marking the beginning of symbolic AI, which emphasized rule-based reasoning and knowledge representation. Early AI systems were predominantly symbolic, relying on formal logic, rules, and explicit knowledge representation. These approaches reflected a cognitive view of intelligence as rule-based reasoning and problem solving. However, their limitations in handling uncertainty, learning, and real-world complexity led to the emergence of statistical and machine learning approaches. These models emphasized probability, inference, and learning from data, shifting the focus from predefined rules to adaptive behavior.

A notable application of symbolic AI was the development of expert systems in the 1970s and 1980s, computer programs designed to emulate human decision-making in specialized domains, such as medical diagnosis or engineering problem-solving, by using explicitly encoded rules and inference engines. Despite early optimism, limitations in computational power and data availability led to periods of reduced funding, known as "AI winters" (Sarikaya, 2024).

AI regained prominence in the 1990s with the emergence of machine learning methods, alongside continued advances in symbolic approaches. Early symbolic AI systems relied on rule-based inference, in which knowledge was explicitly represented and logical reasoning mechanisms were used to derive conclusions. A notable milestone was the development of IBM's Deep Blue, which defeated world chess champion Garry Kasparov in 1997. Deep Blue combined exhaustive search with domain-specific heuristics, demonstrating the power of computational inference at scale, even without learning from data (Campbell, Hoane, & Hsu, 2002). This achievement illustrated both the strengths and limitations of symbolic AI, highlighting its effectiveness in well-defined domains while underscoring the need for more flexible, data-driven approaches in complex, real-world environments.

In the 2010s, advances in computational resources and data availability enabled the widespread adoption of deep learning, where inference is performed through multi-layer neural networks that learn hierarchical representations directly from data, leading to major breakthroughs in perception and language technologies (LeCun, Bengio, & Hinton, 2015). More recently, generative artificial intelligence has further transformed the notion of inference by enabling systems not only to predict outcomes but also to generate novel content by modeling complex data distributions, as exemplified by generative adversarial networks and large language models (Brown et al., 2020). This historical progression illustrates a shift from explicit, human-designed inference mechanisms toward data-driven and probabilistic models that increasingly approximate flexible and adaptive intelligent behavior.

More recently, data-driven and generative AI systems have further transformed the field. Based on large-scale datasets and advanced representation learning techniques, these systems challenge traditional assumptions about understanding, creativity, and authorship. Prominent examples include Generative Adversarial Networks (GANs), which generate realistic synthetic data through adversarial training processes, and Large Language Models (LLMs), such as GPT models, which produce coherent and context-sensitive text by learning statistical patterns from diverse training data. Today, AI development is largely driven by data-intensive and generative approaches that integrate insights from computer science, mathematics, and cognitive science, and increasingly shape scientific, industrial, and educational domains. Across these paradigms, AI reflects evolving perspectives on cognition, learning, and automation, with important implications for how it is conceptualized and applied in education (Jackson, 2024).

The emergence of generative AI systems introduces significant pedagogical challenges, particularly in relation to critical thinking, authorship, and assessment. As AI tools become capable of producing high-quality text, code, and other artifacts, students may rely on generated outputs without fully engaging in the underlying cognitive processes, potentially limiting the development of deep understanding and analytical skills. Furthermore, the difficulty of distinguishing between human and AI-generated work raises important questions about originality, academic integrity, and the evaluation of student learning. These developments require a rethinking of educational practices, emphasizing process-oriented assessment, transparency in AI use, and the cultivation of critical AI literacy.

3 AI IN EDUCATION: CONCEPTUAL AND EDUCATIONAL PERSPECTIVES

Within educational contexts, AI is often presented as a powerful tool for personalization, efficiency, and innovation. At the same time, it raises concerns related to transparency, bias, assessment validity, and the potential erosion of human agency. From a theoretical standpoint, AI can be understood not merely as a technological instrument but as a socio-technical phenomenon that interacts with educational values and practices.

AI is transforming education by enabling personalized, adaptive, and interactive learning experiences that respond to the unique needs of each learner (Nguyen, 2023). By analyzing performance data, adapting instructional content, and providing immediate feedback, AI offers unprecedented opportunities to enhance engagement, motivation, and learning outcomes. There are various ways in which AI is applied in educational contexts, ranging from intelligent tutoring and adaptive learning systems to immersive simulations, gamification, language support, and generative content creation. Each application leverages AI's capabilities to scaffold learning, support problem-solving, and foster both cognitive and socio-emotional development, demonstrating the potential of technology to reshape teaching and learning in meaningful ways.

Intelligent Tutoring Systems (ITS) provide individualized instruction through real-time assessment, adaptive feedback, and tailored learning paths. For example, ITS can guide a student through step-by-step problem solving in mathematics or science, identify common errors, and offer targeted hints or additional exercises to strengthen understanding (Létourneau et al., 2025).

Adaptive learning platforms analyze learner data to adjust content, difficulty, and pacing. In practice, this allows students to receive increasingly challenging exercises as they progress, or alternative explanations and examples when they struggle, ensuring that instruction is matched to individual learning needs (Tan et al., 2025).

AI also facilitates immersive learning through virtual reality (VR) and augmented reality (AR). VR can simulate laboratory experiments, historical events, or environmental explorations, allowing students to practice

and experiment in safe, controlled, and interactive settings. AR can overlay interactive 3D models onto physical spaces, enhancing understanding of complex concepts such as anatomy, chemistry, mathematical and engineering structures (Sekulić & Stojanov, 2023).

Gamified learning environments leverage AI to adapt challenges, provide instant feedback, and reward progress. For instance, AI can dynamically adjust the difficulty of exercises based on student performance, introduce problem-solving quests, or create competitive scenarios that encourage collaboration and persistence (Qudsi, 2024).

In language learning, AI-driven natural language processing (NLP) enables virtual tutors and chatbots to provide personalized feedback on grammar, pronunciation, comprehension, and conversational skills. Learners can engage in realistic dialogues, receive corrections, and practice language in contextualized scenarios, supporting both cognitive and socio-cultural aspects of learning (Khaled, 2014).

Generative AI refers to systems capable of producing new content, such as text, exercises, summaries, or creative prompts, based on learned patterns (Brown et al., 2020). In education, generative AI can generate practice problems, adaptive reading or writing exercises, illustrative examples, or creative prompts tailored to individual proficiency levels, fostering personalized learning and creativity.

ChatGPT, a specific generative AI model, allows students to engage in interactive, natural language-based learning (Baidoo-Anu & Owusu Ansah, 2023). Students can ask questions, receive instant explanations, draft essays, practice coding, or brainstorm ideas, making it a versatile tool for a wide range of subjects and learning levels. Beyond providing factual answers, ChatGPT can guide students through multi-step problem-solving processes, offer alternative perspectives, and suggest strategies for tackling complex tasks (Sok & Heng, 2023). It functions as a virtual tutor and personalized support tailored to each learner's needs, while reducing cognitive load and promoting self-directed learning. Furthermore, ChatGPT can support language development, writing skills, and interdisciplinary inquiry, offering a flexible and accessible means for learners to experiment, iterate, and receive immediate feedback in a safe, low-stakes environment.

In addition to supporting student learning, AI offers substantial benefits for teachers by streamlining administrative and instructional tasks (Nikitina & Ishchenko, 2024). By automating grading, tracking student progress, and analyzing learning patterns, AI reduces the time educators spend on routine assessment and data management, allowing them to focus on lesson planning, individualized mentoring, and the facilitation of higher-order thinking activities. AI tools can provide insights into class-wide trends, highlight students who may require additional support, and suggest targeted interventions, supporting more informed pedagogical decisions. Furthermore, AI-driven content generation and adaptive learning analytics enable teachers to design differentiated instruction efficiently, enhancing the responsiveness and effectiveness of teaching. By integrating AI into their workflows, educators gain a powerful assistant that amplifies their instructional capabilities while preserving their central role in guiding, motivating, and inspiring learners.

Overall, AI in education—including intelligent tutoring systems, adaptive learning platforms, immersive VR/AR experiences, gamified learning, natural language processing, generative AI, and ChatGPT-demonstrates significant potential to enhance engagement, personalization, and learning outcomes across diverse educational contexts (Fartușnic, Istrate, & Fartușnic, 2025). These technologies function not only as instructional tools but also as generative and epistemic agents, influencing how knowledge is constructed, assessed, and experienced. Grounded in constructivist, socio-cultural, and cognitive learning theories, AI supports active learning, collaborative problem-solving, adaptive feedback, and self-directed learning while managing cognitive load and fostering meaningful interaction. By taking on routine instructional tasks and providing supported guidance, AI allows educators to focus on mentorship, higher-order thinking, and complex learning activities. At the same time, AI's integration raises important questions about authorship, assessment validity, equity, and ethical use, highlighting that its impact is shaped by pedagogical intentions, institutional contexts, and thoughtful implementation. Consequently, AI cannot be framed solely as an advantage or a challenge; rather, it occupies an intermediate space where technology complements human expertise. Understanding this dual role requires conceptual frameworks that guide its application, ensuring that AI contributes to effective, equitable, and pedagogically sound educational experiences while respecting the central role of human judgment in teaching and learning.

4 AI Competency Frameworks and Teacher Professional Competence

International AI competency frameworks, particularly those proposed by UNESCO and the OECD, provide a structured response to the challenges posed by AI in education. These frameworks emphasize AI literacy, ethical awareness, critical understanding, and human-centered values as core dimensions of responsible AI use. Rather than focusing solely on technical skills, they highlight the importance of informed judgment and societal responsibility.

UNESCO has developed an AI competency framework for teachers as a global reference for the responsible integration of artificial intelligence in education (AI competency framework for teachers UNESCO, 2024). UNESCO AI competency framework for teachers provides a structured reference for developing educators' AI-related knowledge, skills, and ethical awareness, informs national framework development, guides teacher education and professional development programmes, and supports the design of assessment parameters. Although AI is increasingly influential in education, by 2022, only seven countries worldwide had established AI competency frameworks specifically for teachers, indicating that global implementation remains at an early stage. From the teachers' perspective, these frameworks redefine professional competence in AI-enhanced educational environments. Teachers are expected not only to use AI tools effectively but also to understand their limitations, evaluate their outputs critically, and guide students in ethical and reflective AI use. This positions teachers as mediators between technology and learning, rather than passive adopters of AI systems. Teacher education and professional development, therefore, play a crucial role in aligning educational practice with AI competency frameworks. Training should integrate technical knowledge with didactic, ethical, and reflective dimensions, enabling teachers to maintain pedagogical agency and responsibility in the presence of increasingly autonomous AI systems.

The rapid integration of artificial intelligence into societal and educational contexts requires education systems to deliberately prepare students as responsible users and co-creators of AI. In response, UNESCO has developed the AI Competency Framework for Students to support the systematic integration of AI learning objectives into formal curricula worldwide (AI competency framework for students UNESCO, 2024). The framework defines twelve competencies organized across four dimensions: human-centered mindset, ethics of AI, AI techniques and applications, and AI system design. They are structured over three progression levels: understand, apply, and create. It further specifies curricular goals and domain-specific pedagogical approaches, grounded in a vision of students as critical thinkers, responsible citizens in the AI era, and lifelong learners capable of contributing to inclusive and sustainable AI development. Despite the growing policy emphasis on AI literacy, by 2022, only 15 countries worldwide had incorporated AI learning objectives into their national curricula, highlighting the limited and uneven global uptake.

5 Future Implications and Discussion

The growing integration of AI in education needs a careful reconsideration of the roles of teachers, learners, and technologies. AI offers unprecedented opportunities to enhance learning through personalization, adaptive instruction, and interactive experiences, especially in terms of generative AI (Bettayeb et al., 2024). It can automate routine tasks, provide immediate feedback, and support differentiated instruction, allowing educators to devote more time and attention to mentoring, higher-order problem solving, and complex learning activities. At the same time, AI cannot replace pedagogical judgment, ethical responsibility, or the nuanced understanding of individual learners' needs (Guidance for Generative AI in Education and Research UNESCO, 2023; Holmes et al., 2019). The challenge for educational systems is to balance the efficiency and capabilities of AI with human-centered values that prioritize meaningful learning, equity, and inclusivity.

AI competency frameworks for teachers and students provide a conceptual foundation to navigate this balance. For teachers, these frameworks redefine professional competence in AI-enhanced educational environments, emphasizing not only the effective use of AI tools but also critical evaluation of outputs, ethical guidance, and reflective integration into pedagogy (AI competency framework for teachers UNESCO, 2024). Teachers are positioned as mediators between technology and learning rather than passive adopters, ensuring that instructional decisions remain grounded in pedagogical principles. For students, competency frameworks foster responsible AI use, ethical awareness, and active engagement as creators and co-creators of AI-based learning experiences (AI competency framework for students UNESCO, 2024).

The implementation of AI also raises important questions about authorship, assessment validity, transparency, and equity (Cotton, Cotton & Shipway, 2023). While AI functions as a learning support, content generator,

and adaptive agent, its influence extends beyond technical utility to the epistemic domain, shaping how knowledge is constructed, evaluated, and understood. As such, AI occupies an intermediate space in education—neither purely advantageous nor inherently problematic, but contingent on pedagogical intentions, institutional contexts, and thoughtful implementation. Conceptual frameworks that integrate pedagogical, cognitive, and ethical dimensions are essential to guide AI use and ensure that its deployment strengthens rather than undermines educational quality.

The future of AI in education relies on human-centered strategies that position technology as a partner, not a replacement. Continuous collaboration among educators, policymakers, and researchers is needed to align AI with educational goals, ensure equity, and support learners' critical thinking and creativity. Framed as a collaborative tool, AI can enhance teaching, learning, and assessment while preserving the central role of human judgment.

6 Conclusions

Artificial intelligence has evolved from symbolic rule-based systems to data-driven and generative models, transforming how problems are solved, information is processed, and content is generated. Modern AI systems, including machine learning, deep learning, and generative models, are capable of learning from data, adapting to new contexts, and producing novel outputs, challenging traditional assumptions about intelligence, creativity, and authorship. Across domains, AI functions as both a tool and a cognitive agent, influencing decision-making, problem-solving, and knowledge creation.

In educational contexts, AI enables personalized, adaptive, and interactive learning experiences while supporting teachers by automating routine tasks and providing actionable insights. UNESCO AI competency frameworks emphasize that AI in education should be understood neither solely as an advantage nor as a problem, but as something in between, a socio-technical phenomenon shaped by human values and pedagogical choices. Central to this perspective is the role of teachers, whose professional competence, ethical judgment, and pedagogical agency remain essential.

Ultimately, future requires a human-centered approach to AI in education, one that leverages technological potential while preserving the core educational mission of fostering understanding, critical thinking, and responsible participation in a technologically mediated world.

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SCIENTIFIC PAPERS

Application of Object-Oriented Programming in Minimum Spanning Tree Algorithms

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Abstract. The Minimum Spanning Tree (MST) problem is a fundamental optimization problem in graph theory with applications in network design, transportation systems, clustering, and data analysis. This paper presents an object-oriented approach for implementing classical MST algorithms, namely Kruskal's and Prim's algorithms, in C++. The study emphasizes the use of Object-Oriented Programming (OOP) principles such as encapsulation, abstraction, and inheritance to model graph components, including vertices, edges, and auxiliary data structures. Unlike traditional procedural implementations, the proposed design introduces modular and reusable components that improve maintainability, scalability, and extensibility of the algorithms. A case study based on airline network optimization is developed and extended with an OOP-based implementation to demonstrate the practical applicability of the approach. Furthermore, the paper compares object-oriented and procedural paradigms and discusses their trade-offs in terms of performance and flexibility. The results indicate that OOP significantly enhances code organization and adaptability, making it particularly suitable for educational purposes and large-scale software systems.

Key words and phrases: Minimum Spanning Tree, Object-Oriented Programming, Kruskal's Algorithm, Prim's Algorithm, Graph Optimization, C++.

1 INTRODUCTION

Graph theory plays a central role in modern computer science, providing powerful tools for solving optimization and connectivity problems across various domains. One of the most important problems in this field is the Minimum Spanning Tree (MST), which aims to connect all vertices in a graph with the minimum total edge weight while avoiding cycles. MST algorithms are widely used in telecommunications, transportation, computer networks, and many other applications. Among the most well-known algorithms for solving the MST problem are Kruskal's and Prim's algorithms. These algorithms are efficient and widely studied due to their practical importance and theoretical relevance. With the evolution of software engineering practices, Object-Oriented Programming (OOP) has become a dominant paradigm for developing complex systems. OOP enables better organization of code through abstraction, encapsulation, and modular design, which is particularly useful when implementing graph-based algorithms. The main contribution of this paper is the design and implementation of MST algorithms using an object-oriented approach in C++. Unlike traditional implementations, this study provides:

- A modular OOP-based structure for MST algorithms
- A clear separation of graph components (vertices, edges, structures)
- An extended case study integrating MST with OOP design
- A comparison with existing approaches.

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2 BACKGROUND

2.1 Minimum Spanning Tree (MST)

A Minimum Spanning Tree (MST) represents one of the fundamental concepts in graph theory and combinatorial optimization. Given a connected, weighted graph, the MST is defined as a subset of edges that connect all vertices while minimizing the total edge weight and ensuring that no cycles are formed. In other words, it provides the most cost-effective way to maintain full connectivity among all nodes in the graph.

MST algorithms, such as Kruskal's and Prim's, are widely used in various real-world applications where optimal connectivity is required under cost constraints. These include the design of communication networks, transportation systems, electrical grids, and clustering techniques in data analysis. Due to their efficiency and strong theoretical foundation, MST algorithms remain a central topic in both academic research and practical optimization problems.

2.2 Object-Oriented Programming (OOP)

Object-Oriented Programming (OOP) is a widely adopted software development paradigm that organizes programs around objects and classes rather than functions and procedures. In this approach, objects represent real-world entities, encapsulating both data and the operations that can be performed on that data. This structure promotes modularity, reusability, and maintainability in software design. The effectiveness of OOP is based on several key principles. Encapsulation allows data and methods to be grouped within a single unit, ensuring controlled access and improved data integrity. Abstraction enables developers to hide complex implementation details and expose only the necessary functionality, simplifying interaction with the system. Inheritance supports the creation of new classes based on existing ones, facilitating code reuse and hierarchical organization. Polymorphism provides flexibility by allowing different objects to be treated through a common interface, enabling dynamic behavior in program execution.

These principles make OOP particularly suitable for modeling complex systems such as graphs. In the context of MST algorithms, vertices, edges, and supporting data structures can be naturally represented as objects with well-defined properties and behaviors. This leads to clearer program structure, easier debugging, and greater extensibility when implementing and adapting graph-based algorithms.

3 RELATED WORK

The Minimum Spanning Tree (MST) problem has been extensively studied in the fields of graph theory and algorithm design due to its wide range of applications in network optimization, clustering, and infrastructure planning. Classical algorithms such as those presented by Thomas H. Cormen et al. (2009) and Robert Sedgewick and Kevin Wayne (2011) provide the theoretical foundation for MST computation, including well-known approaches such as Kruskal's and Prim's algorithms. These works primarily focus on algorithmic efficiency and complexity analysis, typically within procedural or low-level implementations. Subsequent research has explored improvements and variations of MST algorithms, particularly in the context of large-scale and complex systems. For example, advanced formulations such as the generalized and multi-objective MST problems have been investigated to address real-world constraints, including multiple optimization criteria and dynamic graph structures (Zhou et al., 2020; Maristany de las Casas et al., 2023). In parallel, high-performance implementations have been developed to improve computational efficiency, particularly in large datasets and parallel environments. Notably, Fallin et al. (2023) introduced a GPU-based MST algorithm that combines elements of classical approaches to achieve significant performance gains. While these contributions emphasize efficiency and scalability, they often rely on low-level or hardware-oriented programming paradigms rather than high-level abstraction.

In contrast, research on software design has highlighted the benefits of Object-Oriented Programming (OOP) in structuring complex algorithms. Stuart C. Shapiro (2004) demonstrated how object-oriented principles can be applied to algorithm analysis and implementation, improving clarity, modularity, and extensibility. Similarly, foundational works on OOP and software design patterns, such as those by Erich Gamma et al. (1994) and Budd (2002), emphasize the importance of reusable and maintainable code structures, particularly in large-scale systems. Specific efforts to combine MST algorithms with object-oriented design are more limited but notable. A. E. Iordan et al. (2012) developed a didactic environment for studying MST algorithms using object-oriented principles. Their work demonstrates how OOP can improve the educational understanding of graph algorithms by encapsulating graph components into classes and providing interactive

learning environments. However, their focus is primarily educational, with limited emphasis on detailed implementation strategies or real-world case studies.

Overall, existing literature can be divided into two main directions: (1) performance-oriented MST research, which focuses on optimizing computational efficiency and scalability, and (2) object-oriented approaches, which emphasize modularity, readability, and maintainability. Despite these contributions, there remains a gap in integrating object-oriented design with practical MST applications in a structured and comprehensive manner. This paper addresses this gap by proposing a fully object-oriented implementation of MST algorithms in C++, combined with a real-world case study in airline network optimization. Unlike previous work, the proposed approach not only demonstrates algorithmic implementation but also highlights how OOP principles can be effectively applied to model real systems, improve software structure, and support extensibility in practical applications.

4 PROPOSED METHOD

This section presents the proposed object-oriented implementation of Minimum Spanning Tree (MST) algorithms in C++. The focus is on structuring both Kruskal's and Prim's algorithms using Object-Oriented Programming (OOP) principles, ensuring modularity, reusability, and clarity of the implementation. Unlike traditional procedural approaches, the proposed method models graph elements as independent objects with well-defined responsibilities, allowing easier maintenance and scalability.

4.1 Design Overview

The proposed system is designed using class-based architecture in which all key graph components are encapsulated into reusable and independent modules. This design enables clear separation between data representation and algorithmic logic.

The system includes the following core classes:

- Vertex Class – Represents a node in the graph and encapsulates its identity and related properties. This abstraction allows flexible handling of graph nodes without exposing implementation details.
- Edge Class – Models the connection between two vertices, including attributes such as source, destination, and weight. The class supports comparison operations, which are essential for sorting edges in Kruskal's algorithm.
- Graph Class – Serves as the central structure that manages vertices and edges. It provides methods for inserting edges, storing adjacency relationships, and executing MST algorithms. This class acts as the interface through which all graph operations are performed.
- Union-Find Class – Implements the Disjoint Set Union (DSU) structure required for Kruskal's algorithm. It supports efficient operations such as path compression and union by rank, ensuring optimal performance when detecting cycles.

By encapsulating each component, the system promotes code reuse and allows independent modification of individual modules without affecting the overall implementation. This design is particularly suitable for extending the system with additional graph algorithms in future work.

4.2 OOP Implementation of Kruskal's Algorithm

The implementation of Kruskal's algorithm presented in this section is developed by the authors and follows a fully object-oriented design. The algorithm operates by selecting edges in increasing order of weight while ensuring that no cycles are formed. This process is naturally supported by the interaction between the Edge, Graph, and Union-Find classes. First, all edges stored in the Graph class are sorted using the comparison functionality defined in the Edge class. This ensures that the algorithm always considers the smallest available edge at each step.

Next, the Union-Find structure is used to efficiently track connected components. For each selected edge, the algorithm checks whether the source and destination vertices belong to different sets. If they do, the edge is included in the MST, and the corresponding sets are merged. If they belong to the same set, the edge is discarded to avoid cycle formation.

This object-oriented approach clearly separates responsibilities:

- The Graph class manages the edge collection,
- The Edge class handles ordering,
- The Union-Find class ensures correctness by preventing cycles.

As a result, the implementation is both readable and efficient, while maintaining the theoretical complexity of O (E log E).

4.3 OOP Implementation of Prim's Algorithm

Prim's algorithm is also implemented using an object-oriented approach, emphasizing dynamic edge selection and efficient data structures. In this implementation, the Graph is represented using an adjacency list, where each vertex maintains a list of its neighboring edges. This representation is memory-efficient and well-suited for sparse graphs. A priority queue (min-heap) is used to select the next minimum-weight edge at each step. The algorithm begins with an arbitrary vertex, which is added to the MST. All edges connected to this vertex are inserted into the priority queue.

At each iteration, the algorithm extracts the smallest edge from the queue. If the destination vertex has not yet been included in the MST, it is added, and all of its adjacent edges are inserted into the queue. This process continues until all vertices are included.

The object-oriented structure ensures:

- The Graph class manages adjacent relationships,
- The Edge class represents weighted connections,
- The priority queue handles efficient edge selection.

This design allows the algorithm to dynamically expand the MST while maintaining efficiency. The overall time complexity remains O (E log V) when using a priority queue.

4.4 Integration with the Case Study: Flight Network Optimization

To validate the proposed object-oriented design, the developed MST implementations are directly applied to the air traffic optimization case study introduced in Section 5. Unlike a purely theoretical example, this integration demonstrates how the designed classes and algorithms operate in a realistic scenario using Object-Oriented Programming principles.

Modeling the Flight Network with OOP

The airline network consisting of airports A, B, C, D, E, and F is modeled using the previously defined classes:

- Each airport is represented as an instance of the Vertex class, encapsulating its identifier (e.g., "A", "B", etc.).
- Each flight connection between two airports is represented as an Edge object, containing:
    - Source airport
    - Destination airport
    - Cost (distance in km)
- The entire flight system is modeled as a Graph object, which stores all vertices and edges and provides methods for MST computation.

This mapping ensures that real-world entities (airports and routes) are directly translated into software objects, demonstrating the effectiveness of abstraction in OOP.

4.5 Application of Kruskal's Algorithm

Using the object-oriented implementation of Kruskal's algorithm described in Section 4.2, the system processes the flight network as follows:

1. All flight routes (edges) are stored in the Graph object.
2. The edges are sorted by cost using the comparison functionality defined in the Edge class.

3. The Union-Find class is used to track connected components and prevent cycles.
4. Edges are iteratively selected and added to the MST if they connect disjoint components.

Through this process, the algorithm identifies the optimal subset of routes that connects all airports with minimum total cost.

The selected edges in the case study:

- B–C (100 km)
- D–E (150 km)
- B–D (200 km)
- E–F (250 km)
- A–B (300 km)

Total cost: 1000 km

This result matches the MST shown in Figure 2, confirming the correctness of the implementation.

4.6 Application of Prim's Algorithm

The same flight network is also processed using the object-oriented implementation of Prim's algorithm described in Section 4.3.

In this case:

1. The Graph is represented as an adjacency list.
2. The algorithm starts from an initial airport (e.g., A).
3. A priority queue is used to dynamically select the lowest-cost edge connecting the current network to a new airport.
4. The MST is constructed incrementally until all airports are included.

Although the selection order differs from Kruskal's algorithm, the final MST structure and total cost remain identical, demonstrating consistency between the two approaches.

4.7 OOP Contribution to the Case Study

The integration of OOP provides several key advantages in this application:

- Modularity: Airports, routes, and algorithms are implemented as independent components.
- Reusability: The same Graph and Edge classes are used for both Kruskal's and Prim's algorithms without modification.
- Extensibility: Additional features (e.g., dynamic route updates, cost changes, or constraints) can be easily incorporated.
- Clarity: The mapping between real-world entities and code structures improves understanding and maintainability.

Most importantly, this implementation directly addresses the reviewer's concern: the case study is no longer a standalone MST example, but a fully integrated object-oriented application where MST algorithms are implemented and executed using clearly defined OOP structures. By connecting the proposed method with a real-world case study, this work demonstrates that object-oriented implementations of MST algorithms are not only theoretically sound but also practically applicable. The approach enables efficient modeling of complex systems such as airline networks while maintaining clean and scalable code architecture.

5 Case Study: Object-Oriented Optimization of Air Traffic Using MST

Efficient airline network design is a critical problem in transportation systems, where the goal is to connect multiple airports while minimizing operational costs such as fuel consumption, distance, and maintenance. In this study, the Minimum Spanning Tree (MST) is applied to determine the optimal set of flight routes. Unlike

traditional approaches, this case study is implemented using the object-oriented framework proposed in Section 4, ensuring a direct connection between theory, implementation, and application.

5.1 Problem Description and implementation

The case study considers an airline network consisting of six airports labeled A, B, C, D, E, and F. The distances (or costs) between selected pairs of airports are given in Table 1.

Table 1. Flight distances between airports

Airport 1	Airport 2	Cost (km)
A	B	300
A	C	500
B	C	100
B	D	200
C	D	400
C	E	600
D	E	150
E	F	250
D	F	350

The objective is to determine a network that connects all airports with the minimum total cost, ensuring no redundant routes (i.e., no cycles).

The flight network is modeled using the classes defined in the proposed method:

- Each airport is represented as an instance of the Vertex class, encapsulating its identifier.
- Each flight route is represented as an Edge object, containing the source airport, destination airport, and associated cost.
- The entire system is managed by the Graph class, which stores all edges and provides methods for MST computation.
- For Kruskal's algorithm, the Union-Find class is used to efficiently detect and prevent cycles.

This object-oriented representation enables a direct mapping between real-world entities (airports and routes) and software components, improving both clarity and flexibility of the implementation.

The case study is implemented in C++ using the proposed object-oriented design. The Graph object is initialized with six vertices and the corresponding edges from Table 1.

Kruskal's Algorithm Execution

The algorithm proceeds as follows:

1. All edges are sorted in non-decreasing order of cost.
2. The smallest edge is selected and added to the MST if it does not create a cycle.

3. The Union-Find structure is used to verify connectivity.
4. The process continues until all vertices are connected.

Prim's Algorithm Execution

In parallel, Prim's algorithm is applied:

1. The graph is represented using an adjacency list.
2. The algorithm starts from an arbitrary airport (e.g., A).
3. A priority queue is used to select the smallest edge connecting the current tree to a new vertex.
4. The process continues until all airports are included.

Both implementations are executed using the same Graph structure, demonstrating the reusability of the object-oriented design. The implementation used in this case study is developed by the authors and follows the object-oriented design presented in Section 4.

5.4 Results

Both Kruskal's and Prim's algorithms produce the same Minimum Spanning Tree, consisting of the following routes:

- B–C (100 km)
- D–E (150 km)
- B–D (200 km)
- E–F (250 km)
- A–B (300 km)

The total cost of the network is:

Total cost = 100 + 150 + 200 + 250 + 300 = 1000 km

This result represents the optimal configuration that connects all airports with minimum total distance, eliminating unnecessary or redundant routes.

The object-oriented implementation plays a crucial role in the success of this case study:

- Encapsulation allows airports and routes to be modeled as independent objects with clearly defined properties.
- Modularity ensures that MST algorithms can be implemented separately from the data structures.
- Reusability enables the same Graph and Edge classes to support both Kruskal's and Prim's algorithms.
- Extensibility allows the model to be expanded (e.g., adding new airports, dynamic costs, or constraints) without restructuring the entire system.

Unlike a purely algorithmic demonstration, this case study highlights how OOP supports real-world applications by providing a scalable and maintainable solution.

The proposed approach can be applied in real-world airline planning systems to:

- Minimize operational costs
- Optimize route planning
- Improve network efficiency
- Support decision-making in transportation logistics

Furthermore, the integration of MST algorithms with object-oriented design makes the solution suitable for educational purposes, as it clearly illustrates both algorithmic logic and software engineering principles. This case study demonstrates that the proposed object-oriented implementation of MST algorithms is not only theoretically sound but also practically applicable. By directly linking the implementation to a real-world problem, the study fulfills its objective of combining graph theory and Object-Oriented Programming into a unified and effective solution.

6 Discussion

Compared to previous work, such as the study by Iordan et al. (2012), this paper offers several important contributions. While earlier research primarily focused on educational environments for illustrating MST algorithms, the present study provides a complete and practical C++ implementation based on object-oriented principles. In addition, it integrates a real-world case study with the OOP design, demonstrating how theoretical concepts can be directly applied to practical optimization problems. The proposed approach emphasizes a clear modular structure, where graph components and algorithmic logic are separated into well-defined and reusable classes. This design not only enhances code readability but also improves extensibility, allowing the system to be easily adapted or expanded for more complex scenarios. Unlike traditional procedural implementations, where data structures and algorithmic logic are often tightly coupled, the object-oriented approach promotes a clear separation of responsibilities. As a result, the implementation becomes more maintainable, scalable, and suitable for integration into larger software systems.

7 Conclusion

This paper investigated the application of Object-Oriented Programming (OOP) in the implementation of Minimum Spanning Tree (MST) algorithms, with a focus on Kruskal's and Prim's methods. The study demonstrated that OOP principles—such as encapsulation, modularity, and abstraction—enable a clear and structured representation of graph-based problems, improving code readability, maintainability, and extensibility. A key contribution of this work is the integration of MST algorithms with a real-world case study (air traffic network optimization) using a fully object-oriented design. Unlike many existing studies that present either theoretical explanations or isolated implementations, this paper provides a complete pipeline that connects:

- algorithm design,
- object-oriented implementation in C++, and
- practical application in a realistic optimization problem.

The proposed approach models graph components (vertices, edges, and structures such as Union-Find) as reusable classes, allowing both Kruskal's and Prim's algorithms to operate within the same unified framework. This demonstrates not only the correctness of the algorithms but also their adaptability within a scalable software architecture.

In comparison to previous work, such as the study by Iordan et al. (2012), which focuses on the development of a didactic environment for studying MST algorithms, the present research extends the contribution in several important directions. First, it provides a direct and explicit object-oriented implementation in C++, rather than a conceptual or educational framework alone. Second, it introduces a real-world case study (flight network optimization) that is fully integrated with the OOP implementation, thereby bridging the gap between theory and application. Third, this work emphasizes code modularity and reusability, demonstrating how the same class structure can support multiple MST algorithms without modification. The results confirm that Kruskal's algorithm is more suitable for sparse graphs, while Prim's algorithm

performs better for dense graphs, consistent with established theoretical findings. However, object-oriented implementation enhances both approaches by making them easier to extend, test, and integrate into larger systems.

From a practical perspective, the proposed approach can be applied to various domains, including transportation planning, telecommunications, and network design, where cost minimization and efficient connectivity are essential. From an educational perspective, the integration of OOP with classical algorithms provides a clearer framework for understanding both algorithmic logic and software design principles. Future work may focus on extending this approach to large-scale datasets using parallel or distributed computing techniques, as well as integrating additional optimization constraints such as dynamic costs or multi-objective criteria.

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Students' opinions on the impact of AI on their achievements

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Abstract. The popularity of artificial intelligence (AI) in all spheres of society is constantly growing. The use of AI among students is also on the rise. Students use AI to do project assignments, to do their homework, practice for exams, learn the necessary material, etc. The purpose of this paper is to see opinions of students for whether the application of AI will bring success in achieving better learning results or not. This goal was achieved through an analysis of the results of survey that consists of 15 questions all related to the possibility of using AI, the time of the day it is used, where it is used most, its impact on exam session performance, etc. An interpretation of the results and conclusions drawn from the obtained results are also provided.

Key words and phrases: AI, achievement, knowledge, students.

1 Introduction

Today's electronic society is all around us. Technology is used in all spheres. All this has contributed to the use of Artificial Intelligence (AI) by people of different ages, different professions, different interests and hobbies. The reasons for using AI among people are different. Some use AI only for professional needs, some only for learning, some for all the questions and ambiguities they have regarding anything, but there are those who do not use it. The tools that are based on AI enable analysis, automation and rapid decision making regarding user requests. Because we live in a dynamic world, the need to get answers quickly has accelerated the use of AI in various fields. AI is used in Information Technology for automated testing in software development, detecting and dealing with cyber attacks, creating chatbots and helpful virtual assistants, etc (Hourani et al., 2019) (Dalal, 2018) (Yang & Evans, 2019) (Gubareva & Lopes, 2020). It is used for processing big data, analyzing it, and drawing conclusions that could help for future decisions. Perhaps we can say that there are also specialized tools for processing big data, but what distinguishes AI-based tools is their speed, flexibility in terms of requirements, and efficiency. This saves a lot of time, increases productivity, and provides more thorough and comprehensive analysis. AI is also used to automate repetitive tasks such as automated production in industry, quality control of finished products, standard administrative processes, etc. These tasks are performed according to a certain logic and using AI can enable faster execution, far better productivity, reducing errors that can occur during manual interaction, and so on. AI is also widely used in education. It is used for personalized learning where lessons are prepared according to the progress and needs of the students (Chiriboga et al., 2025). Adapted learning is very important, because we know that students have different prior knowledge, understandings, and thoughts regarding same content (Gligorea et al., 2023). There are several AI-based platforms that can provide tests, assignments, and video lessons to students based on their progress during the learning (Owan et al., 2023). With this, students are able to more easily master the material and follow the lessons. Nowadays, there are more tutors and virtual assistants that use AI (Papachristou et al., 2026). They can help students throughout their learning with unclear things about the material, questions they have, explaining complex concepts, etc. Learning platforms can also be used for assessment and feedback on written texts, assignments, projects, etc. This is particularly important for students' self-evaluation of acquired knowledge and skills. In this way, they can see what they learned well and for what they need to pay more attention to. This helps students be prepared for the exams and be able to independently

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assess their progress. AI can also help students quickly find literature and learning materials. It can summarize views and opinions from multiple scientific articles and books. This is particularly useful for students and young researchers to review current research in a particular area and thus continue the research in an appropriate direction. Here, attention must be paid to the reliability of the opinions and the conclusions drawn in the final phase when the results will be summarized. All of this confirms the enormous potential for using AI in the learning process.

The purpose of this paper is to examine students' opinions about the impact of AI on their achievements. To accomplish the goal of this paper, a survey of students was conducted to see how many of them use AI and how its use affects the learning outcomes. The results of the survey give us information of students' opinion of how AI helps in dealing with new challenges when mastering newly learned material. The students' opinions will be supported and confirmed by a detailed analysis of the impact of AI on student achievement which will be made in the future in a much larger study conducted through testing before and after learning with AI. This research is just the beginning of the overall idea that needs to be realized in the future.

2 Literature Review

Research related to AI is done before as (Saliu & Ramadani, 2024) in their paper collected some data from students from Southeast European University in Tetovo to see for what purposes in academia they use AI. (Gašić et al., 2024) present the current implementations of AI in education, the technologies enabling its application and the experiments conducted in educational environments. The focus is on adaptive systems, virtual tutors and learning analytics, which contribute to improve the educational process. AI offers opportunities to tailor content based on student progress and learning styles (Holmes et al., 2019). Anyway, there are challenges in the application of AI in education, including ethical concerns, security, way of usage, privacy, etc. Further research is needed for adaptation of AI systems in various educational environments and cultures (Aoun, 2017). (Brtka et al. 2023) in their paper explore the impact of AI on online education, highlighting its ability to personalize the learning, automate teacher tasks and enhance student engagement. Authors predict significant benefits from the application of AI in educational environments, such as customized assessments and increased interaction. Additionally, the paper compares the evaluation of knowledge retention and interaction between AI systems and human instructors. The technical and ethical challenges accompanying the implementation of AI in educational processes are also emphasized. Huang et al. (2021) evaluated the application of AI in education, highlighting its positive impact on the quality of the teaching and the learning process. The authors demonstrated how AI can be applied in methods such as adaptive learning, assessment and virtual classroom management, thereby improving student engagement and creativity. Additionally, the paper addresses the challenges that AI may face in the educational sector in the future, emphasizing the importance of reforming the educational system through the introduction of innovative technologies. (Krstić et al., 2022) explored the automation of tasks such as grading. The paper emphasized the advantages of AI usage, including increased efficiency and flexibility in meeting educational needs. Additionally, there is a growing interest for AI in education, with predictions of a significant rise in the use of this technology in the coming years, especially considering the challenges brought by the COVID-19 pandemic. This paper contributes to the understanding of that how AI can transform the traditional educational practices.

3 Methodology

For the purpose of this paper, the survey for the use of AI, for students from the technical faculty at Goce Delcev University was done through a questionnaire which can be seen in Appendix A. As an opportunity to see the situation of the AI usage, we conducted an examination of the students through anonymous questionnaire. The students were from different study years with a total number of 50 students, which gave us a clear understanding of the students' opinion for their readiness for working with AI. The questionnaire itself consists of 15 questions. The research includes students from different socio-economic backgrounds which means that the ability to own electronic devices and the internet is not equal for everyone. The students are also of different ages. In context of the analysis, a clear division into genders is made, in order to show trends in AI between the male and female students. In the end of the paper, conclusions from the results are drawn and an idea for change in the learning process is provided.

4 Results and Discussion

The popularity of AI in recent times gave us an idea for research in which we want to see its significance in the educational process. To realize our idea, a questionnaire with 15 questions related to AI was created. 50

students answered the questionnaire. Some data about the students included in the conducted survey can be found in Table 1.

Table 1. Group structure

Group structure		Number of students
Age	18-23	44
	other	6
Gender	Female	25
	Male	25
Total number of students in the group		50

The first question in the questionnaire is about the availability of internet in students' homes. Students who have access to internet at home have easier way of mastering various computer applications including AI tools that they encounter in the learning process. The results of the responses are: 37 yes, and 13 no. In context of the gender the results are: Female 15 yes and 10 no, and male 22 yes and 3 no.
The second question is about the use of AI at faculty. The students' answers to this question are divided. 25 students answered with yes, and 25 answered no. In terms of gender 11 female students are with answer yes and 14 with no, and male students are with 14 yes and 11 no.
The third question is about the use of AI at home, female students are with 9 yes and 16 no answers and male students responses are 18 yes and 7 no, or the total yes is 27 and the total no is 23.
The data from the questionnaire regarding the answers of the fourth question for possession of a laptop, a desktop computer, smartphones, tablets and other electronic devices are: both girls and boys have some kind of electronic device, so the answers are 50 yes and 0 no.
According to the responses, all 50 students used AI during the last three months. So, 50 answers are yes and 0 are no.
In terms of the period before the last three months, it can be seen from the responses that AI was used, but not 100 percent, as the responses showed that 21 females and 22 males used AI.
Almost everyone want to use AI while studying for exams in examination session except 13 students (10 girls and 3 boys) who stated that they do not have internet at home.
From the answers to the eighth question, it can be seen that mostly of the students use AI from 1 to 2 hours, which is not a lot of time (Figure 1). As an explanation of the answers, they said that for educational purposes they use AI for a short period of time because they get the answers quickly. So, it doesn't take so much time to set the problem and get a response back containing a solution to the given problem. The answer a) is circled from 19 female students, b) 6 and c) 0, and from the male students 24 circled a), only 1 b) and 0 c).

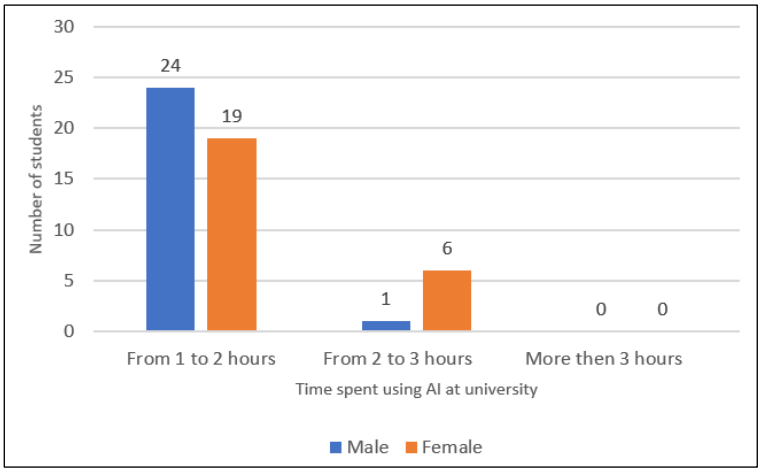


Figure 1. Time spent using AI while studying at the university

Since using AI does not require programming knowledge, learning to use tools, prior preparation, etc., it can be said that there are almost no difficulties in use, so the answers for the ninth question is 45 no and only 5 yes. 3 male and 2 female students reported that they have difficulty with logging into ChatGPT.

About the desire to use AI, according to the results we can say that it is not represented among all students, because 10 responded that they had no desire to use AI because it was not interesting to them, and they found it an unproductive waste of time because they received an answer that meant nothing to most of them if there was no teacher to explain the answer. But, the other 40 students, 22 male and 18 female say that they have a desire and use AI very often.
For the next 5 questions that provide the clearest understanding of the impact of AI on student achievement, we have the following results:
In the end of the semester in which students did not have a recommendation to use AI, the results for failed exams from female students are c) 18, d) 2, a) 1 and b) 4 and for male c) 14, d) 4, a) 2 and b) 5 (Figure 2).
In the end of the semester in which students have a recommendation to use AI the results for failed exams for female students are c) 1, d) 2, a) 18 and b) 4 and for male students are c) 1, d) 1, a) 18 and b) 5 (Figure 2).

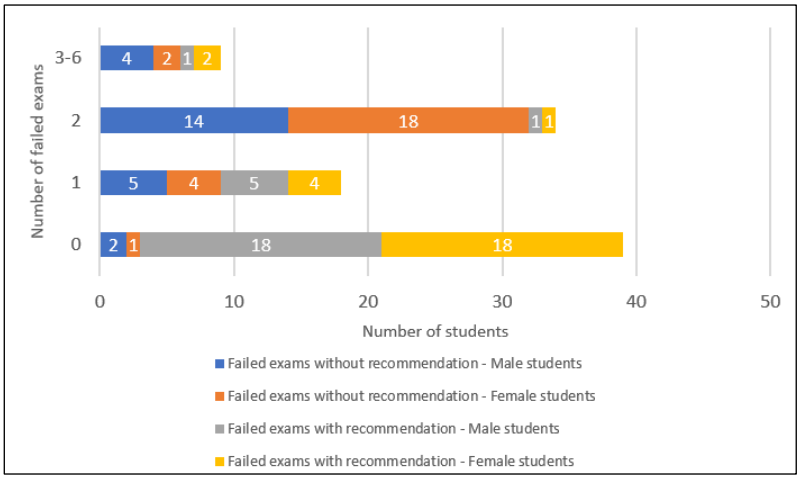


Figure 2. Failed exams with and without recommendation to use AI

After the end of the semester in which the students did not have a recommendation to use AI, the results for number of passed exams for female students are c) 1, d) 20, a) 1 and b) 3 and for male students are c) 3, d) 18, a) 0 and b) 4 (Figure 3).
After the end of the semester in which the students had a recommendation to use AI, the results for the number of passed exams for female students are c) 0, d) 24, a) 0 and b) 1 and for male students are c) 4, d) 20, a) 0 and b) 1 (Figure 3).

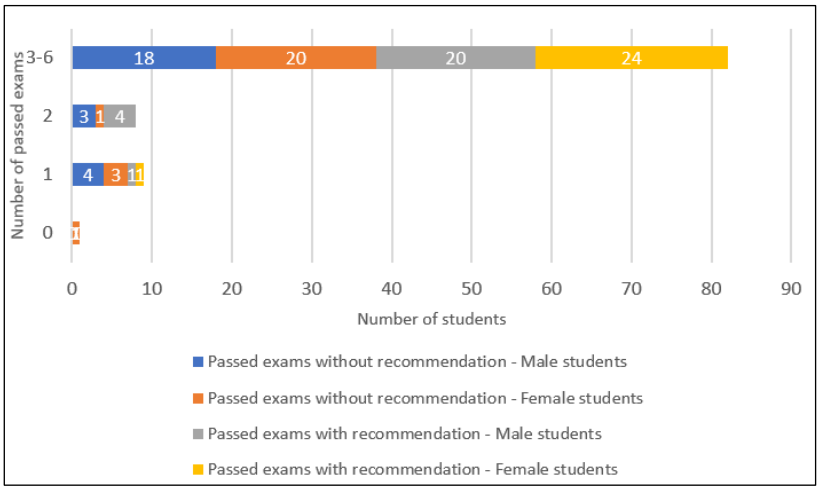


Figure 3. Passed exams with and without recommendation to use AI

Regarding the exams for which the students did not have the courage to register them after finishing the semester in which there was no recommendation to use AI, the answers from female students are c) 18, d) 2, a) 1 and b) 4 and from male students are c) 14, d) 3, a) 2 and b) 6.
From the results, the students say that AI helps them to achieve better results in exam sessions expressed through passing multiple exams. So as an idea from this survey, we can say that it is good for students to use AI because the learning is easy, more interesting, simpler, richer with content which cannot be find in the books, etc. AI could transform the traditional educational process into modern learning.
From the results, it can be also seen that the trend of AI usage between female and male students is just the same. Maybe the boys have a greater desire to use AI, but also the female students are also showing interest in using AI. In terms of the age of the students there was no difference in the usage of AI because all students included in the survey want to use it.
This research is preliminary i.e., it is an initial work as a part of a larger research in which in addition to student opinions, achievement of students in exam sessions after learning with and without AI will be analyzed. Then, students will have to solve a test with exercises from the topics studied in mathematics subjects before and after using AI. The limitations of this study include the limited number of surveyed students and the subjectivity of the responses.

5 CONCLUSION

The educational process nowadays is often aided using software, AI, calculators, search engines, etc. The learning with AI provides personalized support for the students. Students say that AI allows them to adjust the content of learning according to the needs. However, in general, the use of AI in the learning process brings several benefits and challenges that can affect the way in which students learn. AI can be beneficial for students because they can access the learning content at any time and from anywhere. The use of AI in the learning process helps to create more accessible and efficient educational environment for students. By using AI they could better solve the problems and achieve better results such as passing more exams than when they only use traditional lecture based learning. From the survey, can see that when the students use AI, they feel more prepared for exams, register more exams, and pass more of them.

Based on this research, an idea emerges for a change in the teaching process by advising students to use AI at home as well as in practice classes for help when they have something complex to solve alone.

In future research, we plan to broaden this study with obtaining results through solving a test with exercises from the topics studied in mathematics subjects before and after using AI.

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APPENDIX A: QUESTIONNAIRE - A LIST OF QUESTIONS
Questionnaire related to AI
Circle one answer:

1. Do you have internet at home?
   Yes No

2. Do you use AI at faculty?
   Yes No

3. Do you use of AI at home?
   Yes No

4. Do you have a device which can be used for accessing AI tools?
   Yes No

5. Did you use AI in your learning in the last three months?
   Yes No

6. Did you use AI in your learning in the period before the last three months?
   Yes No

7. Do you want to use AI while studying for your exams in examination session?
   Yes No

8. How much time did you spend using AI while studying at the university?
   a) From 1 to 2 hours b) From 2 to 3 hours c) more then 3 hours

9. Is it difficult for you to use AI?
   Yes No

10. Do you want to use AI for everything you need?
    Yes No

11. How many failed exams were there after the end of the semester in which you did not have a recommendation to use AI?
    a) 0 b) 1 c) 2 d) 3-6

12. How many failed exams were there after the end of the semester in which you have recommendation to use AI?
    a) 0 b) 1 c) 2 d) 3-6

13. How many exams were passed after the end of the semester in which you did not have a recommendation to use AI?
    a) 0 b) 1 c) 2 d) 3-6

14. How many exams were passed after the end of the semester in which you have a recommendation to use AI?
    a) 0 b) 1 c) 2 d) 3-6

15. How many exams did you not have the courage to register for after finishing the semester in which there was no recommendation to use AI?
    a) 0 b) 1 c) 2 d) 3-6

Impact of Mobile Phone Ban on Student Discipline and Socialization: A Longitudinal Study in Serbian Schools

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Abstract. The rapid expansion of mobile technologies has transformed contemporary education, positioning mobile phones as both educational tools and sources of distraction. In recent years, Serbian schools have increasingly introduced regulations banning mobile phone use during school hours in order to improve student discipline, attention, and social interaction. This paper presents a longitudinal study examining the impact of a mobile phone ban on student discipline and socialization in primary and secondary schools in Serbia. The research was conducted in two phases during the implementation of the national regulation on mobile phone use. Data were collected through anonymous questionnaires completed by students, teachers, and parents. The first survey was administered immediately after the introduction of the ban (N = 11590), while the second survey was conducted one month later (N = 10660). The study analyzes changes in attitudes toward the ban and perceived effects on classroom behavior and social interaction. The results indicate a significant shift in attitudes over time. Student resistance to the ban decreased, while support among teachers and parents increased. The findings suggest improvements in classroom discipline, student focus, and peer communication, as well as a stronger perception of positive socialization effects. The study highlights the complex role of digital technologies in education and suggests that, in the current educational context, restricting mobile phone use can function as an effective pedagogical intervention with positive social and disciplinary outcomes.

Key words and phrases: mobile phones, school discipline, socialization, digital technologies, education, longitudinal study

1 INTRODUCTION

The accelerated development of digital technologies has profoundly influenced contemporary education, reshaping teaching methods, learning environments, and student behavior. Over the past two decades, educational systems have increasingly emphasized the integration of information and communication technologies (ICT) in order to enhance learning outcomes and align education with the demands of a digital society. Among these technologies, mobile phones have become the most widely used and accessible digital devices, particularly among children and adolescents. Although mobile phones offer numerous educational possibilities, their presence in schools has raised significant pedagogical and social concerns (Hercog, 2023). Excessive and uncontrolled use of mobile devices has been associated with decreased attention, reduced academic engagement, and an increase in disciplinary problems. Furthermore, mobile phones have contributed to the emergence of new forms of digital misconduct, including cyberbullying, unauthorized recording, and the misuse of social media during school hours. These challenges have intensified discussions regarding the appropriate role of mobile technologies in formal education (Đukić Popovic et al., 2023).

In the Serbian educational context, the issue of mobile phone use in schools has become particularly prominent in recent years. As early as 2022, the need to limit mobile phone use or introduce strictly defined rules

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regarding their application in school settings was recognized (Hercog, 2023). While mobile devices were initially perceived as potential tools of modern educational practice, they increasingly began to be viewed as obstacles to the development and progress of young people (Đukić Popovic et al., 2023). Following a series of pedagogical and safety concerns, many primary and secondary schools introduced regulations that restrict or completely prohibit the use of mobile phones during classes and school breaks. This shift marks a transition from earlier approaches that promoted mobile devices as learning aids toward a more restrictive model aimed at restoring classroom discipline and strengthening interpersonal communication among students (Popovic et al., 2023). The widespread adoption of mobile phones is unprecedented in the history of technological devices. Ling (2004) emphasizes that one of the most common arguments for mobile phone use is the perception of security and protection. Security has become an integral part of the social image of mobile phones, shaping how individuals integrate them into everyday life (Nasar et al., 2007). Parents often justify providing children with mobile phones based on safety concerns, while children use the same argument to advocate for ownership (Relja, 2012). However, research highlights the paradoxical nature of this perceived security. While mobile phones enable users to call for help, they may simultaneously encourage riskier behavior and increased exposure to potentially dangerous situations (Gordon, 2002). Moreover, mobile phone use reduces awareness, distracts attention, slows reaction time, and increases the likelihood of accidents, particularly traffic accidents among young people (Milisa, 2006).

Another significant concern related to mobile phone use among youth is the emergence of digital violence. Cyberbullying represents a new and particularly harmful form of violence facilitated by digital technologies (Campbell, 2005). Compared to face-to-face violence, digital harassment can have prolonged and repeated psychological effects, as harmful messages can be revisited multiple times (Butler el al., 2010). Furthermore, digital violence can occur at any time, often invading the perceived safety of the home environment and intensifying feelings of helplessness among victims (Stanic, 2007). Mobile phone use simultaneously expands young people's sense of freedom while also extending parental supervision and control. Unsupervised or excessive use during developmental stages can have long-term consequences for social behavior, emotional development, and overall well-being (Đukić Popovic et al., 2023). Prior to the COVID-19 pandemic, some studies argued that mobile devices themselves are not the direct cause of violence among youth and that bans alone would not reduce problematic behavior; rather, preventive pedagogical approaches were considered essential (Andevski, 2019). At the same time, numerous authors emphasized the positive and innovative potential of mobile phones as educational tools (Matijevic, 2014). However, following the pandemic period and a series of concerning incidents in Serbian schools, public and professional discourse increasingly shifted toward more restrictive measures. Teachers and educational professionals began to observe that the negative consequences of uncontrolled mobile phone use such as cheating during tests, misuse of applications for completing assignments, unauthorized audio and video recordings, and signs of digital dependency often outweighed their potential educational benefits (Đukić Popovic et al., 2023). In 2024, the majority of schools in Serbia adopted regulations implying a complete ban on mobile phone use during school hours. Despite the growing number of schools implementing such measures, empirical evidence regarding their longitudinal effects on student discipline and socialization remains limited. Most studies focus on short-term outcomes or single stakeholder perspectives without including students, teachers, and parents simultaneously (Nasar et al., 2007). Therefore, systematic research is needed to examine how mobile phone bans influence discipline, peer interaction, and overall school climate over time. (Đukić Popovic et al., 2025)

The aim of this study is to analyze the impact of a mobile phone ban on student discipline and socialization in Serbian primary and secondary schools using a longitudinal research design. The study is based on two large-scale surveys conducted at different stages of the ban's implementation and includes the perspectives of students, teachers, and parents. In the following sections, the methodology, review of previous research, and the most recent findings from schools within the School Administrations in Belgrade and Niš where mobile phones were completely excluded not only during classes but also during breaks and extended school activities are presented. By examining changes in attitudes and perceptions over time, this research contributes to the ongoing debate on the role of digital technologies in education and provides evidence-based recommendations for educational policy and school practice.

2 RESEARCH METHODOLOGY

2.1. Research Design

This study was designed as a longitudinal empirical research aimed at examining the impact of banning mobile phone use on student discipline and socialization in Serbian schools. (Đukić Popovic et al., 2024) The research represents a continuation and expansion of previously conducted studies that examined the role of mobile phones in education, student discipline, and social interaction. Earlier research provided initial insights into the challenges of mobile phone use in schools and identified emerging pedagogical and disciplinary issues. Building on these findings, the present study adopts a longitudinal approach in order to capture changes in attitudes and perceptions over time following the implementation of a comprehensive mobile phone ban. A comparative research design was applied to analyze attitudes and perceptions of key stakeholders at two different points in time: immediately after the introduction of the mobile phone ban and one month after its implementation. This approach enables a deeper understanding of short-term effects and allows for comparison with earlier research phases in which mobile phone use was either partially regulated or permitted. (Jevtic et al., 2011) The research was conducted within the framework of the School without Mobile Phones initiative, a pilot pedagogical project that evolved from earlier experimental practices implemented by individual teachers and schools. The initiative gradually expanded into a broader, system-level intervention implemented in an increasing number of primary and secondary schools across Serbia.

2.2. Participants

The research included three categories of participants students, teachers, and parents and was conducted in 2025 through two large-scale surveys carried out during the early phase of the implementation of the national regulation on mobile phone use in schools. The participant structure and sampling strategy were designed to ensure continuity with previous studies conducted in 2024, while significantly expanding the scope and representativeness of the sample. Compared to the 2024 research phase, which examined the initial implementation and immediate reactions to school-level regulations, the 2025 study focused on a broader and more systemically regulated context, allowing for a more comprehensive longitudinal comparison. The first survey was conducted during the first week of September 2025, immediately after the introduction of the ban, and included a total of 11 590 respondents, comprising 5 260 students (45.38%), 710 teachers (6.12%), and 5 620 parents (48.50%). The second survey was conducted one month later, during the first and second week of October 2025, and included 10 660 respondents, with 5 950 students (55.83%), 620 teachers (5.81%), and 4 090 parents (38.36%). Compared to previous research, the substantially increased sample size allows for a more comprehensive examination of trends and strengthens the validity of the findings through broader stakeholder participation.

Table 1. Structure of respondents

No	**First survey**		
	Category of respondents	***Number of responses***	***%***
1	Students	5260	45,38
2	Teachers	710	6,12
3	Parents	5620	48,50
	Total responses	11590	

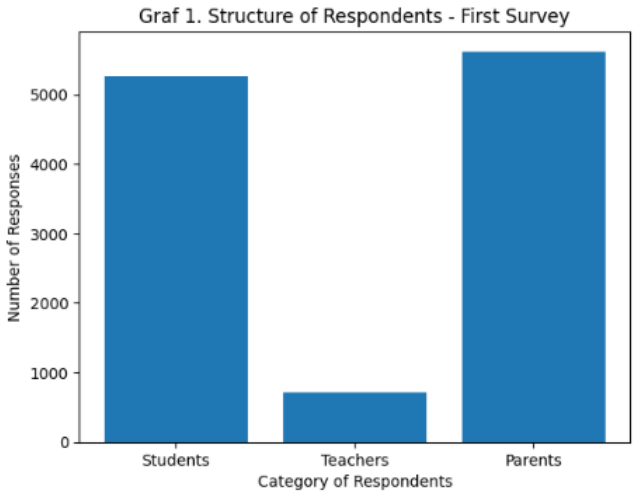
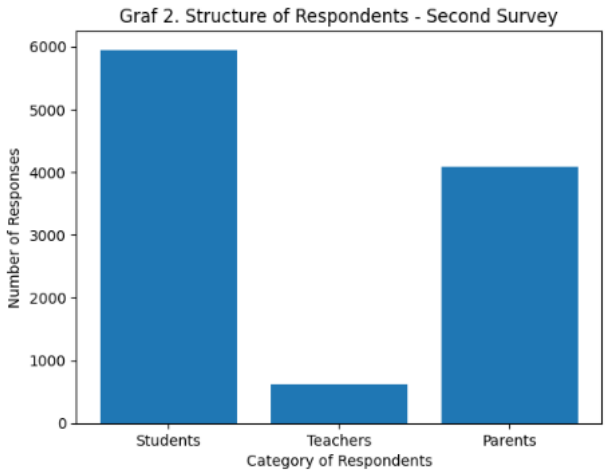


Table 2. Structure of respondents

No	First survey		
	Category of respondents	***Number of responses***	***%***
1	Students	5950	55,83
2	Teachers	620	5,81
3	Parents	4090	38,36
	Total responses	10660	



2.3. Research Instrument

Data were collected using anonymous questionnaires developed specifically for this research and conceptually aligned with instruments used in earlier studies. This continuity enabled direct comparison between previous findings and the current research phase. Separate but structurally aligned questionnaires were designed for students, teachers, and parents to ensure clarity and relevance for each group.

The questionnaires consisted of closed-ended questions focusing on:

-attitudes toward the ban on mobile phone use in schools,

-perceived effects of the ban on student discipline and classroom behavior,

-perceived impact on student socialization, peer interaction, and empathy.

Responses were collected using predefined categorical options, enabling quantitative analysis and longitudinal comparison.

2.4. Procedure

The questionnaires were distributed through schools participating in the School without Mobile Phones initiative. Teachers involved in the project coordinated the distribution process to students and parents, ensuring voluntary participation and anonymity. The research procedure followed the same ethical and organizational principles applied in previous studies, including informed participation and confidentiality of responses. The same research procedure and questionnaire structure were applied in both phases of the study, enabling direct comparison not only between the two surveys but also with earlier research stages. Minor variations in response rates between participant groups were observed in the second survey, particularly among parents and teachers, representing an additional contextual factor for interpretation.

The collected data were analyzed using descriptive statistical methods. Frequencies and percentages were calculated to examine the distribution of responses within and across participant groups. Comparative analysis between the first and second survey was applied to identify changes in attitudes toward the ban and perceived effects on discipline and socialization, while results were interpreted in relation to findings from previous research phases. The results are presented through tables and figures in order to provide a clear and transparent overview of the findings.

3 DATA ANALYSIS

The analysis of questionnaire data focused on examining changes in attitudes toward the mobile phone ban and perceived effects on student discipline and socialization across two research phases. The results are presented through a comparative analysis of responses provided by students, teachers, and parents immediately after the introduction of the ban and one month later. Descriptive statistical indicators were used to identify trends, shifts in perception, and differences among stakeholder groups.

3.1. Attitudes Toward the Mobile Phone Ban

The initial analysis revealed a pronounced divergence in attitudes among the three groups of respondents immediately after the implementation of the ban. In the first survey phase, students demonstrated a strong resistance to the restriction of mobile phone use, with the majority expressing opposition to the ban. In contrast, teachers showed a substantially higher level of support, while parents exhibited divided opinions, with a slight predominance of supportive responses. The second survey phase indicated a significant shift in attitudes, particularly among students. Although opposition to the ban remained present, the proportion of students supporting the restriction increased markedly after one month of implementation. This change suggests an adaptive process in which students gradually adjusted to the new school environment and began to recognize certain benefits associated with reduced mobile phone use. Teachers continued to demonstrate a predominantly supportive stance, while parental support increased considerably, indicating growing confidence in the educational and social effects of the measure.

3.2. Perceived Effects on Student Discipline

Analysis of responses related to student discipline revealed consistent patterns across both survey phases. Teachers reported noticeable improvements in classroom behavior, including increased attention during lessons, reduced disruptive incidents, and fewer conflicts related to unauthorized mobile phone use. These findings were more pronounced in the second survey phase, suggesting that the effects of the ban became more visible over time. Parents similarly reported improvements in student discipline, particularly in terms of reduced dependency on mobile phones during the school day and improved focus on school obligations. While students were initially less inclined to associate the ban with positive disciplinary outcomes, the second survey showed a gradual increase in student acknowledgment of improved classroom order and learning conditions.

Table 3. Perceived Effects on Student Discipline

Respondent Group	Survey Phase	Improved Attention During Lessons	Reduced Disruptive Behavior	Fewer Conflicts Related to Mobile Phones	Improved Classroom Order
Students	First Survey	28.4%	25.1%	22.7%	30.3%
	Second Survey	41.9%	39.6%	37.8%	45.2%
Teachers	First Survey	61.7%	58.3%	63.5%	66.1%

Table 3. Perceived Effects on Student Discipline

	Second Survey	78.4%	75.9%	81.2%	83.6%
Parents	First Survey	52.6%	49.8%	54.2%	57.0%
	Second Survey	70.3%	68.5%	72.7%	74.9%

3.3. Impact on Student Socialization and Peer Interaction

One of the central aspects of the analysis concerned the perceived impact of the mobile phone ban on student socialization. In the first survey, respondents' opinions were relatively evenly distributed between positive, negative, and neutral assessments of the ban's influence on social interaction. A considerable proportion of respondents expressed uncertainty, reflecting skepticism and a lack of immediate observable effects. In contrast, the second survey demonstrated a clear shift toward positive evaluations of the ban's impact on socialization. A majority of respondents across all groups reported enhanced peer communication, increased face-to-face interaction during school breaks, and improved social engagement among students. These changes were particularly emphasized by teachers, who observed reduced isolation among students and greater participation in group activities. Parents also noted improved communication skills and social behavior, while students increasingly recognized benefits related to peer interaction and emotional connection.

Table 4. Impact on Student Socialization and Peer Interaction

Respondent Group	Survey Phase	Positive Impact	Negative Impact	No Significant Impact	Undecided
Students	First Survey	31.2%	34.5%	22.8%	11.5%
	Second Survey	57.6%	21.4%	14.9%	6.1%
Teachers	First Survey	48.9%	27.3%	18.2%	5.6%
	Second Survey	72.5%	12.8%	10.4%	4.3%
Parents	First Survey	39.7%	30.6%	21.9%	7.8%
	Second Survey	68.1%	15.7%	11.3%	4.9%

3.4. Comparative Longitudinal Trends

The longitudinal comparison of the two survey phases highlights a consistent pattern of attitudinal and perceptual change over time. Initial resistance, uncertainty, and concern especially among students gradually gave way to greater acceptance and recognition of positive outcomes. The observed trends suggest that the effects of the mobile phone ban are not immediate but develop progressively as students and other stakeholders adapt to the new school norms. The convergence of student, teacher, and parent perspectives in the second survey phase indicates a growing consensus regarding the positive role of the ban in improving both disciplinary climate and social dynamics within schools. This convergence strengthens the validity of the findings and supports the interpretation of the ban as an effective short-term pedagogical intervention.

3.5. Summary of Key Findings

Overall, the analysis of questionnaire data indicates that:

-student opposition to the mobile phone ban decreases over time,

-support among teachers and parents increases after the initial implementation phase,

-perceived improvements in discipline and classroom behavior become more evident with continued enforcement of the ban,

-positive effects on student socialization and peer interaction are increasingly recognized across all stakeholder groups.

These findings provide a strong empirical basis for further discussion on the role of mobile phone regulation in schools and its implications for educational practice.

4 DISCUSSION

The findings of this longitudinal study indicate that the introduction of a mobile phone ban in schools produces measurable positive effects on student discipline and socialization over a relatively short period of time. The observed changes in attitudes and perceptions among students, teachers, and parents suggest that the initial resistance to the ban gradually diminishes as school communities adapt to the new rules and experience their practical implications. (Milicic et all. 2026) One of the most significant findings of this research is the dynamic nature of student attitudes. While strong opposition was evident immediately after the implementation of the ban, the second survey revealed a substantial shift toward acceptance. This change may be interpreted as a process of behavioral and social adjustment, during which students begin to recognize the benefits of a learning environment with fewer distractions and increased opportunities for direct interpersonal interaction. Similar patterns have been reported in previous studies addressing behavioral regulation and digital dependency among students, indicating that restrictive measures often require a period of adaptation before their positive effects become visible.

Teachers' responses consistently emphasized improvements in classroom discipline, student focus, and communication. These findings align with earlier research highlighting the challenges teachers face when managing classrooms in which mobile phones are freely accessible. The reduction of conflicts related to unauthorized phone use and the elimination of distractions associated with social media and digital content appear to contribute to a more stable and predictable teaching environment. Parents' growing support further reinforces the perception that the ban positively affects not only academic engagement but also students' social behavior and emotional well-being.

The results related to socialization are particularly noteworthy. Increased face-to-face interaction, improved peer communication, and reduced social isolation were reported more frequently in the second research phase. These findings suggest that limiting mobile phone use creates conditions that encourage spontaneous social interaction and cooperative behavior among students, which are essential components of social development. In an educational context increasingly shaped by digital communication, such outcomes highlight the importance of preserving spaces for direct human interaction.

From a broader perspective, the findings of this study support the view that regulating mobile phone use in schools should not be understood as a rejection of digital technologies, but rather as a pedagogically justified measure aimed at restoring balance between technological innovation and fundamental educational values. While digital tools undoubtedly have an important role in modern education, their use must be clearly structured, purpose-driven, and developmentally appropriate.

Based on the convergence of positive outcomes observed in this study, it can be argued that implementing a mobile phone ban at the national level would be a purposeful and effective measure. A uniform, state-level regulation would ensure consistency across schools, reduce ambiguity in rule enforcement, and support teachers and school administrations in maintaining disciplinary standards. Moreover, such a measure has the potential to contribute to an overall improvement in the educational climate by fostering better discipline, stronger social relationships, and a more focused learning environment throughout the education system.

5 CONCLUSION

This longitudinal study examined the impact of a mobile phone ban on student discipline and socialization in Serbian primary and secondary schools. By analyzing data collected from students, teachers, and parents at two different points in time, the research provides insight into both immediate reactions and short-term developmental changes following the implementation of the ban. The findings demonstrate that initial resistance particularly among students decreases over time, while recognition of the positive effects of the ban increases. Improvements were observed in classroom discipline, student focus, and interpersonal communication, as well as in overall social interaction during school activities and breaks. These results suggest that the benefits of restricting mobile phone use are not instant but become more evident as students adapt to the new learning environment. The study also confirms that teachers and parents play a key role in evaluating the effectiveness of such measures. Their growing support indicates increased confidence in the ban as a means of improving both the educational climate and students' social development. The convergence of perspectives among all stakeholder groups strengthens the validity of the findings and underscores the relevance of the mobile phone ban as a pedagogical intervention. Although mobile phones can function as valuable educational tools, the results of this research indicate that their unrestricted use in schools currently poses significant challenges to

discipline and socialization. In this context, restricting mobile phone use should be viewed not as a rejection of digital technologies, but as a necessary step toward creating a more balanced and developmentally appropriate educational environment. Overall, the findings support the conclusion that a clearly defined and consistently applied mobile phone ban can contribute to improved discipline, enhanced social interaction, and a more focused learning atmosphere. Implementing such a policy at the national level would ensure uniform standards across schools and could lead to a broader improvement in the quality and stability of the educational system. Future research should focus on long-term effects and explore models for integrating digital technologies into education in a controlled and pedagogically justified manner.

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Quantum Computers: Foundations, Computational Potential, and Opportunities for Education

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Abstract. Quantum computers represent a fundamentally new computing paradigm, exploiting quantum physics to process information in ways that differ from classical systems. Unlike classical bits, which exist in states 0 or 1, quantum bits (qubits) can exist in superposition and become entangled, enabling correlated behaviour across multiple qubits.

This paper provides an accessible overview of key principles, including qubits, superposition, entanglement, quantum gates, and measurement, using intuitive explanations supported by elementary linear algebra. The discussion also addresses technological challenges, such as noise and error correction, as well as potential computational advantages and application areas where quantum computers may outperform classical systems.

From an educational perspective, quantum computing presents both opportunities and challenges. It offers a novel framework for conceptual understanding and problem-solving, but also introduces complexities that make curriculum integration difficult. The paper concludes by emphasizing strategies to make the quantum computing conceptually accessible and engaging, supporting students and educators in exploring this emerging technology as both a powerful computational tool and a rich learning domain.

Key words and phrases: Quantum Computing, Emerging Technology, Educational perspective.

1 INTRODUCTION

The history of computing has been characterized by successive waves of technological transformation. From the earliest vacuum-tube machines of the 1940s to the silicon-based microprocessors that power contemporary devices, each era has brought dramatic gains in speed, miniaturization, and affordability. These advances were famously anticipated by Gordon Moore, whose 1965 observation, that the number of transistors on a chip doubles approximately every two years, served as a reliable engineering roadmap for decades. Yet as transistor dimensions approach atomic scales, both physical and economic limits are constraining further progress along this trajectory, (Theis & Wong, 2017). The semiconductor industry now faces a genuine inflection point, one that has intensified interest in radically different computational models.

Quantum computing has emerged as one of the most promising of these alternatives. Rather than encoding information as binary digits constrained to the values zero or one, quantum computers exploit the principles of quantum mechanics to process information in fundamentally new ways (Nielsen & Chuang, 2010). The quantum bit, or qubit, can exist in a superposition of states, and pairs of qubits can become entangled, a phenomenon with no classical analogue, in which the state of one qubit is correlated with another regardless of the physical distance between them. A third key resource, quantum interference, allows certain

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computational paths to be amplified while others are suppressed, enabling algorithms that converge on correct answers more efficiently than their classical counterparts, (Rieffel & Polak, 2011).

These properties collectively open paths that classical architectures cannot pursue. Shor's algorithm, for instance, demonstrated that a sufficiently powerful quantum computer could factor large integers in polynomial time, a result with profound implications for public-key cryptography (Shor, 1994). Grover's algorithm provided a quadratic speedup for unstructured search problems (Grover, 1996). Beyond cryptanalysis and search, quantum simulation uses a quantum device to model other quantum systems and offers the prospect of accelerating drug discovery, materials science, and fundamental physics research.

Alongside its technological dimensions, quantum computing carries significant educational implications. It sits at the intersection of physics, mathematics, computer science, and engineering, offering a rich context for developing interdisciplinary reasoning and computational thinking. At the same time, its conceptual demands, particularly concerning the departure from everyday intuitions about measurement and probability, pose genuine pedagogical challenges, (Greinert et al., 2023).

The educational landscape surrounding quantum computing has grown rapidly in recent years. Studies across multiple continents have examined how to build quantum-ready curricula at every level of education. At the undergraduate level, Asfaw et al. (2022) and Aiello et al. (2021) offer detailed frameworks for quantum engineering programs, while Mykhailova & Svore (2020) demonstrate the effectiveness of software-driven approaches. At the global level, Kaur & Venegas-Gomez (2022) surveyed the worldwide landscape of quantum education initiatives, mapping learning pathways across online courses, conferences, games, and community networks designed to build a diverse and sustainable quantum workforce.

This paper addresses both dimensions. It provides an accessible introduction to the core principles of quantum computing, including qubits, superposition, entanglement, quantum gates, and measurement, grounding each concept in elementary linear algebra and geometric intuition. The paper also presents a concrete example of a simple quantum circuit implemented on a real device, illustrating how these abstract concepts can be made tangible. It concludes by examining strategies for integrating quantum computing into educational curricula in a way that is both rigorous and engaging.

2 The Key Principles of Quantum Computers

2.1 Physical Realization of Quantum Computers

Physicists already in the 1980s came to the idea of quantum computers (National Academies, 2019), where some basic quantum mechanical principles (Parshant, 2007) like superposition, entanglement, interference, decoherence, and tunneling are applied. While classical transistors work with bits, quantum transistors work with quantum bits, so-called qubits. A classical bit can be in state 0 or 1, while a qubit can have state 0, 1, or a superposition of these two states. After performing a measurement qubit can only be in state 0 or 1 with a certain probability.

Due to the entanglement, for example, for two isolated qubits even at a large distance, if we measure the state of one qubit, we automatically also know the state of another qubit. These properties of multi-qubits system lead to the possibility of parallel processing and operating on a vast number of input data simultaneously. This can be very effectively applied to cryptography and breaking of the public keys. The phenomenon of interference is used in decision making in quantum computers because the resulting amplitude of probability waves, when amplified lead to correct answers, while no peaks at all lead to incorrect ones. Interaction of isolated qubits with the environment, called decoherence, presents a problem as quantum systems due to it becomes classical ones. So one of the goals of hardware designers is to minimize decoherence of a given quantum system, which is similar to the problem of noise in classical computers.

Practical realization of quantum computers has been performed in a few different ways. Electrons, ions, photons, etc., can be used as a qubit. Based on the technology used to implement and work with qubits, quantum computers can be distinguished as superconducting, photonic, neutral atoms, trapped ions, silicon spin, and so on. Based on the computing model, there are gate-based quantum computing models and analog quantum computing models (adiabatic quantum computing, quantum annealing, and quantum simulation). In this paper, we present a study performed with a superconducting (gate-based) IBM quantum computer.

2.2 Mathematical and Geometrical Representation of Qubits

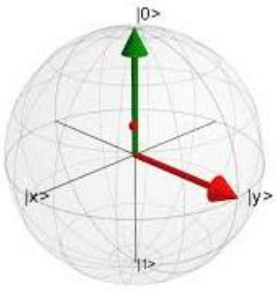
While the physical realization of a qubit depends on the underlying hardware, its logical state and evolution are described using a common mathematical formalism. Independent of the physical platform used to realize a qubit, its logical state and dynamics are presented within a unified mathematical framework, which admits both an abstract Hilbert-space formulation and an equivalent geometric representation using the Bloch sphere (Petrila & Manta, 2013; Wong, 2022).

From a mathematical perspective, a qubit is described as a vector in a two-dimensional complex vector space, known as a Hilbert space. Using the computational basis states $|0\rangle$ and $|1\rangle$, any qubit state can be expressed as a linear combination:

$$|\psi\rangle = \alpha\,|0\rangle + \beta|1\rangle,$$

where α and β are complex numbers representing probability amplitudes. These amplitudes satisfy the normalization condition $|\alpha|^2 + |\beta|^2 = 1$, which ensures that the probabilities of obtaining measurement outcomes sum to one. The physical meaning of a qubit state is independent of an overall global phase factor, meaning that only the relative amplitudes and phase between the basis states influence observable results. Quantum operations acting on qubits are modeled by unitary matrices, which preserve normalization, while measurements are described by projection operators, with outcome probabilities determined according to the Born rule.

The geometric representation of the state space of a single qubit is provided by the Bloch sphere, in which pure quantum states are mapped to points on the surface of a unit sphere, enabling an intuitive yet rigorous description of superposition and phase. In contrast to classical bits, which occupy only two discrete states, qubit states are continuously parameterized by angular coordinates and encompass infinitely many superpositions of the computational basis states $|0\rangle$ and $|1\rangle$, represented by the north and south poles of the sphere (Fig. 1).



[1]

[2] **Figure 1. The Bloch sphere.**

Single-qubit quantum gates correspond to rotations of the Bloch vector about specific axes, with basic quantum gates, marked as Pauli X, Pauli Y, and Pauli Z gates, which implement 180° rotations about the X, Y, and Z axes, respectively. The Hadamard and general rotation gates $R_x(\theta)$, $R_y(\theta)$, and $R_z(\theta)$ produce arbitrary rotations. As these operations are unitary, they preserve the magnitude of the Bloch vector, making the Bloch sphere a concise and powerful framework for analyzing the evolution of single-qubit states in quantum circuits.

3 The Quantum Computers in Education

The rapid development of quantum computing has begun to influence educational practice at multiple levels, extending beyond advanced research contexts into secondary and higher education. Although quantum computers remain under development, existing quantum devices, simulators, and cloud-based platforms already support educational applications. The aim of these initiatives is primarily to foster conceptual understanding, computational thinking, and interdisciplinary competencies related to quantum information science at all levels of education (Nielsen & Chuang, 2010).

At the high school level, quantum computing is typically introduced in an exploratory and conceptual form, often embedded within physics, mathematics, or computer science courses. Instruction focuses on foundational ideas such as qubits, superposition, entanglement, and probabilistic measurement. Educational applications at this level frequently include interactive simulations and simplified quantum programming environments, which allow students to experiment with basic quantum circuits without requiring access to physical hardware.

Also, game-based learning and visualization techniques are increasingly used to introduce abstract quantum concepts in an engaging manner (Seskir et al., 2022). Cloud-based simulators and visual tools are used to support intuitive understanding of quantum phenomena (Hughes et al., 2022). Also, various quantum computer simulators and educational platforms are commercially available and can be purchased for educational use, enabling hands-on experimentation and learning (https://www.spinquanta.com/products/).

At the university level, quantum computing is becoming an established component of curricula in physics, computer science, engineering, and related disciplines. Undergraduate and graduate courses are upgraded to integrate quantum computation with foundational quantum mechanics, covering topics such as quantum gates, algorithms, noise, and error correction (Nielsen & Chuang, 2010). A major educational application is the use of cloud-accessible quantum computing platforms, which allow students to design and execute quantum circuits on real quantum processors. Studies indicate that access to real hardware enhances learning by exposing students to experimental constraints, decoherence, and measurement uncertainty, thereby strengthening the connection between theory and practice (Fox et al., 2020). Platforms such as Qiskit and similar frameworks also support inquiry-based and project-based learning, enabling students to develop quantum programs through experimentation. Quantum computing is also frequently embedded in interdisciplinary projects, where students apply quantum methods to problems in optimization, cryptography, and molecular simulation (Wootton et al. 2020).

For this paper, we will demonstrate one simple example by using a cloud-accessible quantum computing platform. Students can make first steps in the field of quantum computing by performing a simple exercise described in the next section.

4 THE EXPERIMENT

Quantum logic gate (quantum gate) represents a basic quantum circuit. There are several types of such quantum gates, as was said before. Quantum gate works on a small number of qubits. There is a similarity with logic circuits used in electronics. A sequence of quantum gates applied to qubits forms a quantum circuit.

The experiment is performed on the IBM Quantum Platform (https://quantum.cloud.ibm.com/), where it is possible to perform the experiment on a real, remote quantum computer. An account was previously created on this platform to use it. Qiskit software was used for the realization of operations. It is an open-source, Python-based software development kit for designing, simulating, and executing quantum circuits and algorithms on IBM Quantum processors developed by IBM (https://www.ibm.com/quantum/qiskit).

In this paper, we present the use of one quantum gate called the Pauli X-gate. The Pauli X-gate belongs to the basic quantum gates, as it was presented. It gives the same result as a classic NOT gate. It rotates the qubit by 180° on the Bloch sphere around the X axis, (Fig. 2). It performs the following state transformations: $|0\rangle$ to $|1\rangle$, and $|1\rangle$ to $|0\rangle$. The initial value at the input of the circuit, which was used, was $|0\rangle$. On the output, a value of $|1\rangle$ was expected.

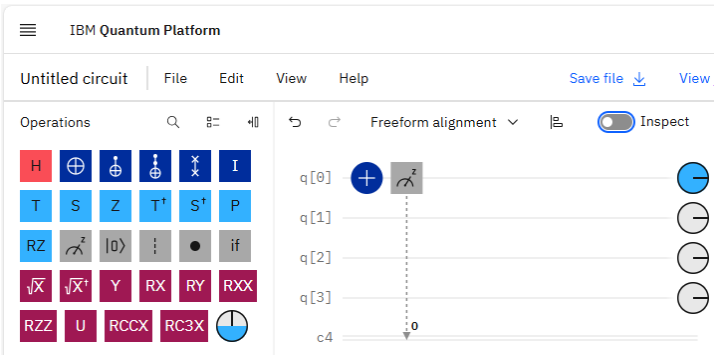


Figure 2. Quantum Circuits containing one Pauli X-gate and one measurement.

We implemented our quantum circuit on a quantum computer labeled ibm_torino (https://quantum.cloud.ibm.com/computers?system=ibm_torino), which has 133 qubits.

The mathematical representation of the operation we expect can be written as follows:

$$X|0\rangle = \begin{bmatrix} 0 & 1 \\ 1 & 0 \end{bmatrix} \begin{bmatrix} 1 \\ 0 \end{bmatrix} = \begin{bmatrix} 0 \\ 1 \end{bmatrix} = |1\rangle$$

The Bloch sphere was used to illustrate the situation (by using Qiskit software). Fig. 3 shows the states before the transformation (left) and after the transformation (right).

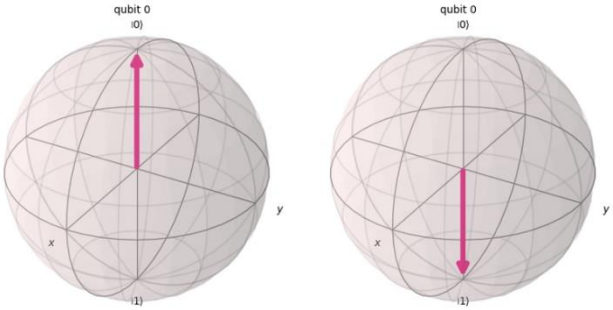


Figure 3. The state before applying the Pauli X-gate (left) and after applying the Pauli X-gate (right).

After this work was completed obtained results are shown on the Fig. 4. It can be seen that a correct result $|1\rangle$ was obtained in 872 cases and an incorrect result $|0\rangle$ in 152 cases. There were a total of 1024 attempts, so in 85.16% of cases, the correct result was obtained after execution.

Job results ×

Measurement outcome	Frequency
0000	152
0001	872

Figure 4. Job results.

5 CONCLUSION

Quantum computing redefines the way information can be represented and processed, moving beyond classical binary logic toward a framework grounded in the principles of quantum mechanics. Instead of emphasizing only the underlying phenomena, this paper has highlighted how these principles such as: superposition, entanglement, and interference, translate into concrete computational models, supported by both mathematical formalism and geometric interpretation through the Bloch sphere. The presented example of implementing a Pauli X-gate on a real quantum device illustrates how theoretical constructs can be operationalized, while also revealing practical limitations such as noise and imperfect measurement outcomes.

Rather than viewing quantum computing solely as a future technological breakthrough, it is equally valuable to consider its role as an educational medium. Engagement with quantum concepts encourages new forms of reasoning, particularly in dealing with probabilistic systems, abstract representations, and non-classical logic. At the same time, the inherent conceptual difficulty of the subject requires carefully designed pedagogical approaches that balance rigor with accessibility.

The increasing availability of cloud-based quantum platforms and interactive tools creates opportunities to incorporate hands-on experiences into teaching, allowing learners to experiment with authentic quantum systems. Cloud-accessible platforms and open-source frameworks such as IBM's Qiskit allow students to design, simulate, and execute quantum circuits on real quantum hardware, supporting experiential and inquiry-based learning. In this sense, quantum computing serves not only as an object of study but also as a catalyst for developing interdisciplinary thinking and modern scientific literacy. Continued efforts toward curriculum

design, resource development, and teacher support will be essential for making this field approachable and meaningful across different levels of education.

Across educational levels, quantum computing applications function less as direct training and more as a mode for developing higher-order cognitive skills and interdisciplinary problem-solving. By engaging learners with authentic tools and emerging technologies, quantum computing in education supports a forward-looking approach to STEM learning and contributes to the preparation of students for future scientific and technological landscapes.

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Software Ports and Secure Communication in Operating Systems

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Abstract. This paper examines software ports as a fundamental mechanism for communication between applications and the operating system, with an emphasis on security aspects in networked environments. The theoretical part presents core operating system concepts, inter-process communication, system calls, and the role of software ports within the TCP/IP model. Transport layer protocols TCP and UDP are analyzed, along with port classification and basic security mechanisms such as firewalls and port scanning. The practical part presents a TCP client-server application implemented in the C programming language using the Winsock library, demonstrating socket creation, connection establishment, data exchange, and connection termination. In addition, basic security mechanisms are implemented, including token-based authentication and connection logging to a file, providing controlled access and monitoring of network communication.
Keywords and phrases: software ports, operating system, TCP/IP, TCP and UDP, sockets, client–server communication, security, authentication, logging.

1 INTRODUCTION

Operating systems (OS) form the foundation of modern computing by managing hardware resources and enabling user interaction with software applications. (Akhtar, 2024) The motivation for this research stems from the critical role that software ports play as essential abstraction layers, allowing the operating system to multiplex network traffic across various applications. In an era of escalating cyber threats, such as DdoS attacks, securing these communication channels is a technical necessity.
This paper introduces core concepts of software ports and their interaction with OS, followed by a C language-based experimental setup to simulate Server-client communication by using Winsock library. Due to the importance of secure communications, a simulation of defense mechanisms against DoS attacks and unauthorized access is also included.

2 THEORETICAL FOUNDATIONS AND RELATED WORK

To ensure a better understanding of this paper, the key theoretical concepts will be explained in the following section.

2.1 Communication between Operating System, Applications and Network

Modern computing systems are founded on the interaction among applications, the operating system, and the network. Applications do not have direct access to hardware resources or input/output devices, rather, they interact with them through well-defined mechanisms: Inter-Process communication and System calls.

2.1.1 Inter-Process communication

Inter-process communication mechanisms are used for transferring data between processes (Venkatamaran, Jagadeesha,/ 2015). There are two fundamental models of Inter-process communication: (M.E. College,2023)

A) **SHARED MEMORY** - In shared memory communication, processes exchange data by reading from and writing to a shared memory space.

B) **MESSAGE PASSING** - Processes communicate by exchanging messages over communication link. Once it is established, data is transferred using basic primitives such as send() and receive().

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While these mechanisms traditionally operate within a single system, network sockets extend the message-passing model to facilitate IPC between processes residing on different hosts across a network, effectively bridging the gap between local computing and remote communication.

2.1.2 System calls

System calls provide an interface to the services made available by an operating system. These calls are generally available as routines written in C and C++. System calls can be grouped roughly into six major categories: process control, file manipulation, device manipulation, information maintenance, communications, and protection. (Silberschatz, 2013) Fundamental system calls are bind(), listen(), accept(),connect(), send()/write(), recv()/read() and close().

2.2 Software ports

To enable reliable packet transmission between client and servers, an additional identifier beyond IP addresses is required. This function is fulfilled by ports, which are included in every network packet together with IP addresses and the data. If IP addresses represent neighborhood addresses, ports represent phone numbers identifying specific recipients. (Jiasheng, 2026)

Ports are 16-bits numbers (ranging 0-65535) and are categorized as follows:

Well-Known Ports (0-1023) – standard services (HTTP, HTTPS, FTP, SMTP)
Registered Ports (1024-49151) – specialized services and applications
Dynamic/Private ports (49152-65535) – temporary ports used by client applications for communication

2.3 TCP/IP Protocol

The Transmission Control Protocol/Internet Protocol suite has become the industry standard method of interconnecting hosts, networks, and the internet. It can be understood as the engine behind the Internet and networks worldwide. Like most networking protocols, TCP/IP is modeled in layers:
Application layer is provided by the program that uses TCP/IP protocol for communication. An application is a user process cooperating with another process, typically on a different host. The interface between this and transport layer is defined by port numbers and sockets. The next layer is Transport layer that provides end-to-end data transfer by delivering data from an application to its remote peer. The most used transport layer protocol is indeed Transmission Control Protocol which ensures connection-oriented, reliable data delivery, prevents duplicate data, and provides mechanisms for congestion and flow control. Following layer is the Internet layer, which provides “virtual network” image of an internet. The most important protocol in this layer is Internet Protocol (IP). The last layer is the Network interface layer, the role of this layer is to be interface to the actual network hardware.

2.4 Security – DoS attack

A secure operating system is an operating system where its access enforcement satisfies the reference monitor concept. The reference monitor concept defines the necessary and sufficient requirements for access control in a secure OS. A firewall is a core security mechanism that regulates traffic between a host and the network. It functions based on rules defining which ports remain open or closed and which traffic types are permitted or blocked.

In this paper, a DoS attack will also be presented, to show how attack affects client-server communications. A Denial of Service (DoS) attack originates from a single machine or source, whereas a Distributed Denial of Service (DdoS) attack is launched from multiple distributed sources, most commonly through a botnet of compromised computers.(Acharya, 2016) The implemented attack represents a Denial of Service (DoS) attack executed from a single source (specifically a Flood attack), where repeated TCP connection requests are generated in a continuous loop, leading to resource exhaustion on the target server and preventing legitimate clients from establishing a connection.

To connect these theoretical foundations with practical security challenges, the following section reviews key research on the evolution of exploits targeting system communication.

Modern OS security relies on the reference monitor concept (Jaeger, 2008), which ensures all access attempts are strictly mediated. However, as Hansman & Hunt (2005) note in their security taxonomy, vulnerabilities often stem from poorly classified attack vectors. Their work highlights that understanding these threats is crucial for building resilient systems that can withstand both local and network-based exploits.
Furthermore, protecting communication endpoints is essential. Paul Congdon (2000) demonstrates that Port-Based Network Access Control (PNAC) is a vital defense, as authenticating devices at the port level prevents unauthorized entry. Integrating such port-level controls with a firewall creates a robust, multi-layered defense that effectively shields OS

services from external interference. Pandey and Saini (2014) analyze vulnerabilities in the TCP/IP suite, highlighting the flaws of its 'implicit trust' design. They categorize key threats like IP spoofing and SYN flooding while evaluating defense tools, including firewalls and IDS, for secure communication. Panjwani et al. (2005) analyzed 48 days of traffic to correlate port scans with actual attacks. Their study confirms that while scans often precede intrusions as an early-warning sign, not every scan results in an immediate exploit, highlighting the need for continuous OS monitoring. Schuba et al. (1997) specifically analyze how these floods exhaust critical operating system resources by saturating connection state tables, a vulnerability that remains a universal threat.

3 METHODOLOGY

This experiment uses a Server-Client-Attacker model in C programming language to demonstrate TCP Client-Server communication and a DoS attack. The Server is a single-threaded Winsock program, vulnerable to blocking I/O and a limited listen() backlog. The Client provides a connectivity baseline via a token, while the Attacker runs a while(1) loop to rapidly saturate the server's connection slots with a TCP flood. By occupying the server's only available thread, the Attacker forces a "Connection Refused" state for the Client, proving how resource exhaustion compromises availability.

4 EXPERIMENAL ENVIRONMENT PREPARATION

The goal of this experiment is to show TCP communication between Client and the Server, to show how to protect the communication with basic token and to show what a simple DoS attack does to this communication. To achieve this goal, three individual programs were written in C programming language. The main program represents Server, that accepts connection from the second program - Client, that sends request. The third program is Attacker, that does DoS attack and turns Client into a victim.
The networking component is implemented using the Winsock 2.2 library, following the standard Berkley Sockets model. The implementation is summarized below:
Socket Lifecycle – The system utilizes a TCP socket created via socket() and bound to port 8888 via bind().
Vulnerability Simulation – The Server enters a passive state with listen(), using a restricted backlog parameter to intentionally simulate vulnerability to connection exhaustion.
Connection Handling – A single-threaded blocking accept() call is used, which becomes the primary target for the DoS attack.
Handshake – Communication is secured via token-based handshake handled through send() and recv() functions.

5 EXPERIMENTAL RESULTS

The experiment confirmed both the effectiveness of the implemented security and the inherent vulnerability of open ports. The Server successfully enforced password-based authentication (Token: 2468), granting access and generating ports_report.txt and connections.log only after a valid handshake. This validated the integrity of the logging and data management mechanisms.

However, during the DoS flooding attack, the server becomes overwhelmed by rapid connection requests. The legitimate client failed to connect, returning WSAGetLastError 10061 (Connection refused). This proves that while authentication secures data, open ports remain a primary vector for service disruption, necessitating additional defenses like firewall filtering or rate-limiting. In the following, screenshots are included in the right order, and programs will be run properly, with steps to guide the reader through this experiment.

Figure 1: The image shows the server listening on port 8888 and the client establishing a secure connection by providing the correct 2468 authentication token.

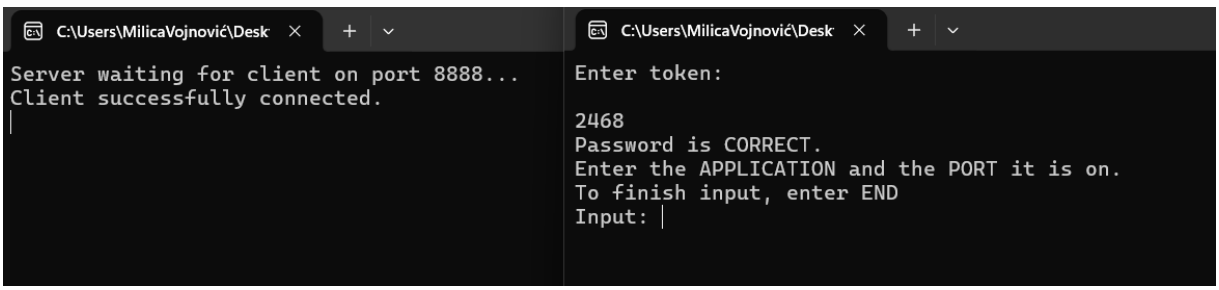


Figure 1 - Successful connection

Figure two: The third step, as indicated by the Client program, is to enter the application and its port:



Figure 2 - Result after the Client finishes with previous input

Figure three: This state represents normal program operation and remains unchanged until the Flooding DoS attack is initiated.



Figure 3 - As a result of DoS attack, Server is unreachable.

Figure four: Error 10061: failed connection.

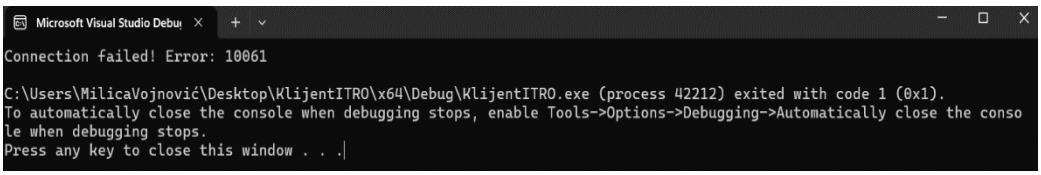


Figure 4-Client`s failed connection to the Server

To provide a quantitative analysis of the system performance, telemetry data was captured during both normal operation and the attack phase.

Metric	Baseline (normal)	During DoS attack
CPU Utilization (%)	3%	6%
Processor Speed (GHz)	1.63 GHz	1.72 GHz
Active Processes	331	343
Connection Status	Successful (Figure 1)	Failed (Figure 4)

Figure 5 – Table: System Performance and Connectivity Metrics

The results demonstrate that even a marginal increase in CPU utilization, from 3% to 6%, results in a total loss of service availability. While the Intel Core i7-1355U was not fully saturated, the legitimate client received a WSAGetLastError (10061) error as shown in Figure 4. This proves that the bottleneck in a single-threaded server architecture is not raw processing power, but the exhaustion of the network backlog queue. Once the attacker's rapid requests fill the OS-level

buffer for pending connections, the accept() function cannot reach legitimate clients. This validates that while authentication secures data, open ports remain a primary vector for service disruption, necessitating defenses like rate-limiting.

6 CONCLUSION

This project successfully demonstrated that while application-level security, such as token-based authentication and connection logging, effectively controls access, it cannot mitigate a DoS flooding attack targeting the operating system's network stack. The experiment proved that an open port remains a primary vector for service disruption, as the single-threaded server's backlog queue was exhausted long before the hardware resources of the i7-1355U were fully utilized.

From an educational perspective, this model serves as a valuable instructional tool for students of computer science and IT. By visualizing the disparity between CPU metrics and service availability, students can better understand the low-level complexities of OS resource management and the "implicit trust" flaws inherent in the TCP/IP suite. This practical approach bridges the gap between theoretical operating system concepts and real-world cybersecurity challenges. To address the limitations identified in this research and fulfill the requirements for further exploration, future work will focus on the transition from attack simulation to proactive defense implementation.

Specifically, the next phase of the project will involve:

Implementation of SYN Cookies: Developing a mechanism in C to handle connection requests without immediate state allocation, thereby mitigating the impact of flood attacks.

Rate-limiting Algorithms: Integrating a "Token Bucket" or "Leaky Bucket" algorithm at the application level to restrict the number of requests from a single IP address.

DDoS Simulation: Expanding the environment to a distributed model (multiple attackers) to test how these defensive mechanisms scale against a coordinated botnet.

By integrating these defensive strategies, the model will evolve into a comprehensive educational framework for studying both offensive and defensive cybersecurity within modern operating systems.

ACKNOWLEDGEMENTS

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Performance Measurement in Concurrent Programming With POSIX Threads

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Abstract. This paper presents an analysis of parallel programming using the POSIX Threads library (pthreads.h) in the C programming language. The main goal of the project is to show the impact of multi-core execution on program performance by comparing sequential and parallel implementation of computationally demanding tasks, as well as understanding the principles of Time Sharing, Task Parallelism and Data Parallelism.

The study focuses on thread creation, their synchronization and load distribution using different methods, with an analysis of the difference in performance between them. Performance measurements were performed by changing the number of threads and analyzing execution time. The results show a significant reduction in execution time when applying parallel execution, especially on multi-core processors, which confirms the advantages of multi-threaded programming.

Additionally, processor performance statistics, including temperature impact and processor load, are monitored using the Linux shell programs htop, glances, and lm-sensors.

The presented project demonstrates that the pthreads library provides an efficient and flexible approach to parallel programming in C, enabling better utilization of modern hardware architectures. This work contributes to a clearer understanding of the concepts of concurrent programming and can serve as a practical example for students and programs interested in optimizing performance using threads.

Keywords: POSIX pthreads, Multithreading, Time Sharing, Task Parallelism, Data Parallelism.

1 INTRODUCTION

Multicore and multithreaded CPUs have become a primary approach for increasing CPU performance. They enable concurrent program design and parallel execution of tasks across multiple cores, which improves overall system performance and reduces execution time (Sodan et al., 2010).

The motivation for this research is based on the importance of understanding the relationship between CPU cores and threads, as well as multithreaded CPU architectures and performance-oriented computing. This research explores fundamental aspects of parallel programming, including task parallelism and data parallelism. The study also analyzes real execution time and CPU time, as well as factors that influence these metrics. Additionally, this research investigates situations in which parallel programming provides performance improvements over sequential execution, and cases where performance gains are limited. Understanding these aspects is important for efficient utilization of modern hardware systems.

2 BACKGROUND

2.1 Sequential Programming

Sequential programming represents a traditional model of computation in which a sequence of instructions is executed step by step by a single processing unit. In this model, each instruction must be completed before the next instruction begins, resulting in predictable and deterministic execution behavior. Because operations are executed in a strictly defined order, sequential programs typically produce consistent results when executed

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multiple times with the same input. This execution model avoids concurrency-related issues such as race conditions and synchronization conflicts (Akl & Nagy, 2009).

2.2 Concurrent Programming

Concurrent programming is a computing model in which multiple tasks can execute during overlapping periods of time. Unlike sequential programming, concurrent programs allow multiple tasks to be active at the same time, even if they are not executing simultaneously on multiple processing units. Concurrent systems often involve multiple threads or processes that require synchronization mechanisms to ensure correct execution. Improper coordination between competing tasks can lead to problems such as race conditions, deadlocks, and resource conflicts.

This model of computing plays a key role in modern software system, enabling efficient multitasking and serving as the basis for parallel execution on multicore architectures (Raynal, 2012; Charpentier, 2022).

2.3 Parallel Programming

Parallel programming is a computing model in which multiple tasks are executed at the same time. Unlike concurrent programming, where tasks may progress during overlapping time periods, parallel programming requires true simultaneous execution.

In sequential programs, processing is usually performed through a single processing location. In contrast, parallel computing allows processing to take place simultaneously in multiple locations, enabling significantly higher computing throughput and improved performance for computationally intensive tasks (Valiant, 1990). Modern multicore processor architectures enable practical implementation of parallel programming by allowing multiple processing units to execute tasks or independent code segments simultaneously (Sodan et al., 2010). Parallel processing can also be achieved through data parallel approaches, where the same operations are applied simultaneously to multiple data elements, improving efficiency for large-scale computations (Hillis & Steele, 1986).

2.4 Task vs Data Parallelism

There are two widely used styles of parallelism in multicore programming: task parallelism and data parallelism. These two paradigms represent different approaches to distributing computational work across multiple processing units and are commonly used to improve performance in parallel applications.

Task parallelism is a type of parallelism in which multiple threads perform separate tasks at the same time. Task parallelism is often used in applications where different operations can be performed independently or organized in processing pipelines.

Data parallelism is a type of parallelism in which multiple threads perform the same task on different data elements. The goal of data parallelism is to divide data into multiple parts that can be processed by different threads. Each thread processes a portion of the data simultaneously. Data parallelism is particularly effective for large data sets where identical computations must be applied to many data elements.

In many practical parallel computing systems, optimal performance is achieved by combining both task and data parallelism. The choice between these approaches often depends on the size of the data set, the structure of the application, and the characteristics of the hardware architecture (Subhlok et al., 1993).

2.5 Performance Metrics – Real Time vs CPU time

When measuring program execution time, two commonly used metrics are real time (wall-clock) and CPU execution time.

Real time represents the total execution duration that includes various system effects such as operating system scheduling, background system activity, resource contention, and I/O related delays (Laba Y., 2019).

Because real time reflects the total time observed externally from program start to completion, it is commonly used to represent user perceived performance and overall system responsiveness.

CPU time is a measurement of actual processor execution time, excluding waiting periods and most external system related delays such as waiting, idle work etc. CPU time represents actual processor utilization and computational effort required to complete a task. (Ehthardt, 2013).

2.6 Thread Based Execution

A thread represents an independent execution unit within a process. Unlike processes, which have separate memory spaces, threads within the same process share the same address space while maintaining their own execution context, including program counter, stack, and register set. Because threads share memory resources, thread creation and context switching are generally more lightweight operations than process management. This makes thread based execution particularly suitable for parallel programming in shared memory systems. (Butenhof, 1993).

Designing a program so that it executes in multiple threads within a process for starters requires a thread creation routine and a way of letting the new thread know where in the program should it begin to execute. POSIX Threads (pthreads) is dividing task into subtasks that can be run interleaved or in parallel or better said Pthreads library provides a standardized model for multithreaded programming in the C. One specific thing for pthread is that it specifies threads starting point as a procedure name unlike other thread packages. This design provides clear control over thread behavior and lifecycle management (Nichols et al., 1996).

The pthread library enables explicit thread creation, synchronization and termination management. Basic functions such as pthread_create() and pthread_join() allow developers to control the lifecycle of threads and coordinate execution flow between them (Barney, 2009).

3 RELATED WORK

Multicore and multithreaded CPU architectures have become a key approach for improving CPU performance. Multicore architectures focus on performance and scalability (Sodan et al., 2010). Their work highlights design trade-offs between sequential processing and thread-level parallelism. The study provides insight into how architectural decisions influence overall system efficiency.

(Akl & Nagy, 2009) present a theoretical overview of parallel computation models and algorithm design approaches. Their work emphasizes the performance advantages of parallel algorithms over sequential ones.

Concurrent objects are entities that can be accessed by multiple processes simultaneously through defined operations (Raynal, 2012) introduces. The work highlights the importance of specifying correct behavior and managing interactions between processes when working with shared resources in concurrent systems.

(Charpentier, 2022) presents fundamental concepts of functional programming, including functions and immutability. The work emphasizes the role of immutability and pure functions in improving code reliability and predictability, which is important in concurrent programming environments.

Parallel computation is a model in which processing occurs simultaneously across multiple locations, enabling higher computational throughput and improved performance (Valiant, 1990). The work highlights the advantages of parallel execution over sequential approaches in computationally intensive tasks.

(Hillis and Steele, 1986) present data parallel algorithms, where the same operations are applied simultaneously to multiple data elements. Their work demonstrates how this approach improves performance, especially for large-scale computations.

In many practical parallel computing systems, optimal performance is achieved by combining both task and data parallelism. The choice between these approaches often depends on factors such as data size, application structure, and hardware characteristics (Subhlok et al., 1993).

(Laba, 2019) focuses on measuring program performance using wall-time. The work explains how real execution time reflects the actual behavior of a program and provides ideas for implementing performance measurement in practice.

(Ehrhardt, 2013) explains how CPU time is measured and how it differs from real execution time. The work helps in understanding processor usage and performance evaluation.

(Butenhof, 1993) focuses on thread-based programming using POSIX threads. The work explains how threads enable efficient parallel execution within a shared memory environment and highlights their advantages over process-based approaches.

(Nichols et al. 1996) present POSIX Threads (pthreads) as a standardized approach for multithreaded programming in C. The work explains how programs can be divided into multiple threads with clearly defined starting routines, enabling efficient concurrent and parallel execution.

(Barney, 2009) presents practical examples of POSIX thread programming, focusing on thread creation, synchronization, and coordination. The work demonstrates how mutexes and condition variables are used to manage shared data and ensure correct execution in multithreaded applications.

(Akhter and Roberts, 2006) explain how multi-core processors enable parallel execution of threads. The work highlights how dividing work across multiple cores improves program performance.

4 METHODOLOGY

The experimental work presented in this study is based on executing computationally intensive CPU tasks using several execution models: sequential execution, task parallelism, data parallelism, and data parallelism with thread scaling. The purpose of this approach is to compare execution behavior and performance characteristics between different parallel programming strategies as well as differences between real time and CPU time. The benchmark workload consists of a CPU intensive task designed to minimize memory and I/O influence. The workload is composed of repeated arithmetic and logical operations including multiplication, addition, modulo operations, bitwise XOR, bit shifting, and bit rotation operations. The workload is executed inside a loop with a total of 5,000,000,000 iterations to ensure measurable execution time and stable performance measurements.

In the sequential execution model, the workload is executed using a single thread, representing a baseline reference for performance comparison. This execution mode allows observation of processor behavior without parallel workload distribution.

Task parallelism is implemented by assigning identical computational workloads to multiple threads, where each thread executes the complete workload independently. Thread creation and synchronization are implemented using POSIX thread mechanisms, allowing simultaneous execution of identical tasks across multiple execution units.

Data parallelism is implemented by dividing the workload into separate data ranges that are distributed among multiple threads. Each thread processes a specific portion of the total iteration range. For example, when using two threads, the first thread processes iterations from 1 to N/2, while the second thread processes iterations from N/2 + 1 to N.

For data parallelism with scaling, the total workload is dynamically divided based on the number of active threads. The iteration range N is divided into equal segments corresponding to the number of threads, and each thread processes its assigned segment independently. This approach enables evaluation of workload distribution efficiency across multiple execution units.

Execution time measurements are performed using the POSIX clock_gettime() function from POSIX time interface. Real execution time is measured using CLOCK_MONOTONIC, while CPU execution time is measured using CLOCK_PROCESS_CPUTIME_ID. These measurements allow comparison between total elapsed execution time and actual processor execution time.

The following images show the program execution alongside system monitoring during runtime. The monitoring tools display per thread CPU utilization, overall processor load, memory usage, and real time temperature readings.

The numbered horizontal bars (0, 1, 2, 3, etc.) represent individual logical CPU threads. Each bar indicates the utilization percentage of specific thread during execution. The aggregate CPU utilization is shown below the per thread indicator, providing an overview of total processor load.

In upper left section of the monitoring interface, temperature values for each core are displayed, allowing observation of thermal behavior during sequential and parallel workloads.

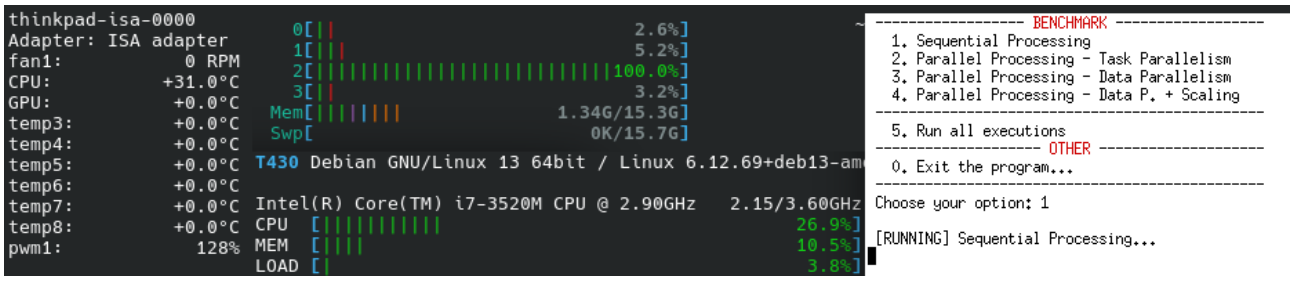


Figure 1. - Sequential Processing on T430 (i7 3520m) - Stats monitoring

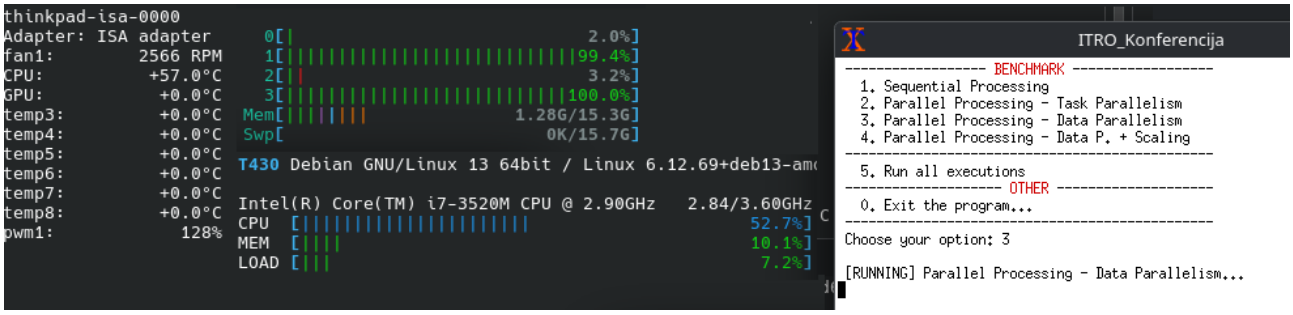


Figure 2. - Data Parallelism on T430 (i7 3520m) - Stats monitoring

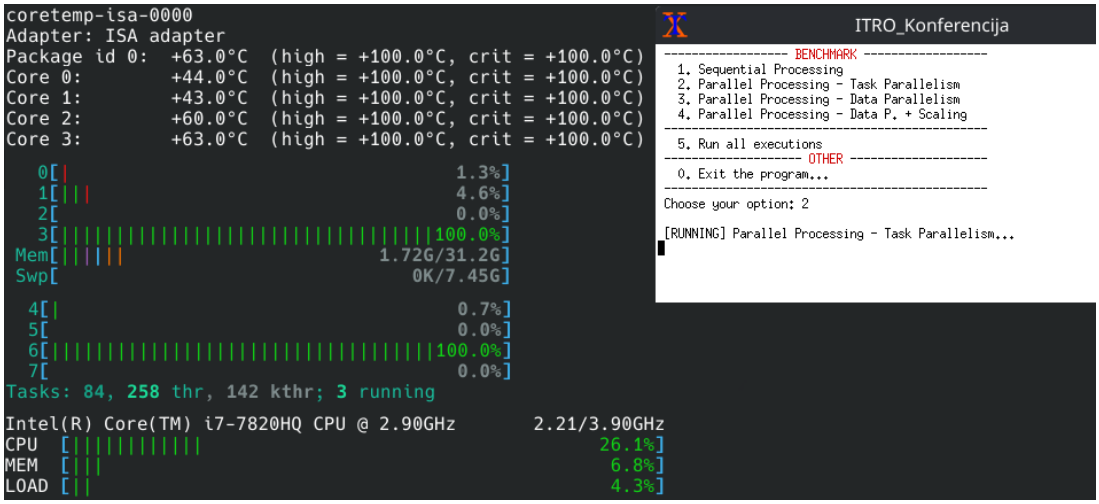


Figure 3. - Task Parallelism on P51 (i7 7820hq) - Stats monitoring

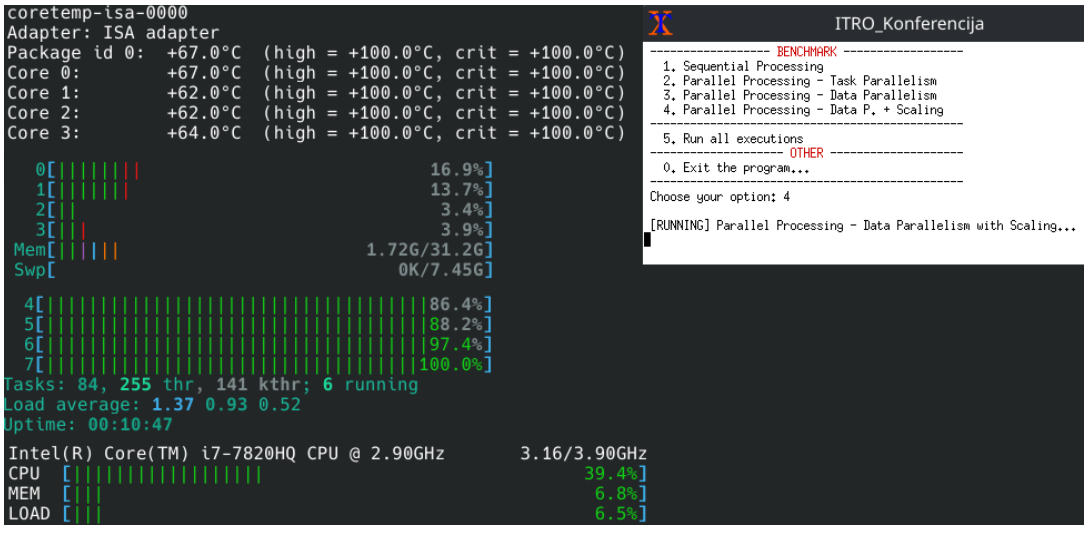


Figure 4. – Data Parallelism + Scaling on P51 (i7 7820hq) – Stats monitoring

The following code segments illustrate the basic implementation of each execution model used in this study, along with the arithmetic and logical operation loop performed by each model.

```c
///---------- SEQUANTIAL PROCESSING ----------
void sequential_processing()
{
    unsigned long long f = 1;
    unsigned long long i;

    struct timespec start_rt, end_rt, start_ct, end_ct;

    printf("\n [RUNNING] Sequential Processing...\n");

    clock_gettime(CLOCK_MONOTONIC, &start_rt);
    clock_gettime(CLOCK_PROCESS_CPUTIME_ID, &start_ct);

    for(i=1; i<5000000000ULL; i++)
    {
        f = f * i;
        f = f ^ (f >> 13);
        f = f + (i % 17);
        f = (f << 7) | (f >> (64-7));
        f = f * (i % 19 + 1);
        if(f > 100000000000000000ULL) f = 1;
    }

    clock_gettime(CLOCK_MONOTONIC, &end_rt);
    clock_gettime(CLOCK_PROCESS_CPUTIME_ID, &end_ct);

    double real_time_1 = (end_rt.tv_sec - start_rt.tv_sec) + (end_rt.tv_nsec - start_rt.tv_nsec) / 1e9;
    double cpu_time_1 = (end_ct.tv_sec - start_ct.tv_sec) + (end_ct.tv_nsec - start_ct.tv_nsec) / 1e9;

    printf(" Real execution time: %f seconds\n", real_time_1);
    printf(" CPU execution time: %f seconds\n", cpu_time_1);
}
```

Listing 1. – Sequential Implementation

```c
void pthread_task_parallelism()
{
    pthread_t thread1, thread2;
    struct timespec start_rt, end_rt, start_ct, end_ct;

    printf("\n [RUNNING] Parallel Processing - Task Parallelism...\n");

    clock_gettime(CLOCK_MONOTONIC, &start_rt);
    clock_gettime(CLOCK_PROCESS_CPUTIME_ID, &start_ct);

    pthread_create(&thread1, NULL, task_tp, NULL);
    pthread_create(&thread2, NULL, task_tp, NULL);

    pthread_join(thread1, NULL);
    pthread_join(thread2, NULL);

    clock_gettime(CLOCK_MONOTONIC, &end_rt);
    clock_gettime(CLOCK_PROCESS_CPUTIME_ID, &end_ct);

    double real_time_2 = (end_rt.tv_sec - start_rt.tv_sec) + (end_rt.tv_nsec - start_rt.tv_nsec) / 1e9;
    double cpu_time_2 = (end_ct.tv_sec - start_ct.tv_sec) + (end_ct.tv_nsec - start_ct.tv_nsec) / 1e9;

    printf(" Real execution time: %f seconds\n", real_time_2);
    printf(" CPU execution time: %f seconds\n", cpu_time_2);
}

///---------- TASK PARALLELISM ----------
void *task_tp(void *arg)
{
    unsigned long long f = 1;
    unsigned long long i;

    for(i=1; i<5000000000ULL; i++)
    {
        f = f * i;
        f = f ^ (f >> 13);
        f = f + (i % 17);
        f = (f << 7) | (f >> (64-7));
        f = f * (i % 19 + 1);
        if(f > 100000000000000000ULL) f = 1;
    }
    return NULL;
}
```

Listing 2. – Task Parallelism Implementation

```c
///---------- DATA PARALLELISM ----------
void pthread_data_parallelism()
{
    unsigned long long N = 5000000000ULL;
    struct timespec start_rt, end_rt, start_ct, end_ct;
    pthread_t t1, t2;
    thread_data_t data[2];

    data[0].start = 1;
    data[0].end = N / 2;

    data[1].start = N / 2 + 1;
    data[1].end = N;

    printf("\n [RUNNING] Parallel Processing - Data Parallelism...\n");

    clock_gettime(CLOCK_MONOTONIC, &start_rt);
    clock_gettime(CLOCK_PROCESS_CPUTIME_ID, &start_ct);

    pthread_create(&t1, NULL, task_dp, &data[0]);
    pthread_create(&t2, NULL, task_dp, &data[1]);

    pthread_join(t1, NULL);
    pthread_join(t2, NULL);

    clock_gettime(CLOCK_MONOTONIC, &end_rt);
    clock_gettime(CLOCK_PROCESS_CPUTIME_ID, &end_ct);

    double real_time_3 = (end_rt.tv_sec - start_rt.tv_sec) + (end_rt.tv_nsec - start_rt.tv_nsec) / 1e9;
    double cpu_time_3 = (end_ct.tv_sec - start_ct.tv_sec) + (end_ct.tv_nsec - start_ct.tv_nsec) / 1e9;

    printf(" Real execution time: %f seconds\n", real_time_3);
    printf(" CPU execution time: %f seconds\n", cpu_time_3);
}

///---------- SETUP FOR DATA PARALLELISM FUNCTIONS
typedef struct {
    unsigned long long start;
    unsigned long long end;
} thread_data_t;

void *task_dp(void *arg)
{
    volatile unsigned long long f = 1;
    unsigned long long i;
    thread_data_t* data = (thread_data_t*)arg;

    for(i = data->start; i <= data->end; i++)
    {
        f = f * i;
        f = f ^ (f >> 13);
        f = f + (i % 17);
        f = (f << 7) | (f >> (64-7));
        f = f * (i % 19 + 1);
        if(f > 10000000000000000000ULL) f = 1;
    }
    return NULL;
}
```

Listing 3. – Data Parallelism Implementation

```c
/// ---------- DATA PARALLELISM + THREAD SCALING ----------
void pthread_data_parallelism_scaling()
{
    unsigned long long N = 5000000000ULL;
    int NUM_THREADS = 4;
    struct timespec start_rt, end_rt, start_ct, end_ct;
    pthread_t threads[NUM_THREADS];
    thread_data_t data[NUM_THREADS];

    for(int t=0; t<NUM_THREADS; t++) {
        data[t].start = t * (N / NUM_THREADS) + 1;
        data[t].end = (t == NUM_THREADS-1) ? N : (t+1)*(N/NUM_THREADS);
    }

    printf("\n [RUNNING] Parallel Processing - Data Parallelism with Scaling...\n");

    clock_gettime(CLOCK_MONOTONIC, &start_rt);
    clock_gettime(CLOCK_PROCESS_CPUTIME_ID, &start_ct);

    for(int t=0; t<NUM_THREADS; t++) {
        pthread_create(&threads[t], NULL, task_dp, &data[t]);
    }

    for(int t=0; t<NUM_THREADS; t++) {
        pthread_join(threads[t], NULL);
    }

    clock_gettime(CLOCK_MONOTONIC, &end_rt);
    clock_gettime(CLOCK_PROCESS_CPUTIME_ID, &end_ct);

    double real_time_4 = (end_rt.tv_sec - start_rt.tv_sec) + (end_rt.tv_nsec - start_rt.tv_nsec) / 1e9;
    double cpu_time_4 = (end_ct.tv_sec - start_ct.tv_sec) + (end_ct.tv_nsec - start_ct.tv_nsec) / 1e9;

    printf(" Real execution time: %f seconds\n", real_time_4);
    printf(" CPU execution time: %f seconds\n", cpu_time_4);
}
```

Listing 4. - Data Parallelism + Scaling implementation

EXPERIMENTAL SETUP AND EXECUTION ENVIRONMENT

All experimental measurements were performed on two Linux based systems. The Linux operating system was selected due to its strong POSIX compatibility, efficient process scheduling, and availability of system monitoring used for measuring CPU load, thread activity and temperature parameters.

Test System 1: Lenovo ThinkPad T430
CPU model: Intel i7-3520m (Ivy Bridge)
Number of cores: 2
Number of threads: 4
Max freq. per core: 3.60 GHz
Max freq. multicore: 3.40 GHz
RAM: 16 GB DDR3 / 1600 MHz (2x8 GB)
OS: Debian GNU/Linux 13 (trixie)
IDE: Code::Blocks 25.03
Compiler: GNU GCC Compiler
Terminal: Xterm
Monitoring tools: htop, glances, lm-sensors

Test System 2: Lenovo ThinkPad P51
CPU model: Intel i7-7820hq (Kaby Lake)
Number of cores: 4
Number of threads: 8
Max freq. per core: 3.90 GHz
Max freq. multicore: ~3.50 GHz
RAM: 32 GB DDR4 / 2400 MHz (4x8 GB)
OS: Debian GNU/Linux 13 (trixie)
IDE: Code::Blocks 25.03
Compiler: GNU GCC Compiler
Terminal: XTerm
Monitoring tools: htop, glances, lm-sensors

5 Results And Performance Analysis

All execution models were evaluated sequentially during the full benchmark run. For each execution model, both real execution time and CPU execution time were measured and displayed afterwards. The measurements were performed on two previously described Linux based systems, and the results for each are presented in the following tables.

Computation model	Number of threads	Real execution time (seconds)	CPU execurion time (seconds)
Sequential	1	30.41	30.40
Task Parallelism	2	32.65	65.02
Data Parallelism	2	18.27	36.46
Data Parallelism + Scaling	4	16.36	63.48

Table 1. – Results of all runs on T430 (i7 3520m)

Computation model	Number of threads	Real execution time (seconds)	CPU execurion time (seconds)
Sequential	1	22.09	22.06
Task Parallelism	2	23.32	46.55
Data Parallelism	2	12.39	24.56
Data Parallelism + Scaling	4	6.48	25.81

Table 2. – Results of all runs on P51 (i7 7820hq)

In Table 1., differences between execution models can be clearly observed. Sequential execution utilizes a single core and performs the workload using only one thread. As expected, real execution time and CPU execution time are nearly identical, since the processor is executing a single thread continuously without parallel workload.

In task parallelism execution, two threads execute identical workload independently. The real execution time is slightly higher than in sequential execution due to thread management overhead, including thread creation, task assignment, operating system scheduling, and synchronization. Additionally, CPU execution time is significantly higher than real time because CPU time represents the cumulative processor time consumed by all active threads. Since two threads are actively executing, total CPU time is approximately doubled compared to real execution.

Data parallel execution shows significantly improved real execution time compared to task parallel execution. In this model, the workload is divided between two threads, allowing each thread to process a portion of the total workload simultaneously. As in task parallel execution, CPU time remains higher than real time because CPU time represents the sum of processor time consumed by all threads.

Data parallel execution with thread scaling demonstrates the best real execution performance among all tested models. By disturbing the workload across four threads, the total execution time is reduced further. However, increasing the number of active threads may introduce additional overhead and can be influenced by processor frequency scaling and thermal limits, especially on older processor architectures such as the Intel i7 3520m. In this case, CPU execution time increases proportionally with the number of active threads, since CPU time represents the cumulative execution time across all threads.

In Table 2., using a newer processor architecture results in significantly better performance across all execution models compared to the older system results shown in Table 1. The performance difference between two threaded and four threaded execution is also more noticeable, demonstrating improved parallel scaling efficiency on modern hardware versus the old architecture where the clock drop is significantly higher and the difference between using two threads and four threads is much smaller. Of course, in addition to the newer architecture, we have to take into account the smaller CPU utilization itself, since newer architectures has larger number of cores and threads in this case.

The following images show the measured outputs obtained directly from the program, confirming the results shown in the table

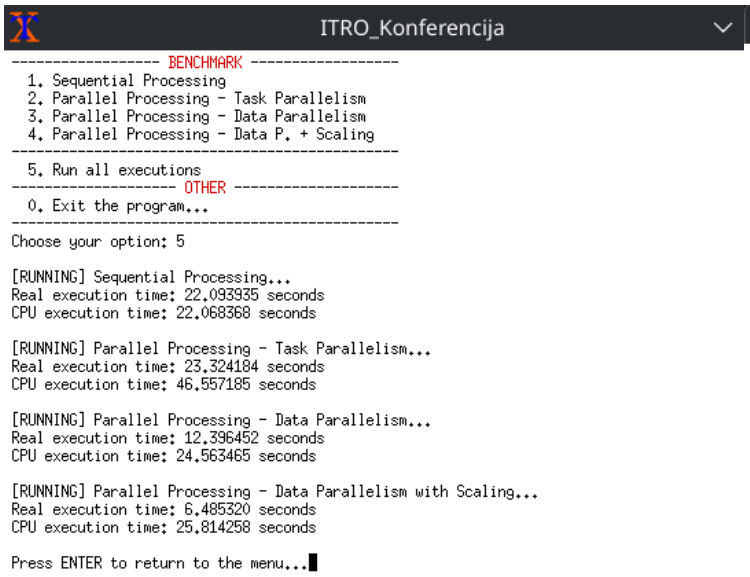


Figure 5. – Results of all runs on T430 (i7 3520m)

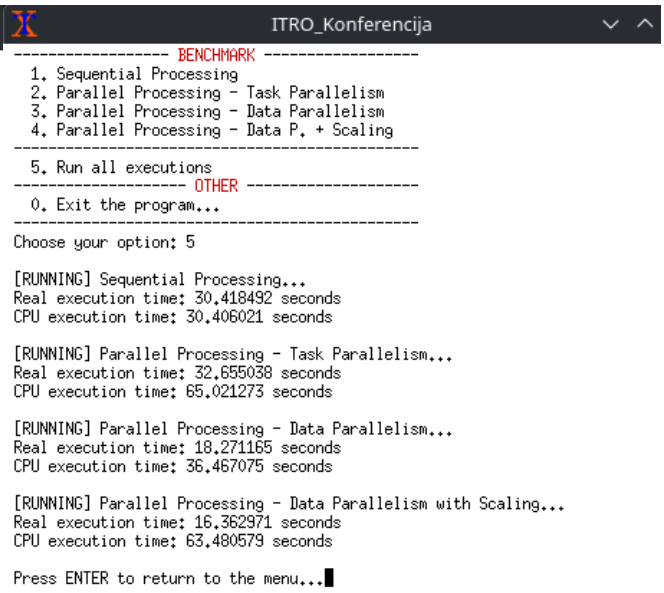


Figure 6. – Results of all runs on P51 (i7 7820hq)

6 Conclusion

The main goal of this study was to create program capable of simulating all execution models using POSIX Threads library in the C programming language, as well as to analyze and monitor their performance in order to better understand the difference between sequential execution, task parallelism, data parallelism, and data parallelism with thread scaling.

Results demonstrated that parallel execution does not automatically guarantee performance improvement. While task parallelism introduces additional overhead due to thread management and synchronization, data parallelism provides significant performance gains when workload is properly distributed across multiple threads.

The comparison between real execution time and CPU execution time further illustrates the impact of multithreaded execution on processor utilization. The results confirm that CPU time increases proportionally with the number of active threads, while real execution time depends on workload distribution efficiency and hardware capabilities.

Overall, the use of the POSIX Threads library enables effective utilization of multicore processor architectures and provides a flexible framework for implementing parallel programming strategies. Understanding the differences between sequential, concurrent and parallel execution models is essential for designing efficient high performance applications.

Future work may include experimenting with thread scheduling policies (schedule.h), reducing system level interference during measurements, allowing dynamic selection of the number of threads per workload, comparing POSIX threads with alternative parallel programming models, evaluating larger thread counts and extending the program to real world data processing scenarios such as large scale data analysis.

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Random forest - a bridge between classical statistics and artificial intelligence

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Abstract. This study presents Random Forest as a bridge between classical statistics and artificial intelligence, demonstrating its application in analysing student academic achievement. Rooted in statistical foundations Random Forest extends traditional methods by capturing non-linear relationships and complex interactions without strong parametric assumptions. Applied to educational data, the model achieves high predictive accuracy and provides interpretable feature importance, attendance, and engagement as key determinants of success. By combining statistical rigor with machine learning flexibility, Random Forest serves as a powerful yet accessible tool for data-driven decision-making in education.

Key words and phrases: Random Forest, Machine Learning, Student Performance Prediction, Classification, Regression

1 INTRODUCTION

The integration of artificial intelligence into educational research has expanded the toolkit for understanding student performance. Among machine learning algorithms, Random Forest (RF) stands out as a method that seamlessly connects classical statistical principles with modern AI capabilities (Breiman, 2001a). Unlike deep learning models that operate as "black boxes," RF maintains interpretability while surpassing traditional models like linear and logistic regression in predictive power (Shmueli, 2010). While classical linear models assume fixed trends, RF identifies complex relationships where the impact of a single factor depends on the complex context of student behavior (James, Witten, Hastie, & Tibshirani, 2013).

RF is grounded in statistical concepts such as bootstrapping (sampling with replacement) and variance reduction through aggregation, first formalized by Breiman (2001a). It builds an ensemble of decision trees, each trained on a bootstrap sample of the data and a random subset of features, thereby reducing overfitting and improving generalization (Hastie, Tibshirani, & Friedman, 2009). This approach aligns with the statistical tradition of inference while embracing the predictive focus of artificial intelligence (AI).

For analyzing student achievement, where data is often tabular and interpretability is key, shallow learning, particularly RF, offers a balanced approach that integrates statistical rigor with predictive power.
In this study, we apply RF to analyze factors influencing student achievement, illustrating how it bridges interpretability and performance. The model not only predicts outcomes accurately but also reveals which variables are most influential, offering actionable insights for educators.

2 RELATED WORKS

Classical statistical methods like linear regression have long been used in educational research due to their simplicity and interpretability (James et al., 2013). They assume linearity and additivity, limiting their ability

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to model complex behavioral patterns. RF leverages ensemble learning to overcome these limitations while retaining transparency through feature importance metrics (Breiman, 2001b).

Recent studies highlight RF's effectiveness in educational data mining. Nachouki, Ammor, and El Yassini (2022) used RF to predict student grades, finding that prior academic records were the strongest predictors. Agyemang, Ansong, and Boateng (2021) reported 85.42% accuracy using RF, outperforming logistic regression and support vector machines. These results confirm RF's ability to handle non-linearities and interactions common in real-world educational datasets.

RF supports the growing demand for explainable AI in sensitive domains like education (Doshi-Velez & Kim, 2017). Unlike neural networks, which obscure decision logic, RF allows stakeholders to understand model behavior through variable importance and partial dependence plots. This makes it particularly suitable for policy-making and intervention design, where accountability and fairness are essential.

Recent applications include predicting student satisfaction in online learning with 90% accuracy (Balabied & Eid, 2023), early detection of at-risk students in open learning environments (Pan & Dai, 2024), and major compatibility prediction using survey-based models (Wijaya, Julian, Wunarto, & Ibrahim, 2025). A study by Guevara-Reyes, Ortiz-Garcés, Andrade, Cox-Riquetti, and Villegas-Ch (2025) demonstrates that RF, combined with SHAP interpretability, enables actionable insights for educational decision-making.

3 THEORETICAL BACKGROUND

Shallow learning refers to machine learning models with limited architectural depth - typically one or two layers of non-linear feature transformations. Deep learning models learn hierarchical representations from raw data, and shallow ones rely on handcrafted features and well-structured input, which makes them closely aligned with classical statistics and mathematical modeling (Hastie et al., 2009). Main differences are presented in Table 1.

Table 2. Shallow vs. Deep Learning

Feature	Shallow Learning	Deep Learning
Architecture	Simple, few layers (e.g., decision trees, SVM)	Complex, many layers (e.g., CNNs, Transformers)
Feature Engineering	Requires manual feature extraction	Automatically learns features from raw data
Data Requirements	Effective on small to medium datasets	Needs large-scale data for training
Computational Cost	Low; runs on CPUs	High; often requires GPUs/TPUs
Interpretability	High (e.g., feature importance in Random Forest)	Low ("black-box" models)
Training Stability	Convex or stable optimization	Sensitive to hyperparameters, initialization

Shallow learning models build directly on statistical theory:

- Linear and logistic regression are rooted in maximum likelihood estimation and generalized linear models.
- Support Vector Machines (SVMs) use convex optimization and kernel methods derived from functional analysis.
- Random Forest, as an ensemble method, leverages bootstrapping (a statistical resampling technique) and variance reduction through averaging.

These models emphasize interpretability, statistical inference, and stability, aligning with traditional scientific inquiry. Understanding why a prediction is made is as important as accuracy. Advantages of shallow learning in practice are:

- Efficiency: Faster training and deployment, ideal for real-time or resource-constrained settings.
- Robustness: Less prone to overfitting on small datasets.
- Transparency: Models like Random Forest provide feature importance scores, enabling actionable insights; critical in education, healthcare, and policy (Guevara-Reyes et al., 2025).

The term “random” in Random Forest refers to two key sources of randomness that make the model robust and less prone to overfitting:

- Bootstrap sampling (random data selection) - Each decision tree is trained on a random subset of the training data, drawn with replacement (i.e., some samples may appear multiple times, others not at all). This process, known as bagging (bootstrap aggregating), ensures that each tree sees a slightly different version of the data, leading to diverse models. On average, each bootstrap sample contains about 63.2% of the original data, with the remaining approximately 36.8% acting as built-in validation (Out-of-Bag samples) (Sun, 2024).
- Random feature selection - At each node split, the algorithm considers only a random subset of features. This prevents dominant features from appearing in every tree, reducing correlation between trees and increasing diversity (IBM, n.d.).

Random Forest leverages the “wisdom of the crowd” principle: while individual trees may make errors, their collective decision via majority voting (classification) or averaging (regression), is more accurate and stable than any single tree. Just like consulting multiple experts with slightly different experiences leads to better decisions, combining diverse, uncorrelated trees reduces overall variance and improves generalization (Yiu, 2019).

Individual decision trees overfit easily by learning noise in the data. In Random Forest, each tree overfits differently due to random data and features. During prediction, errors cancel out across trees, while correct patterns are reinforced. The final model generalizes better to unseen data (Data Science Dojo, 2024). Thus, the “random” in Random Forest is not arbitrary, it's a deliberate strategy to create diversity, reduce correlation, and build a smarter, more reliable ensemble.

The Gini index indicates the level of impurity of each tree node. It represents the probability of a randomly selected element to be incorrectly labeled based on the distribution of classes in a subset. Random Forest algorithm tries to optimize this measure at each split, in order to increase the purity for each generated node. The cumulative reduction in impurity across all trees is the fundamental mechanism used to calculate the predictive importance of each feature (Breiman et al., 1984).

4 METHODOLOGY

A dataset of 1000000 records was used, with student performance results collected by Qureshi (2024). The dataset is highly reliable, with no missing values, providing an excellent basis for training and reducing preprocessing bias. Variables include:

- Student ID – Unique identifier (not included as a feature in the predictive model)
- Study Hours Per Week – Time spent on independent study
- Attendance rate (%) – Proportion of classes attended
- Level of Participation – Classroom activity level
- Total Points – Cumulative score achieved
- Final Grade – Predicted categorical outcome

Table 3. Descriptive Statistics

	count	mean	std	min	25%	50%	75%	max
weekly_self_study_hours	1000000.0	15.03	6.90	0.0	10.3	15.0	19.7	40.0
attendance_percentage	1000000.0	84.71	9.42	50.0	78.3	85.0	91.8	100.0
class_participation	1000000.0	5.99	1.96	0.0	4.7	6.0	7.3	10.0
total_score	1000000.0	84.28	15.43	9.4	73.9	87.5	100.0	100.0

Descriptive statistical analysis was done before building the model in order to analyze the distribution of the variables. As illustrated by Table 2 and Figure 2, the dataset includes varied behavior of the students.

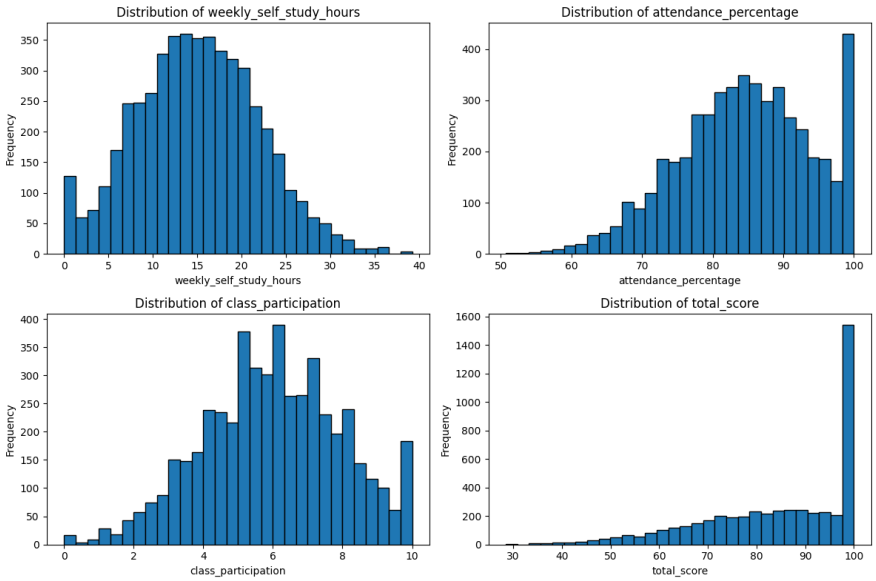


Figure 6. Distribution of key independent variables

Figure 2 illustrates trend in grade frequency, where lower grades are notably less represented compared to higher academic outcomes.

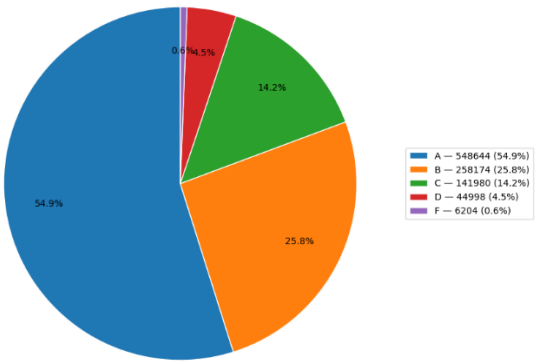


Figure 7. Distribution of final grades

The study employs both classification and regression variants of the Random Forest algorithm to contribute a comprehensive analysis of student performance. For the implementation of these methods, scikit-learn developers (n.d.) library was applied. The dataset was split into 80% training set for model development and a 20% testing set for final performance verification on unseen data.

The classification model aims to determine the student's grade category (A, B, C, D or F). The RF Classifier is customized using the following parameters:

- Number of trees: 100
- Maximum depth: 10
- Criterion: Gini impurity
- Bootstrap: True

To provide a multi-dimensional assessment of the model, the following evaluation metrics are utilized, the accuracy score and the classification report (Precision, F1-Score and Recall).

The regression model is used to predict continuous numeric outcome of Total Points. Although classification allows us to understand whether a student performs well or poorly, RF regressor helps to gain deeper insights into which particular actions of students affect the obtained result precisely.
The model is configured with the following parameters:

- Number of trees: 200
- Maximum depth: 12

- Random state: 42

To measure the error and the predictive power of the regressor, Mean Absolute Error (MAE), Root Mean Squared Error (RMSE), and R-squared (R^2) are used.

5 Results and Discussion

Classification

The initial classification model yielded an accuracy of 99,82%. However, this near-perfect result was identified as target leakage, which occurs when features used to train the model carry information about the target variable that would not be available in a real scenario (Kaufman, Rosset, Perlich, & Stitelman, 2012). To avoid a biased evaluation, we had to exclude the total score from the predictor list.

After this correction, the RF Classifier was able to get an accuracy of 69,6% which is closer to reality. Although we have a high accuracy rate, looking into details about the results (Table 3), it can be noticed that the algorithm performed differently for each of the grades:

- High Accuracy Rate for the best students (grade A)
- Average Accuracy Rate for middle grades (B, C and D)
- Issues with Minority Classes – for the category F, the classifier did not manage to recognize their unique patterns, which means if some classes have fewer observations, the machine learning model cannot learn those patterns.

Table 4. Cassification Report

Accuracy: 0.6959				
	precision	**recall**	**f1-score**	**support**
A	0.83	0.87	0.85	109888.0
B	0.51	0.52	0.52	51556.0
C	0.50	0.48	0.49	28380.0
D	0.50	0.34	0.40	8927.0
F	0.00	0.00	0.00	1249.0

As shown above, the inconsistent accuracy of predicting performance shows that even though behavioral attributes serve as powerful predictors, they may not be enough for predicting the extreme ends of performance for an unbalanced sample.

Table 5. Feature Importance

	Variable	**Importance**
0	**weekly_self_study_hours**	0.9413
1	**attendance_percentage**	0.0367
2	**class_participation**	0.0220

Analysis of Feature Importance in Table 4 shows that weekly self study hours is the absolute dominant predictor, while attendance and participation have minimal impact.

In order to improve the performance of minority classes (Grade F), class weight balancing, SMOTE (Synthetic Minority Over-sampling Technique) for synthetic data generation to address class imbalance classes (Chawla et al., 2002), and Random Forest parameter optimization are proposed.

Regression

Random Forest Regressor was employed to make an accurate prediction of Total points of students. The model achieved the following performance metrics:

- MAE: 6.104
- RMSE: 8.204
- R^2: 0.717

The results indicate good predictive performance. The MAE value implies that the deviation of the prediction from the true score is less than 6 points of a hundred. In addition, the R^2 value shows that the model can explain about 72% of the variation in the scores of students' total scores based on the chosen behavioral factors. The regressor gives better insights compared to the classifier since it is hard to classify students into precise grade "bins". However, their point values are highly predictable.

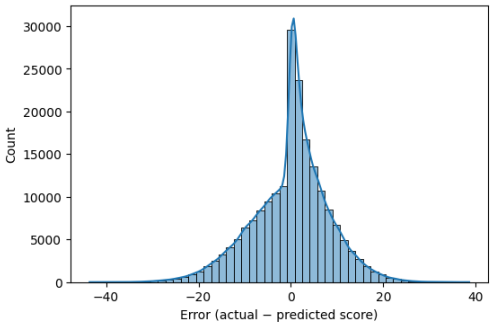


Figure 3. Distribution of Prediction Errors

Figure 3 provides additional support of the efficiency of the regression model. The most prediction errors are clustered around zero, which shows that the estimates of total scores are highly accurate. The nearly normal distribution of the residuals demonstrates that there is no bias in the regression model. There are small tails caused by extreme instances in students' behavior.

A potential strategy for increase regression performance involves identifying and removing outliers during preprocessing, as extreme values can bias the learning process and compromise the model's precision.

6 Conclusion

The results of this research demonstrate that the Random Forest method is a highly effective and user-friendly tool for analyzing educational data. Its main advantage lies in ability to uncover meaningful information from complex student behavior datasets without requiring deep statistical knowledge.

Weekly self-study hours proved to be the strongest predictor of success. This confirms the hypothesis about the critical role of self-engagement in pedagogy and suggests that teachers can give students more individual recommendation to foster their success (Zimmerman, 2002).

The experience with target leakage serves a very important lesson for the application of AI in education. Proper data preparation will ensure that the predictions will be accurate enough to provide the right view and spot those students who need help in time.

In summary, the Random Forest algorithm represents a bridge between raw administrative data and a deeper understanding of the learning process. This enables educators to take evidence-based approaches toward improving their student's experiences

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The Importance of Teachers' Personality Traits and Competencies for the Quality of Educational Practice in the 21st Century

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Abstract: The aim of this research is to examine the significance of teachers' personal characteristics (empathy, consistency, communicativeness, and enthusiasm) and professional competencies for the quality of instruction, classroom climate, and student motivation in the contemporary school context, through the analysis of teachers' self-assessments and students' perceptions. The study included 134 teachers and 165 primary-school students in Novi Sad. The study was designed as a mixed-method research integrating quantitative and qualitative approaches in order to provide a comprehensive understanding of the examined phenomenon. Composite indices were constructed by calculating the arithmetic mean of selected questionnaire items that conceptually belonged to the same thematic domain. Items were grouped according to theoretical and conceptual relatedness (e.g., socio-emotional competencies, didactic-organizational competencies, professional development and innovation). Each item was measured on a five-point Likert scale (1 = strongly disagree to 5 = strongly agree). The index value for each domain represents the mean score of the items included in that category. The results indicate the high significance of teachers' personal traits—empathy, fairness, communicativeness, and enthusiasm—for the quality of teaching and the creation of a positive classroom climate. Furthermore, teachers' pedagogical, methodological, and technological competencies were shown to be significant contributors in enhancing student motivation and the overall effectiveness of the teaching process. The findings highlight the need for continuous professional development of teachers and emphasize their roles as motivators, facilitators, and mentors in contemporary education. Limitations include the relatively small sample size and reliance on participants' self-assessment, while future research may involve larger samples, longitudinal approaches, and more in-depth analyses of teachers' personal and professional qualities.

Key words and phrases: Teacher personality; Teacher competencies; Contemporary schooling; Student motivation; Professional development; Educational research

1 INTRODUCTION

The development of technology, the digitalization of education, globalization, and changes in social values have led to the emergence of new challenges within the educational system. Teachers are now expected to act as mediators of knowledge, motivators, mentors, and facilitators of the learning process. Their role also includes providing emotional support to students and fostering creativity, critical thinking, and mutual respect. A teacher's ability to build trust, communicate effectively, and adapt instructional practice to diverse learning styles represents one of the most important prerequisites for successful teaching. The theoretical framework of this paper is grounded in the concepts developed by Edward Wragg (1994, 1997), who, based on the results of his research, emphasized that the quality of teaching is directly related to a teacher's ability to understand students, organize the teaching process, and employ diverse methods in accordance with students' needs and interests. In addition to Wragg's perspectives, the paper also draws on contemporary approaches to didactics that emphasize the development of both students and teachers as a shared learning process (Gojkov, 2009;

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Vilotijević, 2000). The starting hypothesis of this paper is that the teacher's personality—encompassing character traits, emotional intelligence, professional ethics, and motivation—combined with professional and pedagogical competencies, has a significant impact on teaching outcomes and student achievement. According to Suzić (2006, p. 47), "the teacher's personality and competencies constitute an inseparable whole that determines the quality of teaching," while Potkonjak argues that "the teacher's personality gives meaning and substance to their competencies; without personal maturity and ethical orientation, competencies remain merely formal" (1996, p. 46).

Personal characteristics and qualities of teachers play a key role in creating the classroom atmosphere and significantly influence the quality of the pedagogical process (Havelka, 1998). Traits such as sincerity, fairness, consistency, and reliability foster trust among students; respect and tolerance for differing opinions encourage a culture of dialogue and cooperation; and a positive attitude and enthusiasm for the subject taught motivate students and make instruction more engaging (Danilović, 2001). Of particular importance are emotional intelligence (Suzić, 2005), personal integrity, and professional ethics (Brković, 2008, p. 41). Teacher competencies are defined as "a combination of knowledge, skills, attitudes, and values that enable teachers to achieve the goals of contemporary education" (Suzić, 2005, p. 43). In this regard, continuous professional development enables teachers to remain competent and relevant in their profession, directly affecting the quality of education and student success. Therefore, it is essential that educational institutions and society as a whole recognize and support the importance of this process by providing resources and opportunities for ongoing teacher development (Jokić, 2024, p. 138), as competencies "are not given once and for all, but are continuously developed through experience and self-evaluation" (Šćepanović, 2007, p. 67). This includes subject-matter competencies (Wragg, 1989), pedagogical and psychological competencies (Jokić, 2024, p. 139), methodological competencies (Suzić, 2005, p. 75; Jokić, 2024, p. 138), communication and social competencies (Argyle, 1986; Neill, 1991), organizational and technological competencies, safety-related competencies (Wragg, 1994), competencies for self-evaluation and professional development (Suzić, 2005, p. 122; Jokić, 2024, p. 140), as well as creative and innovative, intercultural, motivational, facilitative, and mentoring competencies (Potkonjak, 1996, p. 30).

It is also important to highlight research conducted in Serbia and the broader region, which over the past two decades has increasingly focused on analyzing teachers' professional competencies and personal characteristics as key determinants of teaching quality. Bogosavljević (2010), in *Contemporary School, Quality Teaching, Competent Teacher*, starts from a theoretical framework in which teacher competence is viewed as a prerequisite for quality teaching. The author emphasizes the importance of cognitive and emotional competencies, as well as value orientations that guide pedagogical action. Nikolić (2017), in her scholarly work *Roles and Competencies of Teachers of Nature and Society in an Efficient School Undergoing Rapid Change*, develops a comprehensive competency model encompassing cognitive, pedagogical, social, emotional, and moral dimensions. Milošević (2015), in *Work Styles of the Contemporary Teacher*, points out that teaching style represents a practical expression of the teacher's personal characteristics. A democratic style, which implies empathy, communicativeness, and respect for students, is associated with higher levels of student motivation and achievement. The most comprehensive empirical study was conducted by Pantić and Wubbels (2010) in *Teacher Competence as a Basis for Teacher Education: Views of Serbian Teachers and Teacher Educators*. Based on a large sample (N = 370), the authors identified four components of competence: value-educational, systemic, subject-pedagogical, and developmental. Particular emphasis was placed on the importance of self-evaluation and continuous professional development, which is increasingly recognized in domestic literature as an indicator of teacher maturity and personal responsibility. Across the analyzed studies, a shared tendency is evident to view the teacher's personality and professional competencies as interconnected and mutually dependent constructs that jointly contribute to higher-quality teaching practice. In addition to the aforementioned studies, the findings of more recent research may also prove to be valuable: Sulaiman & Ismail (2020), Haryani, Coben, Pleasants, & Fetters (2021), Haug & Mork (2021), Đukić Popović, Vuletić, Popović, Popović, Vučković & Ivanković (2023), Eslit (2023), Hercog (2023), Kooi & Annamalai (2023), Popović, Jevtić, Đukić Popović, Ničković, Popović & Čabrić (2023), Randjelović, Jevtić & Janković (2023), Tangney, Girvan, Eilís & Bray (2023), Qureshi (2024), Ranđelović, Jevtić, Stanojević & Veljović (2024).

Subject of the Research: The influence of teachers' personality traits and competencies on the quality of the teaching process in the 21st century.

Research Problem: Whether, to what extent, and in what ways teachers' personality traits and competencies influence the quality of teaching, student motivation, and teacher–student relationships, as well as how students perceive the teacher's personality in the 21st century.
Research Aim: The aim of this research is to examine the significance of teachers' personal characteristics (empathy, consistency, communicativeness, and enthusiasm) and professional competencies for the quality of instruction, classroom climate, and student motivation in the contemporary school context, through the analysis of teachers' self-assessments and students' perceptions.
In order to obtain a comprehensive understanding of the investigated phenomenon, the study combines quantitative and qualitative research approaches. The quantitative component is based on descriptive statistical analysis and the construction of composite indices, while the qualitative component relies on thematic analysis of interview data. The aim of this approach is not to establish causal relationships, but to identify patterns of alignment between teachers' self-assessments and students' perceptions through the convergence of quantitative and qualitative findings.
Research Tasks:

1. To examine the level of socio-emotional and professional competencies of teachers based on their self-assessments.
2. To analyze students' perceptions of motivation, instructional quality, and classroom climate.
3. To determine the degree of alignment between teachers' self-assessments and students' evaluations of key dimensions of teacher competence.
4. To formulate guidelines for enhancing teachers' professional development within the context of the contemporary school.

Research Hypotheses:

H1: There is a clear alignment between teachers' self-assessments of socio-emotional competencies and students' evaluations of support, fairness, and motivation.

H2: Teachers who report higher levels of communication and organizational competencies tend to be evaluated positively by students regarding instructional quality and classroom climate.

H3: Empathy, fairness, and enthusiasm emerge as the most salient dimensions of teacher competence in both quantitative and qualitative findings.

2 METHOD

2.1 Description of the Research Sample

The survey research included 134 teachers and 165 students from various primary schools in Novi Sad. The teacher sample was purposive, meaning that teachers of different genders, ages, lengths of professional experience, and subject areas were included in order to capture a broad spectrum of professional profiles. Students were randomly selected from different classes within the same schools to ensure a balanced sample structure in terms of gender, age, and academic achievement. In addition, the interview-based part of the research involved 57 teachers and 72 students who were randomly selected.

2.2 Structure of the Teacher Sample

The research sample comprised 134 teachers, of whom 98 were female (73.1%) and 36 male (26.9%), all employed in primary schools. The largest proportion of teachers (50%) were over 50 years of age, teachers aged 40–50 accounted for 35.1% of the sample, while younger teachers represented only 5.2%. Nearly half of the teachers (44.8%) had more than 20 years of professional experience, indicating a high level of expertise and long-standing practice. Teachers with 10–20 years of experience were moderately represented (28.4%), while those with 5–10 years of experience accounted for 23.1%. Beginning teachers (up to five years of experience) constituted only 3.7% of the sample, suggesting a relatively low inflow of younger staff into schools.
The sample is diverse in terms of gender, age, and professional experience, which enables a representative insight into the structure of the teaching workforce and their competencies in contemporary education. The

synthetic overview indicates that the teacher sample is predominantly composed of women, older teachers, and those with long professional experience. Such a structure contributes to the maturity of perspectives and richness of experience in the analysis of professional competencies, while simultaneously pointing to the need for greater inclusion of younger teaching staff who could bring new energy and more innovative approaches to teaching.

2.3 Structure of the Student Sample

Within the sample of 165 students, the majority were girls (n = 97; 58.8%), while boys (n = 68) accounted for 41.2% of the total. The largest group consisted of seventh-grade students (35.2%), followed by fifth-grade (27.9%) and sixth-grade students (24.8%), while eighth-grade students were the least represented (12.1%). The synthetic overview indicates that the sample is representative of the school population: the gender distribution is relatively balanced, seventh-grade students are most represented, and eighth-grade students least represented. Overall, the sample provides a solid basis for comparing the attitudes of students of different genders and ages, with a high level of reliability of the results.

2.4 Place and Time of the Research

The research was conducted in schools in the territory of the City of Novi Sad during September and October 2025. Conducting the study during this period enabled data collection under conditions of regular instruction, without external factors that might have influenced the objectivity of the responses.

2.5 Research Design and Data Analysis

The study was designed as a mixed-method research integrating quantitative and qualitative approaches in order to provide a comprehensive understanding of the examined phenomenon. The integration of methods enables triangulation of findings and strengthens the validity and interpretative depth of the results (Creswell & Plano Clark, 2018).

The quantitative component was based on survey research conducted through structured questionnaires administered to teachers and students. The primary aim was to examine patterns of perception and levels of expressed competencies rather than to test causal relationships. For this reason, the analysis relied on descriptive statistics, specifically arithmetic means, and the construction of composite indices for relevant thematic domains.

Student data were available in aggregated form; therefore, inferential statistical procedures such as correlational analysis were not applied. The interpretation focused on identifying consistent patterns and convergence between teachers' self-assessments and students' perceptions.

The qualitative component included semi-structured interviews with selected teachers and students. The data were analyzed using thematic analysis, which allows systematic identification of recurring patterns and dominant categories within participants' responses while preserving contextual meaning (Braun & Clarke, 2006).

2.6 Construction of Composite Indices

Composite indices were constructed by calculating the arithmetic mean of selected questionnaire items that conceptually belonged to the same thematic domain. Items were grouped according to theoretical and conceptual relatedness (e.g., socio-emotional competencies, didactic-organizational competencies, professional development and innovation). Each item was measured on a five-point Likert scale (1 = strongly disagree to 5 = strongly agree). The index value for each domain represents the mean score of the items included in that category.

$$Index = \frac{\sum_{i-1}^{n} x_i}{n}$$

где је:

- x_i вредност појединачне ставке
- n број ставки у индексу

The use of arithmetic means for Likert-scale data is consistent with common practice in educational research (Creswell, 2009).

Instruments:

1. Questionnaire for teachers (self-assessment of professional and personal competencies);
2. Questionnaire for students (perceptions of teachers' traits and competencies);
3. Semi-structured interview for teachers;
4. Semi-structured interview for students (for an in-depth analysis of attitudes).

3 RESULTS

3.1 Teacher Questionnaire

The questionnaire administered to teachers aimed to examine the extent to which personal characteristics and professional competencies influence teaching quality and student achievement in contemporary education. The statements focused on the assessment of teachers' values, ethical standards, organizational abilities, motivation for professional development, and the use of modern technologies in teaching. Among the most strongly endorsed statements were: *I strive to be consistent and fair in my decisions and actions* (52%), *I am willing to adapt to students' needs and learning styles* (44%), *I regularly improve my technological competencies and use digital tools in teaching* (40%), *Emotional understanding and support for students are an important part of my work* (54%), *I encourage students' creativity and independent thinking* (44%), *I adhere to professional ethical standards (objectivity, impartiality) in my work* (60%), *I believe that my organizational skills contribute to teaching quality* (46%), *Collaboration with colleagues and the exchange of experiences support my professional development* (45%), *I regularly follow contemporary pedagogical trends and introduce innovations into my practice* (39%), and *Through my own example, I strive to be a role model of responsible behavior and respect for students* (54%).

The obtained responses provide valuable insight into how teachers perceive their own role in the teaching process and the impact their personality and competencies have on students' motivation, behavior, and achievement. The results indicate that teachers largely demonstrate a high level of professional and ethical awareness, as well as a readiness for continuous professional development. High mean scores across most statements (M = 4.3–4.9) suggest that teachers perceive themselves as responsible, flexible, and committed professionals who seek to foster a positive school climate through their own example. The highest-rated dimensions relate to fairness, ethical standards, and empathy, confirming that teachers place considerable emphasis on interpersonal relationships and moral values in their work with students. Significant attention is also devoted to technological competencies and the improvement of teaching practice, in line with the demands of contemporary education. Overall, the findings indicate a high degree of professional maturity, responsibility, and awareness of the teacher's role in shaping students' motivation and value orientations, confirming that teacher personality represents one of the key factors of successful teaching in the modern educational system.

3.2 Student Questionnaire

The student questionnaire aimed to examine students' perceptions of their teachers' personalities, competencies, and teaching practices. The statements covered various aspects of the teacher–student relationship, including clarity of explanations, fairness, communication, motivational support, use of technology, and respect for diversity. The goal was to determine, from the students' perspective, the extent to which teachers' personality traits, attitudes, ethical values, and pedagogical competencies influence teaching quality and learning motivation. Particular attention was paid to the emotional and communicative aspects of teaching, which are often crucial in establishing a positive school climate. The most strongly endorsed statements were: *The teacher explains instructional content clearly and understandably* (45%), *The teacher is fair in assessment* (42%), *The teacher knows how to motivate students to learn and make an effort* (43%), *There is good communication and opportunity for dialogue in class* (39%), *The teacher uses modern technologies and methods that make lessons interesting* (40%), *The teacher respects different opinions and encourages tolerance in the classroom* (51%), *The teacher provides support when I experience learning difficulties* (40%), *The teacher's enthusiasm and attitude toward the subject increase my motivation* (45%),

The teacher maintains classroom discipline in a fair and nonviolent manner (43%), and *The teacher encourages students to express their own opinions and suggestions* (45%).

The results show that students generally hold a positive view of their teachers and rate their professional and personal qualities highly. Mean scores indicate that teachers largely demonstrate fairness, understanding, enthusiasm, and the ability to foster motivation and active student participation. Particularly high ratings were given to dimensions related to empathy, respect for diversity, and a motivating teacher attitude, suggesting stable and supportive classroom relationships. Students also recognize the importance of contemporary teaching methods and technology, although in some cases they express a desire for greater dynamism and innovation in instructional approaches. Overall, the findings confirm that teacher personality has a decisive influence on the emotional atmosphere, student motivation, and engagement. Teachers who combine professional expertise, ethical conduct, and understanding succeed in creating an environment in which students feel a sense of belonging, respect, and encouragement to learn.

3.3 Teacher Interviews

The teacher interviews aimed to provide a deeper understanding of teachers' views, attitudes, and experiences regarding the influence of personality and professional competencies on teaching quality. The sample of teachers was randomly selected and included 57 participants. Open-ended questions enabled teachers to express personal reflections on the challenges of contemporary teaching, modes of professional development, and relationships with students. Particular attention was paid to self-assessment in the areas of pedagogical and psychological skills, as well as the application of modern methods and technologies in practice. This approach provided deeper insight into the professional role of teachers as agents of change in contemporary education through questions such as: *Which personal traits do you consider most important for high-quality teaching? How do you assess the impact of your competencies on student success and motivation? What challenges do you most frequently encounter in applying modern pedagogical methods? How do you perceive the role of technology in teaching and to what extent do you use it? How do you work on your own professional development? Do you believe that students recognize your efforts in providing support and motivation? Which methods or tools do you use to encourage student creativity? How do you strive to maintain ethical standards in your work? Does collaboration with colleagues contribute to your professional development, and in what ways? What do you consider the most important direction for improving the contemporary teaching role?*

The analysis of teacher interviews indicates that teachers largely recognize the importance of personality and professional competencies as key factors of quality teaching. Teachers emphasize that personal traits such as empathy, consistency, patience, and flexibility have a decisive influence on classroom atmosphere and student motivation. Additionally, the need for continuous professional development and the enhancement of digital and pedagogical competencies is strongly emphasized. While most teachers view technology as a useful tool, they also stress that it cannot replace personal contact and the educational role of the teacher. The interviews suggest that the contemporary teacher must be not only professionally and methodologically competent, but also emotionally stable, communicative, and prepared for continuous change in practice.

3.4 Student Interviews

Student interviews were conducted to explore how students perceive their teachers' personalities, teaching styles, and pedagogical approaches. The student sample was randomly selected and consisted of 72 participants. Through a series of open-ended questions, students shared their views on communication, motivation, support, and classroom discipline. Special emphasis was placed on students' perceptions of teacher–student relationships, the use of technology, and factors that encourage creativity and independent learning. These qualitative data complement the questionnaire findings and allow for a more comprehensive understanding of the teacher's role in contemporary education. The questions included: *What do you like most about your teacher's way of working? Which teacher traits help you most in learning and working? Do you think the teacher sufficiently encourages creativity and independence? How does the teacher respond when problems arise in the classroom or in learning? Do you feel motivated by the teacher's attitude and enthusiasm? Does the teacher use technology in class, and does it help you learn? How does the teacher maintain discipline in the classroom? Do you feel free to express your opinions in class? Which teaching methods do you find most interesting and effective? What would you like the teacher to change or improve in their work?*

The results of the student interviews indicate that students value teachers primarily for their approachability, support, and positive attitudes. Students emphasize the importance of teachers who demonstrate understanding, respect students' opinions, and encourage creativity and independence. Most students believe that technology and modern forms of instruction make lessons more engaging and easier to understand. The importance of teacher enthusiasm and fairness is particularly highlighted, as these directly influence student motivation and achievement. Overall, students perceive teachers as key figures in their education—individuals whose attitudes, behavior, and energy shape the learning environment and the values of the school community.

4 Interpretation and Discussion of Results

This chapter presents and interprets the results of the quantitative and qualitative data analyses. The aim of the interpretation is to determine the degree of alignment between teachers' self-assessments and students' perceptions, as well as to relate the findings to the established research objectives and hypotheses.

4.1 Quantitative Results

The quantitative analysis encompassed the processing of data obtained from the teacher questionnaire (N = 134) and the aggregated results of the student questionnaire. The data were analyzed using descriptive statistics (mean values), and composite indices were constructed according to thematic domains.

4.2 Indices of Teacher Competencies

Based on the grouping of items into thematic categories, three indices were constructed: socio-emotional competencies, didactic-organizational competencies, and professional development and innovativeness.

Table 1. Indices of Teacher Competencies

Index	*Mean (M)*
Socio-emotional competencies	4.41
Didactic-organizational competencies	4.17
Professional development and innovativeness	4.12

The results indicate high values across all examined domains. The highest mean was observed in the area of socio-emotional competencies (M = 4.41), suggesting that teachers place considerable importance on empathy, fairness, and ethical conduct in their professional practice. Didactic-organizational competencies were also rated highly (M = 4.17), reflecting a strong self-assessment in planning and managing the instructional process. The index for professional development and innovativeness (M = 4.12) shows slightly lower, yet still high, values, indicating potential room for further enhancement in the domain of modern teaching methods and technology.

4.3 Indices of Student Perceptions

Based on the aggregated results of the student questionnaire, three indices were constructed: instructional quality, classroom climate, and student motivation.

Table 2. Indices of Student Perceptions

Index	*Mean (M)*
Instructional quality	4.10
Classroom climate	4.15
Student motivation	4.19

Students evaluate all aspects of teacher performance highly. The highest mean was observed in the domain of motivation (M = 4.19), indicating that students recognize the teachers' stimulating role in the learning process. The high rating of classroom climate (M = 4.15) reflects positive relationships and well-developed communication within the classroom, while the instructional quality score (M = 4.10) suggests that students perceive clarity, structure, and methodological variety in teaching.

4.4 Synthetic Overview of Results

To provide a clearer understanding of the relationship between teacher competencies and student perceptions, a graphical representation of the indices is presented. The graphical representation allows for a direct comparison of teacher and student index values. All values exceed 4.00, indicating highly positive evaluations in both samples. The highest value is observed in the domain of teachers' socio-emotional competencies, which corresponds with the high levels of student motivation and a positive classroom climate. This pattern highlights a strong alignment between the relational aspects of teaching and student engagement. A similar convergence is noted between teachers' didactic-organizational competencies and students' assessments of instructional quality, suggesting agreement in perceptions regarding the structure and effectiveness of the teaching process. Although the professional development index is slightly lower compared to other dimensions, it remains within a high range, reflecting a positive attitude toward contemporary approaches while indicating potential for further improvement. The visual proximity of teacher and student index values demonstrates a stable and consistent pattern of results, providing a solid basis for the formal testing of the research hypotheses in the following chapter.

4.5 Results of the Thematic Analysis of Interviews

The qualitative component of the study encompassed the analysis of teachers' and students' responses to open-ended questions. The data were analyzed using thematic analysis, through which dominant themes recurrent in the participants' statements were identified.

Table 3. Dominant Themes in Interviews

Participant Group	***Dominant Themes***
Students	Empathy, support, enthusiasm, active methods, fairness
Teachers	Empathy, ethical conduct, methodological competencies, professional development, ICT

As shown in Table 3, socio-emotional characteristics of the teaching role dominate the statements of both participant groups. Students emphasize empathy and support as key factors in their motivation, while teachers highlight ethical conduct and professional responsibility as the foundation of their practice. Beyond relational aspects, both groups recognize the importance of modern teaching methods and professional development, indicating a high degree of alignment in perceptions.

4.2.1 Student Perception

The analysis of student responses identified four key thematic areas:

1. **Socio-emotional support:** Students most frequently highlight teachers' patience, understanding, and fairness as essential characteristics that contribute to a sense of security and trust. Empathy and the willingness of teachers to provide additional explanations are recognized as important factors in motivation and engagement.
2. **Enthusiasm and positive classroom atmosphere:** Respondents emphasize that teachers' enthusiasm and positive energy in the classroom directly influence their interest in the subject. It is noted that teachers who demonstrate a passion for their work encourage students to participate more actively.
3. **Active methods and creativity:** Students identify project-based learning, group work, discussions, and the use of multimedia content as the most effective teaching approaches. These methods are perceived as stimulating creativity and independent thinking.
4. **Fairness and communication:** The importance of clear rules, consistency, and mutual respect is particularly stressed. Students positively evaluate teachers who maintain discipline through dialogue and reasoning rather than punitive measures.

4.2.2 Teacher Perception

The thematic analysis of teacher responses identified the following dominant categories:

1. **Importance of personal characteristics:** Teachers emphasize empathy, consistency, ethical conduct, and emotional stability as the foundation of professional practice. Personal traits are perceived as crucial for fostering a positive classroom climate.
2. **Competencies and student motivation:** Respondents highlight that methodological and communication competencies directly influence student engagement. Adapting instruction to individual student needs is recognized as a significant factor in achieving educational success.
3. **Modern methods and technology:** Teachers acknowledge the importance of innovative approaches and the integration of ICT, while noting time and technical constraints as challenges to their consistent implementation.
4. **Professional development:** Most teachers underline the significance of continuous professional training, collaboration with colleagues, and lifelong learning as essential conditions for high-quality teaching practice.

4.2.3 Summary of Qualitative Findings

The qualitative findings demonstrate a high degree of alignment between student and teacher perceptions. Socio-emotional characteristics, enthusiasm, and communication skills are recognized as central factors influencing instructional quality and student motivation. At the same time, there is an awareness of the importance of modern teaching methods and technology, alongside a recognized need for their further development. These results provide qualitative support for the quantitative findings and serve as a basis for integration in the following chapter.

4.3 Integration of Quantitative and Qualitative Findings

To achieve a more comprehensive understanding of the investigated phenomenon, the results of the quantitative and qualitative analyses were integrated using the principles of convergence of findings. This approach allows for the comparison and connection of data obtained through different methods and the assessment of the degree of alignment between them.

4.3.1 Socio-emotional Competencies and Student Motivation

Quantitative results indicate that teachers' socio-emotional competencies received the highest ratings (M = 4.41), while the student motivation index also showed a high value (M = 4.19). Qualitative findings further confirm this pattern. Students most frequently highlight empathy, support, and enthusiasm as key factors stimulating their engagement. Teachers, in turn, emphasize the importance of ethical conduct, consistency, and understanding of students as the foundation of professional practice. A clear convergence of findings is observed, indicating that teachers' socio-emotional characteristics play a central role in creating a motivating learning environment.

4.3.2 Didactic-Organizational Competencies and Instructional Quality

The high value of the teachers' didactic-organizational index (M = 4.17) corresponds with students' positive evaluation of instructional quality (M = 4.10). In interviews, students highlight clarity of explanations, lesson structure, and methodological variety as key factors for effective learning. Teachers emphasize lesson planning and adaptation to different learning styles as essential professional competencies. This alignment reflects a stable pattern of perceptions regarding the organization and structure of the instructional process.

4.3.3 Modern Methods and Innovativeness

Although the professional development and innovativeness index is slightly lower compared to other dimensions (M = 4.12), it still falls within a high range. Students recognize the use of technology and active teaching methods as motivating but suggest the potential for more frequent application. Teachers also acknowledge the importance of ICT and contemporary methods, while noting time and technical constraints as potential challenges. In this domain, partial convergence is observed—there is a positive orientation toward innovation, yet room for further improvement remains.

4.3.4 Conclusion of Integration

The integration of quantitative and qualitative findings demonstrates a high degree of alignment between teachers' self-assessments and students' perceptions of the teaching process. Socio-emotional competencies emerge as a central factor for positive classroom climate and student motivation, while didactic-organizational competencies correspond with perceived instructional quality. The results indicate a stable and consistent pattern in the relationship between teachers' personal characteristics, professional competencies, and student engagement, providing a foundation for the formal testing of research hypotheses in the subsequent chapter.

5 TESTING OF HYPOTHESES

5.1 Testing Hypothesis H1

H1: *There is an alignment between teachers' self-assessments of socio-emotional competencies and students' evaluations of motivation.*

Quantitative results show that teachers' socio-emotional competencies received the highest rating (M = 4.41), while the student motivation index also shows a high value (M = 4.19). Qualitative findings further confirm this pattern, as students in interviews frequently highlight empathy, support, and enthusiasm as factors directly influencing their motivation. Teachers, in turn, emphasize the importance of emotional stability and fairness as the foundation of successful practice. Although correlational analysis was not applied due to aggregated student data, the observed convergence of findings indicates a clear pattern of alignment between these dimensions.

Conclusion: The results provide support for H1 through the convergence of descriptive quantitative results and qualitative findings.

5.2 Testing Hypothesis H2

H2: Teachers who rate their communication and organizational competencies highly are positively evaluated by students regarding instructional quality and classroom climate.

The teachers' didactic-organizational index (M = 4.17) corresponds with students' assessments of instructional quality (M = 4.10) and classroom climate (M = 4.15). Interview data indicate that students particularly value clarity of explanations, lesson structure, and methodological variety, while teachers emphasize lesson planning and adaptation to different learning styles as key competencies. The observed alignment of perceptions confirms that teachers with well-developed communication and organizational competencies are positively evaluated by students in terms of instructional quality and classroom climate.

Conclusion: H2 is supported by the alignment of descriptive quantitative indicators and qualitative interview findings.

5.3 Testing Hypothesis H3

H3: Students evaluate more positively teachers who demonstrate empathy, fairness, and enthusiasm.

Teachers' socio-emotional competencies represent the highest-rated dimension, while student results show high levels of positive classroom climate and motivation. Qualitative findings further confirm that students value empathy, patience, and enthusiasm in teachers above all. These elements are directly associated with feelings of safety, respect, and motivation for learning. Integration of quantitative and qualitative data indicates a consistent pattern of positive evaluations for teachers exhibiting these characteristics.

Conclusion: H3 is supported by the consistent alignment of quantitative indicators and qualitative findings.

Overall Conclusion on Hypothesis Testing

All three hypotheses are supported at the level of integrated and convergent findings. The conclusions are based on descriptive statistical indicators and qualitative thematic analysis, rather than inferential statistical testing, due to the aggregated nature of the student data. Although correlation tests could not be applied due to the aggregated nature of student data, the alignment of quantitative and qualitative results indicates a stable pattern of relationships between teachers' personal characteristics, professional competencies, and student motivation. The findings underscore the importance of socio-emotional and organizational competencies in the context of the contemporary educational environment.

6 Discussion of Results

The results of the comprehensive analysis of questionnaires and interviews indicate a high degree of congruence between teachers' self-assessments and students' perceptions regarding the role of teachers' personality traits and competencies in contemporary education. The data confirm that teachers possess well-developed ethical, pedagogical, and emotional competencies to a significant extent, which students recognize and value as key factors of effective teaching. Consequently, all proposed hypotheses were supported at the level of convergent findings, and the findings are consistent with previous research (Pantić & Wubbels, 2010; Bogosavljević, 2010; Milošević, 2015; Nikolić, 2017, Sulaiman & Ismail, 2020).

The strongest alignment was observed in the domain of emotional competencies. Empathy, understanding, and the support teachers provide to students proved to be strong predictors of student motivation and a sense of belonging. Students perceive teachers not only as transmitters of knowledge, but also as individuals who foster self-confidence, encourage creativity, and create a safe learning environment. These findings are consistent with the results reported by Bogosavljević (2010) and Nikolić (2017). They confirm that teachers' emotional intelligence plays an equally important role as professional expertise in building a positive school climate and enhancing student motivation, thereby directly confirming Hypotheses H1 and H3.

A high level of agreement was also observed in the area of ethical standards and fairness, confirming that teachers consistently apply principles of objectivity and impartiality, which students recognize as one of the most important aspects of teacher personality. Such an approach fosters mutual trust, respect, and a sense of justice within the classroom, which directly affects the quality of cooperation and classroom discipline.

The dimensions of teacher motivation and enthusiasm also demonstrated a strong association with student outcomes and interest in learning. Teachers who display enthusiasm and a positive attitude toward their subject create more dynamic and engaging lessons. Students report that this energy and attitude have the greatest influence on their willingness to learn and actively participate in class, confirming that teacher personality functions as a motivational model of behavior. These findings are consistent with Nikolić (2017) and fully confirm Hypothesis H2.

The correlation between the use of technology and contemporary teaching methods showed slightly lower mean values compared to other domains. Teachers who actively apply digital tools and innovative methods achieve higher levels of student attention, interest, and content mastery. However, the findings suggest that

technological competence alone is not sufficient; its effectiveness is greatest when combined with empathy, motivation, and an interactive teaching approach.

A high level of agreement between teachers and students was also observed in the domain of communication and cooperation, confirming the importance of open dialogue in teaching. Students highly value teachers who listen to their opinions and encourage active participation in discussions, while teachers emphasize communication competence as a core component of their professional identity, in line with the findings of Milošević (2015) and Sulaiman & Ismail (2020). Such relationships foster a democratic and supportive school atmosphere based on mutual respect, further confirming Hypothesis H2.

Overall, the results of the integrated analysis support the view that teachers' personality traits and professional competencies represent one of the most significant determinants of educational success in the 21st century. Teachers who combine subject expertise, ethical integrity, empathy, and openness to innovation succeed in building stable, motivating, and partnership-oriented relationships with students. These relationships contribute not only to improved educational outcomes but also to the formation of students' value systems, the development of social skills, and the creation of a positive image of school as a place of shared learning and growth, in line with the findings of Pantić and Wubbels (2010).

It should be noted that the conclusions are based on descriptive statistics and integrated qualitative findings, as the use of aggregated student data did not allow for inferential statistical testing.

7 Concluding Remarks and Pedagogical Implications

The results of this study aim to complement theoretical foundations with empirical evidence from practice and to identify areas in which teachers' professional development requires further improvement. This study examined the relationship between teachers' personality traits, professional competencies, and students' perceptions of teaching quality in contemporary primary schools. The integrated analysis of questionnaire data and interview findings indicates a high level of alignment between teachers' self-assessments and students' evaluations of motivation, classroom climate, and instructional quality. The conclusions are based on integrated descriptive and qualitative findings, which indicate consistent patterns of association between teacher competencies and student perceptions rather than causal relationships or inferential statistical testing.

The findings provide consistent evidence that teachers' personality traits and competencies are important contributors to teaching quality and student motivation in contemporary schooling. By examining the perspectives of both teachers and students, a comprehensive insight was gained into the ways in which personal and professional dimensions of the teaching role intersect and complement one another. Teachers who demonstrate high levels of emotional intelligence, empathy, and flexibility exhibit greater motivation and effectiveness in their work, while students perceive such teachers as fair, supportive, and inspiring.

Particular importance is attributed to communication and methodological competencies, which are directly related to student motivation and instructional quality. Teachers who successfully integrate diverse instructional forms and methods, use digital tools, and encourage active student participation are perceived as more effective and create a more positive classroom climate. At the same time, the study reveals an awareness of the need for continuous professional development, although limited resources and insufficient institutional support often represent obstacles to its full realization. It should also be noted that the findings are based on descriptive statistical indicators and qualitative thematic analysis, while the aggregated form of student data limited the possibility of applying inferential statistical procedures.

From the perspective of educational practice, the findings have several important implications. First, initial teacher education programs should be enhanced to equally emphasize the development of subject-matter, pedagogical, and socio-emotional competencies. Second, systems of continuous professional development should be strengthened through seminars, workshops, mentoring, and horizontal learning among colleagues. Third, schools should foster a culture of collaboration, trust, and innovation, as such a context enables teachers to realize their full professional potential.

The results of this study suggest that teachers' socio-emotional and professional competencies represent an important factor in shaping students' motivation, classroom climate, and overall instructional quality. Teachers who combine professional expertise, ethical conduct, and empathy contribute to the creation of supportive and

motivating learning environments in contemporary schools. A teacher who possesses professional expertise, emotional maturity, integrity, and the ability to motivate students constitutes the foundation of high-quality and humane education. Contemporary schools cannot progress without teachers who are simultaneously professionals, reflective practitioners, and individuals—personalities who inspire students to think critically, create, and believe in themselves.

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Assessment of AI Assistant Capabilities in Compressed Air Distribution System Design

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Abstract. Compressed air, as an energy carrier for driving actuators and many other uses, is widely used in manufacturing facilities. Regardless of whether a compressed air system is designed for a new production plant or change is performed on an existing system, one of the most significant parameters affecting the quality of air supply to consumers is the diameter of the compressed air distribution system. An inadequately dimensioned pipeline leads to unnecessary energy consumption. In engineering practice, the calculation of this diameter is commonly carried out using a highly efficient and effective method based on the application of appropriate nomograms and equivalent length diagrams. This paper presents an experiment investigating the ability of seven different AI assistants to solve the task of calculating the diameter of a compressed air distribution system. A comparative analysis of the obtained solutions was conducted, and appropriate conclusions were drawn regarding the applicability of each of the tested AI assistants in performing this specific engineering task.

Key words and phrases: AI assistants assessment, energy efficiency of compressed air, diameter of a compressed air distribution system**.**

1 INTRODUCTION

In recent years, at the global level, we have been both witnesses to and participants in a specific phenomenon that may be described as the synergy between the increasingly intensive use of AI assistants and the simultaneous rapid expansion of the domains in which they are applied. AI assistants are employed in various ways in everyday life; however, they are also ubiquitous in contexts where experts in particular fields turn to AI assistants for support in solving concrete and highly complex problems that require sophisticated knowledge and skills. It is evident that not all AI assistants are equally suitable for application across all domains, yet it is also a fact that they are continuously improving and expanding their capabilities on an almost daily basis. Their potential to emulate abstract thinking, logical reasoning, and domain-specific expertise is becoming increasingly pronounced (Cappello et al., 2025).

This paper investigates the applicability of seven different AI assistants in solving a specific and, in practice, highly significant task in the field of mechanical engineering. Specifically, in automated manufacturing facilities, compressed air is used as an energy carrier for driving actuators and for various other purposes in a very large number of cases, owing to its numerous advantages. The design of a new, energy-efficient compressed air system, as well as the redesign of an existing system, represents a highly complex engineering task. Within this context, one of the key requirements is the determination of the diameter of the main pipeline for compressed air distribution from the compressor station to the all consumers in an energy-efficient manner.

A typical pipeline diameter calculation requires the determination of flow velocities and is therefore unsuitable for the rapid determination of the desired pipeline diameter. For this reason, a practical engineering method has been developed that enables the pipeline diameter to be efficiently determined in a simple manner with a sufficient level of accuracy. The sizing of pipelines for compressed air distribution involves the use of a nomogram with seven vertical scales and is carried out in two iterations (Kaeser Compressors, 2015, pp. 54 –

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55). For its application, the following parameters must be known: the length of the main pipeline, the required volumetric flow rate, the required operating pressure in the system, and the allowable pressure drop from the point of compressed air generation to the most distant consumer along the main pipeline. (Air Piping Manual, n.d., pp. 71 - 72). In the first iteration, the considered pipeline is

approximated as a straight pipe (which is most often not the case in practice); only frictional losses are taken into account, and the initial diameter is determined. In the second iteration, an equivalent length diagram (Šešlija, 2020, p. 104) or an appropriate table (Atlas Copco, 2019, pp. 93–94) is used to additionally account for local losses, thereby enabling a more precise determination of the required diameter. The calculation is completed by adopting the first larger standard diameter, which eliminates the effects of potential inaccuracies in the procedure. This method has proven to be highly effective and has been successfully used in practice for several decades (Meixner, & Kobler, 1978).

It is important to note that the application of this method and the recommended allowable pressure drop value (0.1 bar) enables good energy efficiency in the distribution of compressed air. When determining the required pipeline diameter, engineers must make a compromise between pipeline construction costs and energy efficiency.

If, during the sizing of a compressed air distribution pipeline in a manufacturing facility, an error is made such that the adopted pipe diameter is larger than required, the negative consequences are predominantly of an economic nature. Most notably, the investment costs increase, since a larger pipeline diameter implies higher material consumption (pipes, fittings, valves), more expensive supports and installation, and higher insulation costs (if insulation is required). At the same time, a positive effect is the reduction of pressure losses in the system; however, the proportional benefit achieved is questionable. A larger diameter also results in a greater volume of compressed air within the network, leading to a larger amount of energy “stored” in the system. Nevertheless, this allows for a faster system response during sudden increases in compressed air demand, making an oversized system suitable for conditions with highly fluctuating compressed air consumers (Šešlija, 2020).

If, on the other hand, an error is made such that the selected pipeline diameter is smaller than required (undersizing), the consequences are significantly more severe than in the case of oversizing and have a direct negative impact on system functionality, reliability, and energy efficiency. A smaller diameter leads to increased air flow velocity and substantially higher linear and local pressure losses. The most significant consequences include insufficient pressure at end users, unstable operation of pneumatic devices, and the need to increase the compressor discharge pressure. To compensate for increased pressure drops, the system is most often operated at a higher working pressure. This has serious energy implications, such as increased electrical energy consumption of the compressor and an increase in specific energy consumption (kWh/m³ of air) (Atlas Copco, 2019; Šešlija, 2020).

2 AI ASSISTANTS

Large language models today have the ability to take on the role of AI assistants. However, there are certain differences between their characteristics and capabilities. We decided to examine as many as seven such systems. Below are their essential characteristics.

GPT. "Generative pretrained transformers (GPTs) are a family of large language models (LLMs) based on a transformer deep learning architecture. Developed by OpenAI, these foundation models power ChatGPT and other generative AI applications capable of simulating human-created output" (Belcic, & Stryker, n.d.-b). ChatGPT is an AI chatbot that allows you to ask questions and get answers through a web browser. It appeared as the first in its class, which gave it an important initial advantage and a wide range of users.

DeepSeek. This chatbot originating from China can, to a good extent, compare to Western solutions, but its characteristic is a significantly lower price compared to its competitors. "What makes DS so special is that in some benchmark tasks it achieved the same or even better results as the big players in the AI industry (e.g., OpenAI’s ChatGPT), but with only a fraction of the training cost." (Gao, Jin, Ke, & Moryoussef, 2025).

Grok. This chatbot is a product of xAI. It is accessible through apps for iOS and Android and is also integrated with Twitter and Tesla's Optimus robot. It takes advantage of real-time data access from the web and the X

social media platform. "It is programmed to “maximize truth and objectivity,” and can answer “spicy” questions with witty and “rebellious” answers." (Glover, 2026).

Perplexity. This system bills itself as an AI-powered search engine. The answers contain links and links to sources of information, which is convenient when we want to additionally check the credibility of those answers. What sets it apart in this selection is that it integrates other AI models. "The platform integrates cutting-edge AI models, including OpenAI's GPT models and Anthropic's Claude, giving you the flexibility to choose the model that best fits your specific needs" (What is Perplexity?, n.d.).

Google Gemini. That is Google’s family of advanced artificial intelligence models and products, designed to act as multimodal AI assistants. According to Manyika & Hsiao (2024) Gemini is an interface to multimodal LLM, with support for text, audio, images and more. The known limitations of this model relate to Accuracy, Bias, Multiple Perspectives, Persona, False positives and false negatives and Vulnerability to adversarial prompting.

Claude. The specificity of this chatbot is that it insists on ethical norms. As of version 3, it is multimodal, claiming to support text, images, and audio. "Claude AI (Claude) is a generative artificial intelligence (AI) chatbot and family of large language models (LLMs) developed by the research firm Anthropic. Claude excels at natural language processing (NLP) and is multimodal: it accepts text, audio and visual inputs and can answer questions, summarize documents and generate long-form text, diagrams, animations, program code and more" (Belcic, & Stryker, n.d.-a).

Meta. It is basically a virtual assistant created by Meta, which owns Facebook, Instagram, and WhatsApp. It's free, based on the Llama 4 model. Although the image generation quality lags behind ChatGPT, this model generates images much faster, which makes it suitable for brainstorming. "Meta AI is now integrated with Meta's social media and messaging platforms: Facebook, Messenger, Instagram, and WhatsApp" (Kane, 2025).

3 EXPERIMENT

The task that we created for the seven AI assistants is presented below.

The volumetric flow rate relevant for pipeline sizing is the amount of air aspirated by the compressor in one hour and, for the given pipeline, amounts to 1000 m^3/h. The installation operates at an average pressure of 7.5 bar. The allowable pressure drop between the receiver and the point farthest from the receiver is specified by the designer and is equal to 0.1 bar. Determine the diameter of the main pipeline if its length is 575 m. The main line contains the following components that represent local flow resistances: one valve with a large pressure drop due to multiple changes in flow direction, 11 tee fittings, and 5 elbows (90° angle bends). The problem should be solved in two iterations using a nomogram and equivalent length diagrams. Explain the complete calculation procedure and cite the references used in solving the problem.

All significant elements of the solution to this engineering problem provided by the authors are presented below. The initial diameter, determined in the first iteration, should be approximately 105 mm (it cannot be read from the nomogram with absolute accuracy; however, due to the calculation procedure itself, such precision is not required). The equivalent pipeline length determined in the subsequent iteration is $L_e = 179$ m. It should be emphasized that the equivalent length of each individual local resistance element is determined from the corresponding diagram with a logarithmic scale; therefore, the readings obtained by the authors and by AI assistants may differ by a few percent. Nevertheless, such minor discrepancies are not eliminative in assessing the accuracy of the solution proposed by the AI assistant. Finally, the required nominal diameter of the compressed air distribution system, adopted after standardization at the end of the second iteration, is DN125.

The complete solution of the problem in two iterations (including the nomogram used, the equivalent length diagram, and the table of standard diameters) provided by the authors can be found at link (Itro2026 Data, 2026). The same link also contains the solutions to this problem obtained 12 January 2026, within the scope of the experiment, by seven different AI assistants. All tested versions of the AI assistants were free versions in order to ensure identical initial conditions for the evaluation. The correctness of the complete solution procedures proposed by these AI assistants, as well as their most significant characteristics, are analyzed in the following section.

3.1 ChatGPT (GPT-5.2)

In the first iteration, GPT concluded that the initial diameter DN100 was borderline and therefore adopted DN125 as an acceptable initial nominal diameter. In the second iteration, this AI assistant selected the next higher standard diameter, DN150. GPT oversized the pipeline. In the first iteration, it used a compressed-air pressure drop nomogram, i.e., a nomogram with seven vertical scales from which the pipeline diameter is determined directly on the basis of four given parameters (Kaeser Compressors, 2015, pp. 54–55). However, the result of the first iteration should not be a nominal diameter (obtained by rounding up to the next higher standard value); rather, it should be only an initial diameter to be used as input for the second iteration. Standardization at this stage resulted in an excessively large diameter being carried into the second iteration. The equivalent lengths of individual local resistance elements, as well as the total equivalent length, are not meaningful to analyze, since they were calculated for an initial diameter larger than required. As, in the second iteration, the total equivalent length predictably increased the actual pipeline length, this AI assistant ultimately adopted the next higher standard nominal diameter, DN150.

3.2 DeepSeek V3

In the first iteration, this AI assistant determined the initial diameter to be DN80, and after accounting for pressure losses due to local energy losses, it adopted DN100. DeepSeek undersized the pipeline diameter. The solution begins with an unnecessary consideration of whether the given average operating pressure of 7.5 bar already includes atmospheric pressure or not. However, engineers working in this field are aware that pneumatic systems are always analyzed using gauge pressure (i.e., in this case, 7.5 bar above atmospheric pressure). At the end of this consideration, DeepSeek makes an error by stating, “I’ll assume $P_{abs,avg}$ = 7.5 bar”. This incorrect assumption resulted in an excessively small diameter at the end of the first iteration.

This AI assistant also performed unnecessary calculations, since the initial diameter should be read directly from the nomogram (using the four given parameters), thereby completing the first iteration immediately. It is particularly noteworthy that the problem statement specifies that “the allowable pressure drop between the receiver and the point farthest from the receiver is specified by the designer and is equal to 0.1 bar.” Nevertheless, DeepSeek recalculated and determined the pressure drop per 100 m of pipeline length, which is entirely unnecessary. Furthermore, the equivalent lengths were determined analytically by this AI assistant, whereas the problem explicitly suggests the use of an equivalent length diagram. The equivalent lengths are not meaningful to analyze, since they were calculated for an initial diameter smaller than required.

3.3 Grok 4

In the first iteration, Grok determined an initial diameter of 108 mm, and in the second iteration, 110 mm. However, it did not perform diameter standardization at the end. Unlike DeepSeek, Grok correctly and routinely concludes that the operating pressure of 7.5 bar represents gauge pressure. In the first iteration, this AI assistant used the compressed-air pressure drop nomogram to determine an initial diameter of 108 mm, which is extremely close to the value of 105 mm obtained by the authors. This minor difference (which does not affect the subsequent calculation procedure) can be attributed to reading from a diagram with a logarithmic scale. Grok did not adopt the next higher standard diameter, nor was this necessary at that stage.

Although its solution states “Use equivalent length diagrams/tables …”, it can be concluded that in the second iteration Grok did not use the equivalent length diagram. Instead, this AI assistant chose to interpolate data from tables of standard diameters in order to determine the equivalent lengths for a diameter of 108 mm, rather than reading the values directly from the equivalent length diagram. It is interesting to note that Grok determined the equivalent length for a “valve with a large pressure drop due to multiple changes in flow direction” to be 36.7 m, which is very close to the value of 40 m read by the authors. Finally, the conclusion provided by Grok regarding standardization and the adoption of the nominal diameter, as shown in Fig. 1, contains a highly dangerous erroneous recommendation.

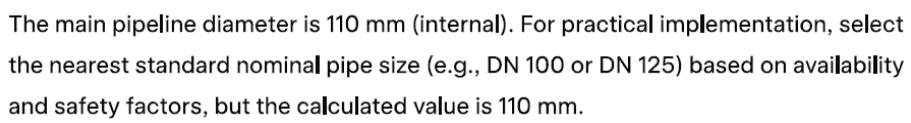


Figure 1. Recommendation for adopting the standard pipeline diameter proposed by Grok

Specifically, the wording "…based on availability …" implies that a nominal diameter of DN100, which is smaller than the value of 110 mm obtained in the second iteration, could also be adopted. A fundamental rule that is applied without exception in all engineering sizing tasks is that the first higher standard value must always be selected.

3.4 Perplexity

This AI assistant proposed a solution in which a diameter of 100 mm was determined in both the first and the second iteration, which means that the pipeline was undersized. Perplexity begins the calculation by assuming an initial pipeline diameter of DN80, without explaining why this particular value was selected. Subsequently, in the first iteration, it determines the equivalent lengths for this diameter, calculates a diameter of 90 mm, and proposes the adoption of the first higher standard diameter—an action that is not required in the first iteration. In the second iteration, Perplexity recalculates the equivalent lengths for the adopted diameter and obtains a total equivalent length of 95 m, which is significantly lower than the 179 m determined by the authors. This result is expected, since the AI assistant performed the calculation for a diameter smaller than required. Upon repeated use of the nomogram, this AI assistant effectively confirms the DN100 diameter obtained in the first iteration, which would imply that all local losses have no effect—an incorrect conclusion. It is also noteworthy that Perplexity cited as many as 19 different references used in solving this task, even though the solution itself is brief and supported by very limited explanation.

3.5 Google Gemini 1.5 Flash

In the first iteration, Google Gemini determined an initial diameter of 100 mm, while in the second iteration it rounded the diameter up to the first higher standard value and adopted the correct nominal diameter DN125. The solution proposed by this AI assistant is concise, but the procedure contains all necessary steps in the correct order. From the presented solution, it can be implicitly concluded that Google Gemini indeed used the compressed-air pressure drop nomogram, as it states: "Based on standard nomograms for these parameters, the internal estimated diameter will likely fall around 100 mm to 125 mm." It is evident that, on the nomogram, the diameter was closer to the lower value (as expected), since the AI assistant concludes: "Let's assume a trial diameter of 100 mm for the first refinement." In the second iteration, Google Gemini determined the equivalent lengths using a table, although the problem statement suggests the use of an equivalent length diagram. The total calculated length of 727 m is very close to the value of 754 m obtained by the authors.

3.6 Claude Sonnet 4.5

In the first iteration, Claude determined the initial diameter to be 73.4 mm (and adopted DN80, which is an unnecessary step). In the second iteration, this AI assistant confirmed that the nominal diameter should be DN80, indicating that Claude undersized the pipeline. Claude makes an error at the very beginning by assuming that the operating pressure of 7.5 bar is an absolute pressure. Furthermore, although the problem explicitly states that a nomogram and an equivalent length diagram should be used, this AI assistant applies an analytical calculation procedure in the first iteration, combining equations for volumetric flow rate, the Darcy–Weisbach formulation, and the Renouard equation (while only mentioning that a nomogram could be used, but not actually using it). Due to adopting the operating pressure as an absolute pressure, the diameter obtained in the first iteration is insufficiently large and is rounded up to the first higher standard value, which should not be done in the first iteration. For determining equivalent lengths, Claude used neither the preferred equivalent length diagram nor a table (as, for example, Grok did), but instead determined them analytically. The diameter from the first iteration was used in these calculations, resulting in incorrect values and an underestimated total equivalent length. The second iteration was carried out using the same formulas as in the first, and Claude did not obtain the expected new and larger diameter value, instead recommending the previously adopted DN80.

3.7 Meta Llama 4

This AI assistant begins the first iteration by assuming an initial diameter of DN100, which results in equivalent lengths being determined in both iterations (similarly to Perplexity). At the beginning of the first iteration, Meta states: "Calculate equivalent lengths for components (using diagrams or tables)," which does not satisfy the requirement to "Explain the complete calculation procedure," as it does not specify whether an equivalent length diagram or a table was used. The obtained results deviate significantly from those determined by the authors, although for a diameter of 100 mm they should be identical or very similar. Consequently, the total length is significantly smaller than required (642 m instead of 754 m). Subsequently, instead of using the seven-scale nomogram from which the diameter could be determined directly, Meta states: "Use a nomogram

(e.g., Crane or similar) to find the pressure drop for DN100," without specifying which nomogram was actually used. After obtaining a pressure drop smaller than the allowable pressure drop specified in the problem statement, Meta concludes: "let's try a smaller diameter, DN80." This diameter is then used in the second iteration, where equivalent lengths are again determined (without specifying the method) and the pressure drop is calculated, ultimately confirming DN80 as the required nominal pipe diameter in the compressed air distribution system. Meta thus undersized the pipeline diameter. It is also noteworthy that this AI assistant cited only a single reference in solving the given problem.

4 CONCLUSION

This preliminary study has shown that Google Gemini currently exhibits the greatest potential for successful sizing of the diameter of compressed air distribution systems. However, in the near future, the testing should be repeated multiple times using the same input data in order to verify whether this AI assistant maintains its accuracy. Furthermore, through a series of experiments, it should be examined whether Google Gemini produces correct results for a range of varied input parameters.The potential demonstrated by Grok also represents a solid foundation, particularly because it is evident that it was the only AI assistant that actually read diameter values directly from the seven-scale nomogram, in the same manner as the authors of the problem. Nevertheless, the final conclusion drawn by this AI assistant regarding the adoption of the standard diameter currently renders it unreliable.

ChatGPT was the only tested AI assistant that oversized the pipeline. As discussed earlier, this has negative consequences in the form of increased investment costs, but also a positive effect, as it enables faster system response, making an oversized compressed air system suitable for conditions with highly fluctuating compressed air demand. However, as many as four AI assistants (DeepSeek, Perplexity, Claude, and Meta) undersized the pipeline diameter. (In a certain sense, Grok could also be placed in this group, since it did not adopt the first higher standard diameter and even suggested that the next smaller standard diameter could be selected.) As explained earlier, this has serious and multifaceted negative consequences, particularly with respect to system functionality, reliability, and energy efficiency.

Thus, despite the fact that the task used to test the seven AI assistants represents a routine engineering problem that is very common in practice and for which a large number of high-quality references and examples are available online, the experiment demonstrated that, at present, only one of them was capable of executing all procedural steps and arriving at the correct result. A single prompt per AI assistant may not be representative and that results could vary across repeated queries.

Although the task for the AI assistants was formulated in greater detail and with more precision than would be necessary for an expert solving such a practical problem, the authors conclude that the task itself could be supplemented with a requirement for AI assistants to provide diagrams illustrating how the relevant quantities were selected (as can be seen from the nomogram and the equivalent length diagram in the solution provided by the authors). It is possible that such a requirement would exceed the capabilities of the free versions of some AI assistants. It is also interesting to note that, although several of the tested AI assistants determined equivalent lengths using tables (which is also a legitimate approach) rather than via equivalent length diagrams (even though this was explicitly required in the task), none of them explained why a tabular method was chosen.

This paper represents a contribution to the improvement of AI assistants in the field of their application to engineering problem-solving, as it is inevitable that, in the near future, such routine engineering tasks will increasingly be addressed using AI assistants.

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Social Media and Gamification in Youth Digital Entrepreneurship Education

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Abstract. This paper examines the potential of social media platforms as informal learning environments for developing digital entrepreneurship competences among youth, with gamification as an educational enhancement tool. The central research problem concerns the absence of a theoretically grounded and structurally integrated conceptual framework connecting social media-based learning mechanisms with gamification principles to support measurable entrepreneurial competence development among youth. This paper is conceptual in nature and addresses the research question: How can social media learning mechanisms be structurally integrated with gamification principles to support measurable entrepreneurial competence development among youth? The analysis of existing platforms reveals that most solutions address either educational or motivational dimensions separately, lacking comprehensive integration. The study proposes a conceptual framework and identifies directions for future empirical research.

Key words and phrases: Digital entrepreneurship, youth education, social media, gamification

1 INTRODUCTION

In the contemporary digital environment, young people spontaneously use social media as informal learning spaces for developing entrepreneurial ideas. However, these processes remain fragmented, unstructured, and unsystematically monitored in terms of competence development. Simultaneously, existing gamified entrepreneurship education platforms rarely integrate social media characteristics with structured entrepreneurial skill development. The central research problem concerns the absence of a theoretically grounded and structurally integrated conceptual framework connecting social media-based learning mechanisms with gamification principles for measurable entrepreneurial competence development among youth. This paper is conceptual in nature and addresses the following research question: How can social media learning mechanisms be structurally integrated with gamification principles to support measurable entrepreneurial competence development among youth?

Digital entrepreneurship has evolved since the early 1990s, expanding from establishing digital businesses to encompassing the intersection of digital technologies and entrepreneurial practices (Kollmann et al., 2022; Primario, 2022). It involves the transformation of business elements through digitalization, the creation, distribution, and sale of digital products and services via electronic networks combining classical entrepreneurial practices with contemporary digital technologies (Ganefri, 2024; Kraus et al., 2019). Digitalization has rendered entrepreneurial boundaries more fluid: products can be continuously improved post-launch, and digital infrastructures enable iterative cycles of rapid testing and adaptation (Nambisan, 2016). Digital entrepreneurship manifests in diverse forms, including e-commerce, content creation, social media influence, online courses, digital services, and platform-based models such as affiliate marketing and transaction platforms (Saputra et al., 2025). New channels for direct customer communication, innovative revenue models such as subscriptions, and collaboration through digital platforms have expanded the competitive landscape for young entrepreneurs (Guerola-Navarro et al., 2024; Mostaghel et al., 2022). Young people, as digital natives, represent a particularly significant demographic for this field, naturally integrating technology into daily life and entrepreneurial learning (Vitvitskaya, 2022).

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2 Theoretical Framework

The theoretical foundations of this paper draw on three interconnected bodies of knowledge, each corresponding to a distinct segment of the proposed conceptual model. Social Identity Theory and Social Cognitive Theory inform the psychological mechanisms layer. According to Social Identity Theory, young people shape their identity through social media by connecting with groups successful in entrepreneurship, strengthening self-confidence. Social Cognitive Theory emphasizes that social media increases youth self-efficacy and motivation for entrepreneurial activities (Afranie et al., 2024). Digital technologies also support entrepreneurial activities in micro-enterprises, strengthening community influence on entrepreneurs (Soluk et al., 2021). Theories of gamification and motivation underpin the gamification layer (Koivisto, 2019; Isabelle, 2020). Together, these frameworks explain how social media features generate psychological effects that gamification can amplify and structure to produce measurable entrepreneurial outcomes.

2.1 Social Media as Learning Environment

Social media represents an important tool that young people use for socialization, academic work, marketing, and market research (Minocha, 2022). These platforms enable youth to develop entrepreneurial ideas, establish contacts, and access relevant information (Gray, 2018). Online communities function as catalysts for entrepreneurial learning through exchange of experiences, advice, and emotional support — expanding entrepreneurial learning from individual to socially grounded processes in digital communities (Shou, Bucher, & Waldkirch, 2021). Platforms such as Instagram, Facebook, YouTube, and TikTok enable entrepreneurs to build direct communication with consumers through comments, live streams, and Q&A sessions, building trust and long-term relationships while leveraging algorithms for precise audience targeting (Duralia, 2024; Saputra et al., 2025).

2.2 Social Media Mechanisms: TikTok as Educational Platform

In the contemporary digital environment, micro-content emerges as a dominant form of communication combining brevity, clarity, and visual attractiveness to convey information efficiently (Kumar & Nanda, 2024). Its characteristics are particularly relevant to entrepreneurial learning: it adapts to shorter attention spans; reduces cognitive load in information processing; enables flexible learning in phases for students with limited time; integrates naturally with mobile technologies; and connects with gamification by making progress measurable and enabling challenge-based assessment instead of traditional exams (Nagy, 2018). These features make micro-content a core mechanism through which social media platforms support entrepreneurial education.

TikTok is increasingly becoming a space for entrepreneurial learning among youth through several interconnected mechanisms: (1) Algorithmic personalization delivers content tailored to user interests, enabling targeted exposure to business models and consumer engagement strategies (Rydenfelt et al., 2025); (2) Real-time peer-generated content provides tutorials and business case studies in formats familiar to students (Lu et al., 2025); (3) Observational learning enables students to imitate successful entrepreneurs, learning sales messaging and audience analysis (Qian et al., 2022); (4) Interactivity and feedback through comments, likes, and duets create iterative learning loops and strategy adaptation (Wang et al., 2023); (5) Micro-learning enables knowledge consumption, production, and social validation, reducing entry barriers to entrepreneurial topics (Khlaif & Salha, 2021; Kumar & Nanda, 2024). However, successful use requires critical digital literacy, as content may include inaccurate or oversimplified advice (Sirait, 2025).

3 Gamification on Social Media Platforms

Gamification is the application of game elements and principles to non-game activities with the aim of making them motivating and engaging, not merely adding points or badges, but designing systems optimized for human motivation and user engagement (Isabelle, 2020). Gamification is increasingly used in digital platforms to increase user engagement; well-designed systems encourage motivation and loyalty, while superficial approaches lead to frustration (Koivisto, 2019). Social networks and gamification complement each other: networks provide platforms for communication, collaboration, and content sharing, while gamification adds motivational elements that increase participation and interaction (Alemany, 2020). A well-known example is LinkedIn, where a visual progress bar led to a 20% increase in profile completion rates (Spanellis et al., 2020).

Table 1 presents an enhanced overview of gamification elements across key platforms, extended with the underlying psychological mechanisms and their position within the proposed conceptual model.

Table 1. Overview of gamification elements on digital platforms

Platform	Gamification Element	Effect on Users	Underlying Psychological Mechanism	Position within Conceptual Model	Effect on Entrepreneurship
LinkedIn	Profile Strength Meter; Skill Badges	Encourages profile optimization and professional self-presentation	Goal-setting; Self-monitoring; Identity reinforcement	Psychological Mechanisms (Identity formation) + Gamification Layer (Progress tracking)	Strengthens professional credibility within entrepreneurial networks
Duolingo (community)	XP points; Streaks; Leaderboards; Badges	Sustains engagement and habit formation	Intrinsic motivation; Habit formation; Competence feedback loop	Gamification Layer (Motivational reinforcement)	Structural model for entrepreneurial skill acquisition platforms
Facebook / Instagram	Challenges; Top Fans badges; Streaks	Enhances loyalty and repeated participation	Social reinforcement; Community belonging; Recognition seeking	Social Media Features + Gamification Layer	Build brand communities and stimulate customer retention
Reddit	Karma points; Awards	Encourages quality participation and reputation building	Reputation economy; Social validation; Peer evaluation	Psychological Mechanisms (Perceived social capital)	Test ideas, gain credibility, refine concepts through feedback
TikTok	Viral Hashtag Challenges; Algorithmic Visibility Rewards	Stimulates mass participation and content replication	Observational learning; Social proof; Reward anticipation	Social Media Features (Observational learning) + Gamification Layer (Visibility incentives)	Viral marketing, rapid brand exposure, market positioning experiments

Existing gamified entrepreneurship platforms demonstrate partial integration of educational and motivational elements. For example, SimVenture provides realistic business simulations but remains academically structured and less socially interactive. GoVenture introduces progression logic and competitive dynamics, yet emphasizes individual performance over collaborative learning. GoodWall prioritizes networking and motivational challenges but lacks structured entrepreneurial skill tracking. These examples indicate that existing solutions address isolated dimensions of entrepreneurship learning, rather than offering an integrated socio-digital competence development framework. The advantage of such solutions is that users can make mistakes without real consequences and develop basic skills; however, most tools focus either on education or motivation but rarely combine both, and few integrate systematic skill development tracking.

4 Proposed Conceptual Model

The following conceptual model synthesizes the theoretical and analytical insights presented above. It illustrates the structural logic connecting social media features, psychological mechanisms, gamification elements, and entrepreneurial outcomes, representing the central theoretical contribution of this paper.

Social Media Features:

Algorithmic personalization | Peer-generated content | Observational learning | Real-time feedback | Micro-content delivery

↓ Influence through social learning mechanisms

Psychological Mechanisms:

Entrepreneurial self-efficacy | Social identity formation | Perceived behavioral control

↓ Strengthened by gamification elements

Gamification Layer (Reinforcement and Structuring Mechanism):

Progress tracking | Challenges and missions | Badges and rewards | Peer competition and collaboration

↓

Outcomes:

Entrepreneurial intention | Skill acquisition | Measurable entrepreneurial competence

The model illustrates the logical flow from social media features to psychological mechanisms influencing entrepreneurial behavior. Gamification operates as a structural layer that stabilizes, amplifies, and renders measurable the learning process. Final outcomes are the development of entrepreneurial intention, concrete skills, and measurable competence. This model is presented as a conceptual integration framework, not as an empirically tested structure, its empirical validation represents an important direction for future research.

5 LITERATURE SYNTHESIS

Table 2 synthesizes key literature according to the mechanisms of the proposed conceptual model, providing analytical grounding for each element of the framework.

Model Mechanism	Core Concept	Representative Authors	Analytical Implication for the Model
Social Media Features	Algorithmic personalization	Rydenfelt et al. (2025)	Personalization functions as an engagement amplifier within the social learning environment.
	Observational learning	Qian et al. (2022)	Learning through imitation of successful entrepreneurial behaviors.
	Real-time feedback	Wang et al. (2023)	Enables iterative behavioral adjustment.
	Micro-learning	Khlaif & Salha (2021); Kumar & Nanda (2024)	Supports fragmented but continuous competence acquisition.
Psychological Mechanisms	Entrepreneurial self-efficacy	Afranie et al. (2024); Primario (2022)	Strengthens confidence in entrepreneurial action.
	Social identity formation	Afranie et al. (2024)	Facilitates identification with entrepreneurial communities.
	Perceived behavioral control	Ganefri (2024)	Increases perceived capability to initiate business activities.
Gamification Layer	Motivational systems	Koivisto (2019); Isabelle (2020)	Enhances sustained engagement through structured incentives.
	Progress tracking	Spanellis et al. (2020)	Visual feedback reinforces persistence and goal orientation.
	Peer competition / collaboration	Alemany (2020)	Social dynamics improve retention and interaction.
Outcomes	Entrepreneurial intention	Soluk et al. (2021)	Digital contexts influence entrepreneurial activation.
	Competence development	Kraus et al. (2019); Nambisan (2016)	Transformation of digital participation into measurable competence.

6 CONCLUSION

This paper has explored the convergence of digital entrepreneurship education, social media learning environments, and gamification approaches for youth development, revealing that digital platforms function as powerful informal learning environments through algorithmic personalization, peer-generated content, and iterative feedback loops.

The theoretical contribution of this paper lies in the proposed conceptual model structurally integrating social media learning mechanisms with gamification principles within a unified framework. This model addresses the identified gap: the absence of a theoretically grounded framework connecting social media-based learning with gamification for measurable entrepreneurial competence development among youth. By mapping social media features, psychological mechanisms, gamification elements, and outcomes onto a coherent structure, the model provides a foundation for future empirical research and platform design.

From a practical standpoint, the model implies that effective entrepreneurship education platforms should combine structured business learning with social media interaction features, enabling experimentation without real-world consequences while building genuine competences. Critical digital literacy remains essential.

Future research should focus on empirically testing the proposed framework, developing platforms that bridge identified gaps through individual skill development and collaborative community features. Longitudinal studies examining the transition from social media-based informal learning to formal entrepreneurial outcomes would provide valuable insights, as would research on balancing engagement with substantive skill development.

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Personal and Social Development (PSD) in Secondary Schools in the Republic of Serbia

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Abstract. Contemporary education is increasingly shifting from purely academic outcomes toward the holistic development of students. Personal and Social Development (PSD) has emerged as a strategic concept integrating personal, social, and emotional competencies within modern educational systems. This paper presents a theoretical and policy-oriented review of PSD in secondary education in the Republic of Serbia. The analysis is based on a review of international research literature and an examination of national legislative and strategic documents. The paper explores the extent to which PSD is normatively embedded within the Serbian educational framework and discusses its practical implementation in relation to curriculum design, school climate, teacher professional development, and evaluation approaches. The findings indicate that although Serbia possesses a solid normative foundation supporting PSD, its implementation remains implicit and fragmented. The paper concludes that sustainable institutionalization of PSD requires clearer curricular articulation, stronger professional capacities, and more systematic evaluation mechanisms aligned with holistic educational goals.

Keywords and phrases: Personal and Social Development, PSD, Implementation, Secondary Education, Serbia**.**

1 INTRODUCTION

Until the end of the last century, research in the field of education primarily focused on its cognitive and academic aspects, that is, on achievement (Tošić Radev & Pešikan, 2017). Today, contemporary educational systems increasingly emphasize the importance of developing the whole personality of the student, not only through cognitive achievement but also through the development of personal and social competencies. In the international context, the concept of Personal and Social Development (PSD) began to be used toward the end of the twentieth century, particularly in the educational policies of Anglo-Saxon countries, where it became associated with Social and Emotional Learning (SEL), active citizenship, and the empowerment of students for their life roles (Slee, 1998; Zins et al., 2004). The concept of PSD represents one of the key dimensions of education aimed at empowering individuals for active, responsible, and functional participation in society.

Research indicates that systematic support for socio-emotional development contributes to students' academic achievement, improved school adjustment, and long-term life success (Greenberg et al., 2003; Zins et al., 2004). Meta-analytic studies further confirm that an integrated approach to social and emotional learning leads to statistically significant improvements in academic performance, as well as a reduction in risk behaviors (Durlak & Weissberg, 2011).

Jones and Bouffard (2012) emphasize that the development of social and emotional competencies should not remain at the level of isolated programs, but must become an integral part of everyday school practice and organizational culture. It is precisely within this broader organizational framework that PSD is positioned as a holistic concept encompassing students' personal, social, and professional development.

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According to Erikson, personal development is closely linked to identity formation and the resolution of developmental crises that may arise at different stages of life, but are particularly characteristic of adolescence (Erikson, 1968). Adolescence represents a highly sensitive "transitional period for the individual, from childhood to adulthood" (Kulić, 2025, p. 28). Therefore, PSD in secondary education—that is, in the education of adolescents—constitutes a highly significant issue in contemporary education as a whole.

When viewed within the educational context, personal development encompasses components such as self-awareness, self-esteem, emotional regulation, motivation, goal setting, decision-making, taking responsibility, resilience, the ability to cope with stress, and conflict resolution skills. The development of these competencies constitutes the foundation of students' mental health and their successful functioning both in the school setting and in the broader social environment (Denham et al., 2010).

Vygotsky argues that individual development occurs through social interaction and that learning and development operate in synergy with the social context (Vygotsky, 1978). Social development itself refers to an individual's ability to establish and maintain high-quality relationships with others, understand social norms, and participate constructively in the community. In the educational context, social development includes communication skills, the development of empathy, understanding others, cooperation and teamwork, non-violent conflict resolution, and respect for diversity and social norms (Krnjajić, 2002; Spasenović, 2013). Progress in social development cannot occur without personal development and the learning process itself—that is, without the education of the individual, particularly during preschool and school age.

The concept of PSD encompasses a set of knowledge, skills, attitudes, and values that enable students to understand themselves, regulate their own emotions and behavior, build high-quality relationships with others, and respond constructively to the challenges of contemporary society. This concept interacts with the idea of lifelong learning, as well as with the educational goals defined in international and national strategic documents (OECD, 2018).

Contemporary international competency frameworks for the 21st century emphasize the importance of communication, collaboration, critical thinking, and adaptability (Partnership for 21st Century Learning, 2019). UNESCO (2015) highlights that education should contribute to the development of responsible, ethical, and socially engaged individuals. These objectives are fully aligned with the principles of PSD, thereby confirming its strategic importance in contemporary education.

In the Republic of Serbia, educational policy has, for several years, been oriented toward the broader development of students, including PSD, primarily through two key strategic documents: *the Law on the Foundations of the Education System* and *the Education Development Strategy of the Republic of Serbia until 2030*. These documents emphasize competencies for life and work and outline ways in which students' personal and social development can be integrated into subject teaching and extracurricular activities. At present, there is no national curriculum that explicitly defines PSD as a distinct and mandatory area, nor is it formally recognized as such within official curricula and syllabi. Nevertheless, elements of PSD are embedded in the Serbian educational system through general educational objectives, learning outcomes, and cross-curricular competencies. Of particular importance are the cross-curricular competency for personal and social development, the subject Civic Education, programs for the prevention of violence and discrimination, homeroom community activities, and extracurricular programs.

This paper applies a qualitative analytical approach based on the review of relevant scientific literature and the analysis of national policy and legislative documents. The aim is not to present original empirical findings, but to provide a structured overview of the theoretical foundations and institutional positioning of Personal and Social Development (PSD) within the Serbian secondary education system.

2 THE NORMATIVE FRAMEWORK FOR THE INTEGRATION OF PSD INTO THE EDUCATION SYSTEM OF THE REPUBLIC OF SERBIA

Contemporary educational theory emphasizes a curriculum-based approach; however, the Serbian education system still predominantly relies on subject-based curricula and syllabi, which makes the systemic and visible integration of students' personal and social development more challenging. The implementation of PSD within teaching plans and programs in Serbia is grounded in strategic and normative documents that define the goals of education. Students' PSD in Serbia has a strong foundation in the current legislative and strategic framework, particularly in *the Law on the Foundations of the Education System* and *the Education Development Strategy of the Republic of Serbia until 2030*, which emphasize the development of key competencies, the strengthening of the school's educational (formative) role, and the creation of an inclusive learning environment (Jakovljević, 2022). In addition to these documents, students' PSD is further supported by other official regulations, such as *the Rulebook on Additional Educational, Health, and Social Support for Children, Students, and Adults*; *the Rulebook on Standards of Quality of Work of Educational Institutions*; and *the Law on Secondary Education*, among others.

As the fundamental normative act of the education system of the Republic of Serbia, particular importance is attributed to *the Law on the Foundations of the Education System* ("Official Gazette of the Republic of Serbia", Nos. 88/2017, 27/2018 – other law, 10/2019, 6/2020, 129/2021, 92/2023, and 19/2025). This law regulates the objectives, principles, learning outcomes, standards, competencies, organization, and conditions for the implementation of preschool, primary, secondary, and adult education. Within the general objectives of education (Article 8), the law explicitly promotes the well-being and holistic development of the child and student, a safe and supportive environment, the development of healthy lifestyles, ecological and civic awareness, critical thinking, teamwork, initiative, positive values, and competencies for active participation in contemporary society. Although the term Personal and Social Development (PSD) is not explicitly defined, its key components are integrated into the objectives, principles, learning outcomes, and cross-curricular competencies of the education system. In this way, the obligation to systematically foster students' PSD in Serbian schools is normatively established.

The Education Development Strategy of the Republic of Serbia until 2030 (2021) represents the overarching strategic document of Serbia's education policy, aligned with international frameworks such as *the 2030 Agenda for Sustainable Development* and the initiative *Towards a Sustainable Europe 2030*. Its vision is grounded in the development of a knowledge-based society founded on universal values—equality, solidarity, mutual respect, and access to quality education. The *Strategy* is oriented toward the development of competencies for life and lifelong learning, moving beyond an exclusively academic approach and emphasizing the development of skills, attitudes, and values applicable in contemporary society. Particular emphasis is placed on strengthening the educational (formative) role of the school and on whole-school support for students, thereby institutionally fostering Personal and Social Development (PSD). Furthermore, the promotion of inclusive education contributes to the development of social competencies through the recognition of diversity and the provision of equitable access to education for all students.

In addition to the overarching legal and strategic acts, the implementation of students' Personal and Social Development (PSD) in Serbia is supported by several other relevant normative documents. *The Rulebook on Additional Educational, Health, and Social Support for Children, Students, and Adults* provides for individualized support aimed at enhancing educational, social, and emotional functioning. *The Rulebook on Standards of Quality of Work of Educational Institutions* obliges schools to ensure a safe, supportive, and inclusive environment based on cooperation and mutual respect. *The Law on Secondary Education* emphasizes the development of personal, social, and professional competencies, while the Nacionalni okvir kvalifikacija Republike Srbije incorporates into learning outcomes not only knowledge and skills, but also responsibility, cooperation, and ethical conduct. Furthermore*, the Career Guidance* and *Counseling Strategy* promotes the development of self-awareness, decision-making, and personal development planning, which is fully aligned with the principles of PSD.

The analysis of these documents indicates that PSD has a solid normative and strategic foundation; however, its implementation remains largely implicit and fragmented. Although its components are integrated into the objectives, standards, and competencies of the education system, PSD is not clearly structured as an independent and measurable domain. Consequently, its practical realization largely depends on the initiative of individual schools and the resources available to them. Therefore, despite the existence of a favorable legal framework, additional improvements and more precise operationalization are necessary to ensure the systemic and consistent implementation of PSD.

3 IMPLEMENTATION OF PSD THROUGH TEACHING IN SECONDARY SCHOOLS IN THE REPUBLIC OF SERBIA

Students' Personal and Social Development (PSD) is more easily integrated into a curriculum-based framework than into a traditional subject-based syllabus, as the curriculum itself encompasses learning outcomes, the educational (formative) dimension, and cross-curricular competencies. In Serbian secondary education, teaching plans and programs still represent the dominant framework for the organization of instruction; however, they are increasingly interpreted in line with a contemporary curriculum approach that places emphasis on learning outcomes, competencies, the formative role of the school, and the active role of students. It is precisely within this space that opportunities emerge for the integration of PSD through clearly defined learning outcomes, teaching methods, forms of classroom organization, and approaches to assessment and evaluation.

Although this paper is primarily theoretical in nature, selected empirical data collected in 2025 are presented illustratively to contextualize the discussion. According to a study conducted in 2025 among 115 secondary school students in Serbia, 35.4% of respondents stated that they "mostly" engage in personal development, 31% reported doing so to a moderate extent, while 8.8% indicated that they do not engage in personal development at all. The areas in which students expressed the strongest interest in improving their skills include strengthening self-confidence (51.3%), managing stress and emotions (46.9%), and developing communication skills, leadership, and time management (approximately 40%). These findings clearly indicate that students recognize the importance of so-called "soft skills," which are essential for personal development, mental health, and future professional success. The competencies identified by the surveyed students undoubtedly represent core elements of PSD. This suggests that, through the systematic and carefully designed introduction of PSD, students in Serbia would be willing to embrace it and engage in personal development to a greater extent than they currently do.

The most effective mechanism for integrating Personal and Social Development (PSD) into existing curricula lies in embedding it within learning outcomes. In addition to cognitive achievements, teachers can plan outcomes aimed at fostering social and personal competencies such as cooperation, communication, responsibility, self-confidence, and critical thinking. In this way, PSD is implemented in parallel with the delivery of regular subject content, in accordance with current regulations that define learning outcomes through knowledge, skills, and attitudes. Furthermore, schools are granted the possibility of adapting a portion of the curriculum (up to 10%), which creates space for interdisciplinary collaboration among teachers and professional associates, as well as for the implementation of thematic workshops and project-based learning. Such an approach contributes to strengthening students' sense of belonging, responsibility, and interconnectedness within the school community. Systematic support provided by pedagogues, psychologists, and teachers plays a crucial role in stabilizing students' socio-emotional development, improving communication and decision-making processes, and represents an important factor in their holistic development.

In secondary schools in the Republic of Serbia, Personal and Social Development (PSD) does not exist as a separate subject; rather, it is present as an integrated component of the educational process. In accordance with the current legislative and strategic framework, PSD is implemented through the learning outcomes of regular instruction, the application of contemporary teaching methods (such as project-based, problem-based, and cooperative learning), as well as through extracurricular activities and practical training. In this way, students develop communication skills, responsibility, teamwork, critical thinking, and social adaptability. Within the Serbian context, vocational secondary schools and the dual education model play a particularly significant role,

as students acquire a professional identity, self-discipline, and work habits through work-based learning with employers in real-life settings. Extracurricular activities, student parliaments, volunteer work, and project engagement further contribute to the development of civic awareness, empathy, and a sense of belonging to the community.

However, although the normative framework enables the integration of PSD, its implementation in practice in Serbia largely depends on the initiative of individual schools, teachers, and the availability of resources. Consequently, there is variability in the quality and intensity of its application, which indicates the need for more systematic planning and clearer monitoring of students' personal and social development outcomes.

4 CREATING A SUPPORTIVE SCHOOL ENVIRONMENT

A supportive school environment constitutes a fundamental prerequisite for the successful and sustainable implementation of PSD. Research indicates that the quality of school climate directly influences the development of students' social and emotional competencies (Cohen et al., 2009; Thapa et al., 2013). A positive school climate—grounded in trust, safety, participation, and mutual respect—represents a key condition for the sustainable implementation of Personal and Social Development (PSD). As Fullan (2007) emphasizes, educational change is not sustainable without the transformation of the school's organizational culture, confirming that PSD should be viewed as part of a broader institutional reform that integrates academic and developmental goals. Rutledge et al. (2015) further highlight that personalized learning approaches, which take into account students' personal and social needs, foster engagement and socio-emotional development, thereby affirming that PSD constitutes an essential dimension of education.

PSD requires a holistic approach that encompasses school culture, relationships within the school community, leadership practices, and everyday pedagogical work. Within such an environment, students develop self-confidence, responsibility, and social skills through open communication, respect for diversity, and non-violent conflict resolution. The role of teachers and school leadership is reflected in modeling professional behavior, providing support, and creating stimulating conditions for students' development. A modern, safe, and functional school environment further contributes to students' sense of belonging and positive identification with the school, thereby strengthening the sustainability of PSD within the education system.

5 TEACHER TRAINING AND PROFESSIONAL DEVELOPMENT

In secondary schools in the Republic of Serbia, where PSD is not established as a separate subject, teachers represent a key factor in its implementation. Through their pedagogical approach, communication style, and selection of teaching strategies, they directly influence the socio-emotional climate of the classroom and students' development. Contemporary research confirms that teachers' socio-emotional competencies significantly shape the school environment (Jennings & Greenberg, 2009), while the concept of the "prosocial classroom" highlights the link between teachers' emotional competence, increased student engagement, and reduced conflict. Hargreaves and Fullan (2012) emphasize the importance of professional capital and continuous professional development, and the OECD (2020) underscores the role of professional autonomy and collaborative networks in fostering students' socio-emotional competencies.

Empirical data collected in 2025 from a sample of 76 secondary school teachers in Serbia indicate a pronounced willingness to engage in professional development, but also highlight the need for additional support in planning and enhancing their own competencies. These findings confirm that the sustainable implementation of PSD is contingent upon continuous professional training, systemic support, and the development of reflective pedagogical practice. In this regard, responsibility for the high-quality implementation of PSD does not rest solely on individual teachers, but also on the education system as a whole, which should ensure adequate training opportunities, mentoring, and the establishment of professional learning communities.

6 EVALUATION AND MEASUREMENT OF OUTCOMES

The evaluation and measurement of PSD outcomes represent a complex yet essential component of its implementation within the educational process. Unlike cognitive outcomes, PSD involves changes in behavior, attitudes, and social skills, and therefore requires a formative, development-oriented, and ethically sensitive approach to assessment. The purpose of evaluation is not to judge students' personalities, but to monitor their progress and improve pedagogical practice.

In Serbia, PSD is not established as a separate subject; rather, it is assessed implicitly through the objectives and learning outcomes of general, vocational, and elective subjects, as well as through the evaluation of students' conduct. In practice, qualitative and combined methods are applied, such as systematic observation, self-assessment, peer assessment, reflective journals, and structured discussions, with the involvement of the homeroom teacher and the school's professional support services. Teachers play a central role in this process, while the evaluation of PSD at the school level can contribute to the improvement of school climate and the strengthening of the educational (formative) function of schooling. Although the normative framework allows for such an approach, a more systematic operationalization of PSD is needed, following the example of educational systems in which it is clearly integrated into national curricula.

7 CONCLUSION

Based on theoretical foundations, international research, and an analysis of the normative and practical framework in the Republic of Serbia, it can be concluded that Personal and Social Development (PSD) represents a key dimension of contemporary secondary education, particularly during adolescence. The collected data confirm that systematic support for the development of personal and social competencies contributes to students' well-being, academic achievement, and long-term life success.

Although PSD is clearly integrated into the framework of 21st-century competencies in the international context, in Serbia it is normatively recognized but remains implicitly and fragmentarily implemented. The absence of a precisely defined curriculum and measurable standards results in uneven practice and a reliance on the initiative of individual schools and teachers.

There is a pronounced awareness of the importance of PSD among both students and teachers; however, its sustainable implementation requires systemic support, continuous professional development, and the cultivation of a supportive school climate. Therefore, for the full institutionalization of PSD, clearer curricular grounding, more precise definition of learning outcomes, and the improvement of evaluation models are necessary, so that PSD may become a visible, systematically planned, and measurable component of the educational system of the Republic of Serbia.

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SportEdu software - quality improvement directions from teaching staff perspective

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Abstract. The modeling of a distance learning system requires a multidisciplinary approach that involves educational experts, IT professionals, designers, and security specialists to ensure a safe and reliable environment. The SportEdu system is an original creation designed to support online education proces of the Faculty of Sport and Physical Education at the University of Novi Sad. This study seeks to determine whether certain factors influence teachers' satisfaction with the use of the SportEdu distance learning system. The system was actively used for six months, corresponding to the duration of the professional training courses for sports coaches. A questionnaire was sent to 60 email addresses, and responses were received from 50 users, representing 83% of the total sample. The impact of specific factors on user satisfaction with the SportEdu system may also affect the further development and improvement of our newly implemented platform.

Key words and phrases: e-learning, distance learning, distance learning systems, modeling distance learning systems, user satisfaction, sports informaton systems.

1 INTRODUCTION

This paper aims to examine and analyze teachers' satisfaction with the SportEdu web application features and future improvement directions. Building on years of collaboration with the Faculty, the idea arose to develop a new, proprietary distance learning system designed to meet the needs of both teachers and students, while remaining highly user-friendly.

2 THEORETICAL BACKGRUOND

2.1 Distance Learning

Distance learning has become an integral part of contemporary education systems, allowing students worldwide to acquire knowledge regardless of geographical distance. To achieve success in distance learning, it is essential to implement specific procedures and techniques that can significantly streamline the process and support the achievement of intended learning outcomes. Designing such a system is a complex process that demands thorough planning and precise implementation.

2.2 Modern Distance Learning System

A distance learning system is developed gradually, built and expanded step by step. Users of such a system expect a simple yet functional experience that provides them with useful information and allows access from any location and through any device. Furthermore, if the system includes tools that enable real-time data analysis and report generation, we can confidently state that a truly modern system has been established — one that ensures user satisfaction.

2.3 SportEdu Distance Learning System Model

Following the theoretical foundation, this paper presents a new distance learning system as one web application model accessible at the following link: https://sportedu.fsfvns.edu.rs

Throughout this pilot phase, all participants successfully completed the online courses using the available learning materials and subsequently passed the final examinations in their professional subjects.

https://doi.org/10.5937/ITRO26015V

3 RELATED WORK

User satisfaction through improvements of the sports information system in the Autonomous Province of Vojvodina (Veličković, D. 2025). This study examines user satisfaction with the upgraded eSavezi sports information system of the Provincial Secretariat for Sports and Youth, Autonomous Province of Vojvodina (APV).

4 RESEARCH METHODOLOGY

4.1 Research Problem

The main component of any distance learning system is its users (teachers and students). This study seeks to determine whether certain factors influence teachers' satisfaction with the use of the SportEdu distance learning system. The impact of specific factors on user satisfaction with the SportEdu system may also affect the further development and improvement of our newly implemented platform.

4.2 Subject of the Research

The subject of this research is the level of teachers' satisfaction examined through five key elements. The SportEdu distance learning system will be analyzed through a survey conducted among its users, in order to determine to what extent they are satisfied with the following core elements of the system: technological infrastructure, user interface design, content management, evaluation and feedback and user support.

4.3 Research Objective

The aim of this research is to determine the level of user satisfaction with the SportEdu distance learning system and to examine whether certain factors influence that satisfaction.

4.4 Research Tasks

The tasks of this research are to identify whether specific factors affect the level of user satisfaction. Therefore, it is necessary to assess user satisfaction with the distance learning system after their experience using the SportEdu platform and to determine whether our variables (type of sport, gender, and age) correlate with the survey questions (i.e., whether there is a connection between these variables and the responses to questions 1-5).

4.5 Research Hypotheses

H0: Users expressed a high level of satisfaction with the use of the SportEdu distance learning system, and there is a significant influence of certain factors on their satisfaction.

- H1 Users expressed a high level of satisfaction with the use of the SportEdu distance learning system.
- H2 There is a significant influence of different factors on user satisfaction with the SportEdu distance learning system.
    - H2.1 There is a significant influence of the type of sport on user satisfaction with the SportEdu distance learning system.
    - H2.2 There is a significant influence of gender on user satisfaction with the SportEdu distance learning system.
    - H2.3 There is a significant influence of age on user satisfaction with the SportEdu distance learning system.

4.6 Description of the Research Sample

A total of 60 user accounts were registered in the SportEdu distance learning system. The majority of users were sports coaches — students enrolled in the professional training course in sports organized by the Faculty of Sport and Physical Education, University of Novi Sad. They actively used the system by attending online courses, accessing lessons and related materials, and completing exams through electronic testing. Most participants were coaches from Serbia (43), Croatia (9), and Bosnia and Herzegovina (5). In addition to the coaches, two instructor accounts were created for teachers who prepared lessons and tests, as well as one administrator account. The system was actively used for six months, corresponding to the duration of the professional training courses for sports coaches. A Google questionnaire was sent to 60 email addresses, and responses were received from 50 users, representing 83% of the total sample.

4.7 Location and Duration of the Research

Location: Republic of Serbia, Autonomous Province of Vojvodina, Novi Sad

Period: August 4-11, 2025

4.8 Research Methods, Techniques, and Instruments

This study employs the method of theoretical analysis, the descriptive method, and finally, the correlational method to determine whether there is a relationship between the selected variables (type of sport, gender, and age) and the responses provided in the questionnaire. The technique used is surveying, while the instrument is a questionnaire, specifically, a Google online form. It consists of eight questions — three general questions (type of sport, gender, age) and five questions related to user satisfaction with the SportEdu distance learning system. For the key questions, a five-point Likert scale is applied to facilitate data analysis, with ratings from 1 to 5, where 1 is "Very dissatisfied" and 5 is "Very satisfied".

5 RESULTS

5.1 Description of the Conducted Research and Discussion about the Results

The results of the research will be presented in tabular and graphical form below and will be eligible for interpretation and further discussion.

The questionnaire was completed by 50 representatives of sports disciplines represented in the Autonomous Province of Vojvodina: Athletics, Aerobics, Baseball, Boxing, Aviation, Water Polo, Rowing, Gymnastics, Golf, Weightlifting. Kayak-Canoe. Karate, Kickboxing, Basketball, Bowling, Kung Fu–Wushu, Motorsport, Volleyball, Orienteering, Paraolympic Sports, Trekking , Swimming, Powerlifting, Rugby, Wrestling, Recreation and Fitness, Diving, Handball, Savate, Sambo, Softball, Sports for All, Adaptive Sports, DanceSport, Sport Fishing, Table Tennis, Archery, Shooting, Taekwondo, Tennis, Triathlon, University Sports, Football , Ice Hockey and Skating, Judo, Chess, School Sports.

5.2 Overview of Responses to the Questions

The results of the technological infrastructure research are shown in Table 2.

	Grade 3	Grade 4	Grade 5
n	4	10	36
%	*8*	*20*	*72*

Table 2 Technological Infrastructure

Considering the high level of user satisfaction with this function (92%), it can be concluded that hypothesis H1 has been confirmed. The results of the user interface design research are shown in Table 3.

	Grade 3	Grade 4	Grade 5
n	4	10	36
%	8	20	72

Table 3 User Interface Design

The results of the content management survey are shown in Table 4.

	Grade 3	Grade 4	Grade 5
n	2	8	40
%	4	16	80

Table 4 Content Management

The results of the evaluation and feedback survey are presented in Table 5.

	Grade 3	Grade 4	Grade 5
n	4	8	38
%	8	16	76

Table 5 Evaluation and Feedback

The results of the user support survey are shown in Table 6.

	Grade 2	Grade 3	Grade 4	Grade 5
n	2	2	2	44
%	4	4	4	88

Table 6 User Support

5.3 Descriptive Method

Descriptive research methods only measure, i.e. show a state of play in order to describe the selected sample. Therefore, they do not have any specific intervention that the researcher carries out on them, their current state, i.e. state of play, is simply observed.

Since the questionnaire was completed by 50 representatives of sports disciplines and in order not to scatter the data because there were 50 completed surveys, sports disciplines have been divided into 2 logical units in Table 7 below:

ID	1. Type of sport
1	Individual
2	*Team*

Table 7 Classification of Sports Types

Similarly, respondents were grouped by age (Table 8) according to coaching levels (operational coaches under 40 and senior coaches over 40).

ID	3. Age
1	Under 40 years of age
2	Over 40 years of age

Table 8 Age classification

Since the following tables exported from the IBM SPSS statistical package shall be used in further activities, the questions have been labelled as follows for clarity:

- ✓ Question 1 = 4 Technological Infrastructure
- ✓ Question 2 = 5 User Interface Design
- ✓ Question 3 = 6 Content Management
- ✓ Question 4 = 7 Evaluation and Feedback
- ✓ Question 5 = 8 User Support

Table 9 contains the basic parameters of the descriptive method:

Descriptive Statistics							
	N	Range	Minimum	Maximum	Sum	Mean	
	Statistic	Statistic	Statistic	Statistic	Statistic	Statistic	Std. Error
1. Type of sport	50	1.00	1.00	2.00	67.00	1.3400	.06767
2. Gender	50	1.00	1.00	2.00	70.00	1.4000	.06999
3. Age	50	1.00	1.00	2.00	77.00	1.5400	.07120
Question 1	50	2.00	3.00	5.00	232.00	4.6400	.08926
Question 2	50	2.00	3.00	5.00	232.00	4.6400	.08926
Question 3	50	3.00	2.00	5.00	236.00	4.7200	.09493
Question 4	50	2.00	3.00	5.00	234.00	4.6800	.08778
Question 5	50	3.00	2.00	5.00	238.00	4.7600	.10126
Valid N (listwise)	50						

	Std. Deviation	Variance	Skewness		Kurtosis	
	Statistic	Statistic	Statistic	Std. Error	Statistic	Std. Error
1. Type of sport	.47852	.229	.697	.337	-1.580	.662
2. Gender	.49487	.245	.421	.337	-1.900	.662
3. Age	.50346	.253	-.166	.337	-2.057	.662
Question 1	.63116	.398	-1.571	.337	1.345	.662
Question 2	.63116	.398	-1.571	.337	1.345	.662
Question 3	.67128	.451	-2.977	.337	9.516	.662
Question 4	.62073	.385	-1.799	.337	2.086	.662
Question 5	.71600	.513	-3.082	.337	8.749	.662

Table 9 Descriptive Statistics

5.4 Correlation Method

The correlation method is used in research that examines whether there is a relationship between two or more variables (for example, whether sport, gender, or age of respondents affect their level of satisfaction). This is verified using appropriate statistical methods and processes. The Pearson correlation coefficient was primarily used for this purpose. In the IBM SPSS statistical package, the same results were obtained, including all types of correlations, as shown in Table 10.

Correlations							
		Type of sport	Gender	Age	Question 1	Question 2	Question 3
Type of sport	Pearson Correlation	1	-.069	-.269	.076	.143	-.015
	Sig. (2-tailed)		.634	.059	.601	.321	.916
Gender	Pearson Correlation	-.069	1	-.229	.274	.144	.160
	Sig. (2-tailed)	.634		.109	.054	.319	.268
Age	Pearson Correlation	-.269	-.229	1	-.082	-.082	-.027
	Sig. (2-tailed)	.059	.109		.570	.570	.855

Question 1	Pearson Correlation	.076	.274	-.082	1	.693**	.721**
	Sig. (2-tailed)	.601	.054	.570		.000	.000
Question 2	Pearson Correlation	.143	.144	-.082	.693**	1	.721**
	Sig. (2-tailed)	.321	.319	.570	.000		.000
Question 3	Pearson Correlation	-.015	.160	-.027	.721**	.721**	1
	Sig. (2-tailed)	.916	.268	.855	.000	.000	
Question 4	Pearson Correlation	-.176	.226	-.024	.638**	.533**	.662**
	Sig. (2-tailed)	.222	.115	.871	.000	.000	.000
Question 5	Pearson Correlation	-.055	.276	-.086	.798**	.708**	.876**
	Sig. (2-tailed)	.705	.052	.552	.000	.000	.000

Correlations

		Question 4	Question 5
Type of sport	Pearson Correlation	-.176	-.055
	Sig. (2-tailed)	.222	.705
Gender	Pearson Correlation	.226	.276
	Sig. (2-tailed)	.115	.052
Age	Pearson Correlation	-.024	-.086
	Sig. (2-tailed)	.871	.552
Question 1	Pearson Correlation	.638	.798
	Sig. (2-tailed)	.000	.000
Question 2	Pearson Correlation	.533	.708
	Sig. (2-tailed)	.000	.000
Question 3	Pearson Correlation	.662	.876
	Sig. (2-tailed)	.000	.000
Question 4	Pearson Correlation	1	.834
	Sig. (2-tailed)		.000
Question 5	Pearson Correlation	.834	1
	Sig. (2-tailed)	.000	

Table 10 Correlations in SPSS

5.5 Discussion of Results

The first part of the analysis focuses on responses to questions 1–5, which were presented in tabular and graphical form in Section 3.9.1. From Table 2, it can be observed that within the technological infrastructure category, the most frequent score was 5, appearing 36 times (72%), significantly higher than score 4 (10 or 20%) and score 3 (4 or 8%). From Table 3, it is evident that in the user interface design category, the score 5 also dominates, appearing 36 times (72%), considerably higher than score 4 (10 or 20%) and score 3 (4 or 8%). From Table 4, regarding content management, score 5 appears 40 times (80%), substantially higher than score 4 (8 or 16%) and score 3 (2 or 4%). From Table 5, in the evaluation and feedback category, score 5 was recorded 38 times (76%), again significantly higher than score 4 (8 or 16%) and score 3 (4 or 8%). From Table 6, in the same evaluation and feedback category, score 5 appeared 44 times (88%), notably higher than score 4 (2 or 4%) and scores 3 and 2 (4 or 8%).

Based on these findings, it can be concluded that users expressed a high level of satisfaction with the SportEdu distance learning system, confirming that Hypothesis H1 is correct.

Tables 10 (Section 3.9.3) show the correlation coefficients for the variables (type of sport, gender, and age) and responses to the five questions. Two data sets are considered correlated if the correlation coefficient is close to one. It should be noted that a statistically significant effect was found between the variable age and question 3. For the remaining variables and questions, no statistically significant correlation was observed. Consequently, the following conclusions have been drawn:

- There is no significant influence of the type of sport on the SportEdu distance learning system user satisfaction, indicating that sub-hypothesis H2.1 has not been confirmed.
- There is no significant influence of gender on the SportEdu distance learning system user satisfaction, suggesting that sub-hypothesis H2.2 has not been confirmed.
- There is a significant influence of age on the SportEdu distance learning system user satisfaction, meaning that sub-hypothesis H2.3 has been confirmed.

As sub-hypotheses H2.1 and H2.2 have been rejected and H2.3 confirmed, Hypothesis H2 has therefore been rejected as well. Since Hypothesis H1 has been confirmed and Hypothesis H2 rejected, it can be concluded that the main hypothesis H0 is not correct. Since each individual hypothesis H1 has been confirmed and H2 has not been confirmed, the conclusion can be drawn that our main hypothesis H0 has not been confirmed either.

6 CONCLUSION

The true measure of a system's value lies in the level of satisfaction of its users.

If users of the SportEdu distance learning system are satisfied, it indicates that the system itself is justified, meaningful, and worth further improvement and development.

Users expressed a high degree of satisfaction with the SportEdu distance learning system, and no significant influence of the examined factors on their satisfaction was observed—except in one case.

The weak correlation between our variables and the questionnaire items should not be a concern. In small samples, even a high correlation cannot guarantee that the data are genuinely related, whereas this issue diminishes in larger samples.

Moreover, learning is an inherent part of any distance education system, and the general evaluation of such a system should not depend on or correlate with variables such as sport, gender, or age. Learning is a lifelong process, pursued by individuals of all genders, and it is not determined by whether someone participates in sports activities.

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Artificial Intelligence in technological education

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Abstract. This article explores the transformative impact of artificial intelligence (AI) on contemporary education and introduces a structured framework for its systematic integration into technological learning. The proposed model encompasses six critical stages: needs analysis, design, development, implementation, maintenance/adaptation, and evaluation. This framework was specifically applied to the "Technology and Entrepreneurship".

The findings suggest that integrating AI tools not only modernizes the instructional process and stimulates project-based activities but also significantly enhances students' creativity and engineering thinking. By bridging the gap between human cognition and advanced technology, the model provides educators with a versatile and scalable architecture adaptable to various educational contexts while maintaining a strong focus on ethics, transparency, and continuous improvement.

Key words and phrases: artificial intelligence (AI), technological education, technology, model.

1 INTRODUCTION

In the modern world, marked by the dynamic development of information technologies and digital transformation, education is subject to serious challenges and expectations (Valeova, V., 2025). Artificial Intelligence (AI) is fundamentally reshaping the landscape of modern education, standing as one of the most disruptive technological advancements of the 21st century. Beyond simple automation, AI enhances pedagogical efficiency and supports data-driven decision-making (Al Samman, 2024; Mai & Li, 2024). Educational institutions are increasingly leveraging AI-powered solutions, including adaptive learning systems, intelligent tutoring, and automated assessment tools, to provide highly personalized learning experiences (Trivedi, 2023; Vrana, 2024).

Since its conceptual emergence in the mid-1950s, AI has expanded its reach across diverse fields such as linguistics, STEM, and medicine (Perrotta & Selwyn, 2020). Today, advancements in machine learning and predictive analytics allow for significant improvements in instructional effectiveness (Roll & Wylie, 2016). Leading international organizations—including UNESCO (2021), OECD (2021), and ISTE (2022)—alongside prominent researchers (Holmes et al., 2019; Luckin et al., 2016), emphasize the need for frameworks that prioritize ethical implementation, human-cantered design, and robust teacher support. In the realm of technological education, AI provides a unique platform for cultivating engineering mindsets, fostering creativity, and enhancing complex problem-solving skills. However, successful integration necessitates adaptable and evidence-based pedagogical strategies (Spector, 2022).

This paper proposes a structured model for implementing AI within technological curricula and validates its efficacy through a quasi-experimental study.

2 APPLICATIONS OF ARTIFICIAL INTELLIGENCE IN TECHNOLOGICAL EDUCATION

2.1. Personalized learning

Personalized learning systems allow for the analysis of individual student parameters and the adaptation of content to their needs (Alam, 2022). This approach leads to higher engagement and more effective learning of the learning material (Luckin et al., 2016).

2.2. Intelligent Learning Systems

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Intelligent Learning Systems (ILS) are virtual instructors that provide guidance and feedback in real time. Their development is related to fundamental research in the field of educational technology (Nkambou et al., 2010; Woolf, 2010).

2.3. Virtual and augmented laboratories

Virtual laboratories, managed by artificial intelligence, provide a safe environment for experimentation and simulation of real technological processes, especially in engineering disciplines (Holmes et al., 2019).

2.4. Adaptive learning platforms

Adaptive systems use algorithms to analyze student behavior and change the learning path in real time (Roll & Wylie, 2016).

2.5. Automated assessment

The use of AI for automated assessment reduces administrative burden and increases the quality and frequency of feedback (Baker & Inventado, 2014). The integration of artificial intelligence leads to a number of benefits, including increased engagement, personalized learning, accessibility for learners with special needs, and optimization of the learning load (Holmes et al., 2019; Spector, 2022).

2.6. AI Tools for Technological Education

Educational Stage	Focus Area	Recommended AI Tools
Primary (Grades 1–4)	Creativity & Visualization	Canva Magic Media, Adobe Firefly, Scribble Diffusion
Middle (Grades 5–7)	Optimization & Analysis	ChatGPT (for brainstorming), Gemini, Tinkercad (AI-assisted)
Junior High (Grades 8–9)	Entrepreneurship & Modeling	NotebookLM, Gamma (presentations), Lean Canvas AI
Cross-Level	Critical Thinking & Ethics	Teachable Machine (Google), AI Literacy Labs

3 METHODOLOGY

3.1. Objective of the Study

The objective of this study is to develop and experimentally validate a model for integrating artificial intelligence into technological education.

3.2. Research questions

The research addresses the following questions:

- What are the objectives of the proposed model?
- What is its structure?
- To which curriculum topics can it be applied?

The methodological framework is based on pedagogical research theories, the competency based approach, and technological culture, supported by Bulgarian and international literature. Methods include theoretical comparative analysis, concretization, generalization, forecasting, and modelling.

The methodological and theoretical basis of the study are the conceptual positions of the methodologies and theories of pedagogical research, the competency approach in education and technological culture, as well as the competence of Bulgarian and foreign authors.

In solving the research problems, a number of complementary general scientific and pedagogical methods were used: theoretical-comparative analysis; concretization; generalization; forecasting; modeling.

4 MODEL FOR IMPLEMENTATION OF AI IN TECHNOLOGICAL LEARNING

The model is grounded in key AI applications such as personalized learning, intelligent tutoring systems, automated assessment, virtual laboratories, and adaptive platforms (Holmes et al., 2019; Alam, 2022). It also incorporates ethical, technological, and pedagogical considerations (OECD, 2021; UNESCO, 2021).

4.1. Goals of the Model

- Enhancing technological literacy through modern AI tools
- Developing engineering thinking (analysis, design, research, optimization)
- Supporting entrepreneurial competencies (idea generation, resource assessment)
- Fostering ethical and critical attitudes toward AI

Increasing student motivation and engagement

4.2. Stages of the model

- The model follows a systematic approach similar to engineering design processes (Figure 1): Analysis, Design, Development, Implemention Increasing student motivation and engagement, Support & Adaptation and Evaluation.

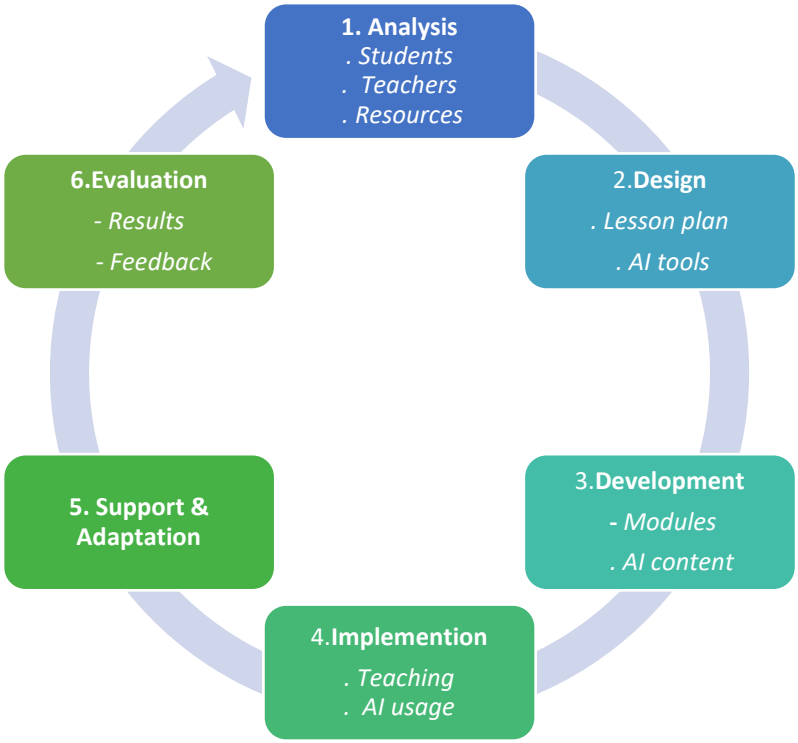


Figure 1. Systematic Framework for AI Implementation in Technological Education

This figure illustrates the iterative life cycle of the proposed model. The process begins with a comprehensive analysis of student and teacher readiness, followed by the development of AI-specific curricula. The development and implementation stages focus on creating adaptive modules and real-time classroom integration. The cycle concludes with adaptation and evaluation, ensuring that learning outcomes are continuously monitored and the model is refined based on empirical feedback and ethical standards.

5 EXPERIMENTAL STUDY

5.1 Objective

The primary aim of this study was to evaluate the effectiveness of the proposed implementation model through a project-based learning (PBL) task: "Design and Construction of a Small Greenhouse" (6th-grade level).

5.2 Participants

The study involved a sample of 48 sixth-grade students, divided into two groups: an Experimental Group (EG, n=24) and a Control Group (CG, n=24).

5.3 Design and Methodology

A quasi-experimental pre-test/post-test design was employed. The intervention focused on the following:

- Experimental Group (EG): Students utilized generative AI tools for concept brainstorming, material optimization, and visual prototyping.
- Control Group (CG): Students followed a traditional instructional path using standard textbooks and manual drafting techniques.
  Both groups were evaluated using identical criteria, including standardized knowledge tests, a project assessment rubric (evaluating functionality and creativity), and a validated motivation questionnaire.

5.4 Results and Impact

The findings indicate that AI-integrated learning significantly outperformed traditional methods. The EG demonstrated a substantial knowledge improvement of 37.7%, compared to 15.8% in the CG. Furthermore, the calculated effect size (Cohen's d ≈ 1.45) indicates a "very large" practical impact on student performance. Motivation levels in the EG reached 85%, suggesting that AI tools foster greater learner autonomy and engagement.

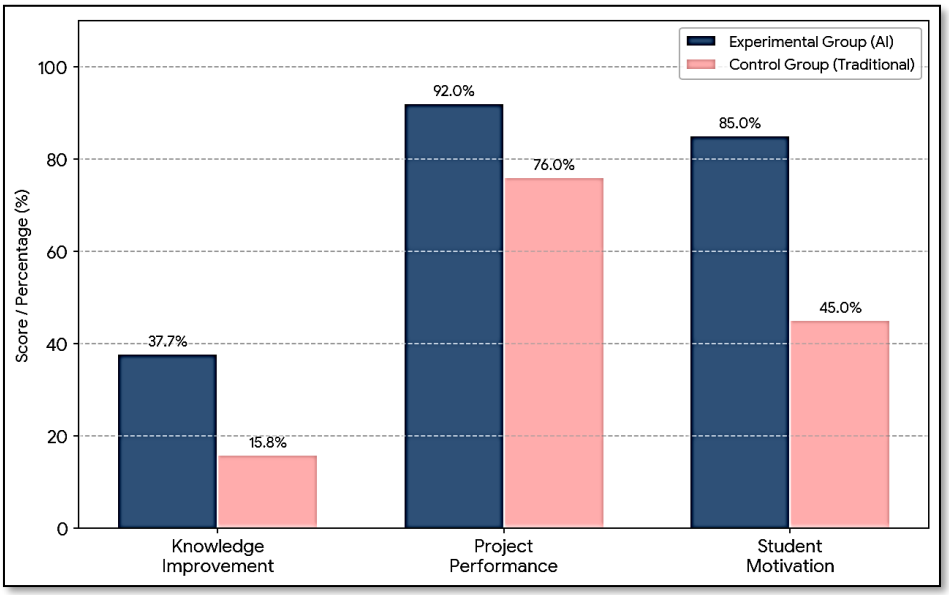


Figure 2. Comparative Impact of AI-Supported Learning vs. Traditional Methods.

Overall, the results suggest that AI-supported learning can serve as a powerful supplement to traditional instruction, enhancing both cognitive and affective learning outcomes. However, further research is needed to explore long-term effects, potential challenges in implementation, and the extent to which these findings generalize across different subjects, age groups, and educational contexts.

6 CONCLUSION

The model presented in this study offers a systematic and scalable framework for integrating artificial intelligence into technological education. By aligning pedagogical, technological, and ethical perspectives, the framework transitions AI from a mere tool to a core component of the engineering design process. The experimental results confirm that AI-supported learning significantly enhances student performance, fostering a 37.7% improvement in knowledge acquisition and a "very large" effect size ($d \approx 1.45$). While traditional instructional methods remain a vital foundation, the integration of AI provides substantial added value in terms of creativity, motivation, and complex problem-solving. However, successful implementation faces challenges, particularly regarding the ethical transparency of algorithms and the need for continuous teacher training. Future research should focus on the long-term cognitive impact of AI-human collaboration and investigate how this model can be adapted to more diverse vocational and STEM contexts. In conclusion, the "AI-Conductor" approach prepares students not just to use technology but to strategically manage it in an increasingly automated reality.

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Programming Structures Ontology Modeling

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Abstract. One of the most suitable ways to represent knowledge from a specific domain area is with ontology engineering. Knowledge from the area of programming languages is suitable for transformation into ontology representation and semantic models. This paper presents a review of research on using ontologies in the field of software engineering. The Ontology model is created by using the Protégé tool to represent essential programming structures with an ontology diagram. This model could be exported into various standardized data formats like: OWL, RDF, JSON, XML, etc. and they can be useful input to code generators, automated software testing tools and educational software (for programming teaching). An example of if-then-else structure is presented with OWL ontology utilization as XML textual representation.

Keywordsand phrases: Software, programming, knowledge, ontology, Protégé**.**

1 INTRODUCTION

Ontologies are suitable for representing, sharing, and reusing knowledge, as a kind of semantic containers formulated in technically readable form. The term "ontology" has various definitions, and the most popular definition of ontology in information technology is that it is a formal specification that describes concepts and their relationships (Shamsfard,&Barforoush, 2003). In the field of information technology, according to (Calero, Ruiz, &Piattini, 2006), ontologies are widely used in artificial intelligence, knowledge engineering, application software for knowledge management, e-commerce, natural language processing, information integration and retrieval, database design and use, education, etc.

In this paper, we have examined the possibilities of using and creating ontologies in software engineering, with particular emphasis on programming structures. The rest of the paper is organized as follows: section two brings a short background about ontologies and Protégé tool, section three provides related work overview of using ontologies in software engineering and programming education, section four presents example of creating ontology with programming structures, section fiveo describes features of proposed tool OntoSQA that could be used for software quality assurance based on ontology utilization and final section describes conclusion.

2 BACKGROUND – ONTOLOGIES IN THE KNOWLEDGE MANAGEMENT

Basic characteristic of all ontologies is the definition of a hierarchy of concepts/objects, between which different semantic connections are established (Lammari & Metais, 2004). An object from the real world (Thing) that realizes semantic connections (Is) with different classes/objects (Class) that are described by certain properties (Properties) and other concepts from the field of ontologies. Concepts in the real world represent concrete objects and concepts. Ontologies can be classified into three categories, depending on the domain, i.e. areas that model (Luo, 2005):

- Ontologies for knowledge representation are knowledge representation systems that combine ontological frameworks. Knowledge is presented either in format which is logically comprehensive and

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provides definitions of objects, functions and relations, or in a computer-oriented language designed for the exchange of knowledge between different programs;

- Ontologies about general world knowledge (Upper Level Ontology);
- Ontologies of specific domains (Domain Specific Ontology) with a primary focus on connecting structures and behaviors through the concept of authorization.

OWL ontology, according to (Horridge, 2009), consists of entities (individuals), properties and classes. Entities are instances of classes while properties are binary relationships between entities. For some relations, inverse relations can also exist. Properties can be limited to only one value, it can be functional. Also, properties can be transitive or symmetric. OWL classes are represented as sets containing individuals. They are described using formal descriptions that contain precise conditions for belonging to a class. Classes can be organized into superclass relationship hierarchies with their subclasses, which are also known as taxonomies. Subclasses are specializations of their super classes. OWL properties represent relations. There are three basic types of properties: Object Properties, Datatype Properties, and Annotation Properties.

Ontologies are created with specific tools. Survey on the most commonly used ontology editors show that the Protégé tool is used by about 70% of users. (Balamurugan,&Iyswarya, 2018). Protégé tool is a free and open source editor for ontology development, developed at Stanford University. It is a cross-platform application system programmed in the Java programming language. It has numerous plugins such as OntoViz, OntoGraf, GraphViz, etc. so that the end user can visualize ontologies. Protégé supports domain experts and knowledge engineers, as well as tool creators. This is the difference between other native tools and Protégé, since other tools are only aimed at knowledge engineers and lack flexibility in meta-modeling.

3 Related work – Ontologies Utilization in Software Engineering and Programming Education

Ontology engineering has been recognized as suitable to be utilized not only in knowledge-based systems, but also in all software that requires models and can be used for design (Devedzic, 2002, Wiebe, & Chan, 2012). Research from (Fridman-Noy & Hafner, 1997) suggests that developers of applied artificial intelligence systems can benefit from their use. Other areas of application of ontology classes include natural language processing, simulation and modeling, intelligent retrieval and searching of information from the Internet, virtual systems, etc. Ontological engineering covers concepts in following areas: modeling and metamodeling, software architectures, programming languages and compilers, traditional software engineering, object-oriented analysis and design, and design patterns.Ontology learning involves extracting semantic elements from input and building ontology from them. Ontology learning uses methods from a wide range of fields such as artificial intelligence, machine learning, knowledge acquisition, information retrieval,and natural language processing, reasoning, and database management. Ontologies can be built manually, automatically, and semi-automatically. Manually building ontologies is a time-consuming, laborious, and error-prone process, so manually built ontologies are expensive and can be dependent on their developer, inflexible, and specific only to their motivated purpose. Automation of ontology building reduces costs and results in better alignment of the ontology with its application.(Shamsfard, &Barforoush, 2003)

Software testing is an essential method for achieving product quality. Recent research suggests software testing is an important set of various activities of software quality assurance (Sun, Hu, Li,& Wu, 2020). Knowledge management is becoming one of the key maintenance methods for improving the software testing process. Ontology can provide a conceptualization of the software testing domain in the form of a knowledge base, be a common vocabulary in the testing domain, identify knowledge objects about testing, etc. (Sharma, Raja,& Bhatt, 2020). Enhancement of the efficiency of traditional testing techniques is proposed in the work of Intana, Tantayakul, Laosen, &Charoenreh(2023) with semi-automatic framework that integrates ontology engineering with software testing for test case generation. This approach enables a framework that combines ontology engineering with the software test case generation approaches to reduce misunderstanding by software developers and results in the incorrect test cases to be generated from unclear user specification. A systematic literature review of ontology-based regression testing was presented in (Hasnain, Ghani, Pasha, &Jeong, 2021). This review has included 24 peer-reviewed studies covering semantic ontologies and regression testing, published between 2007 and 2019.

Domain ontology was constructed to describe the knowledge structure of the domain for learning. Semantic recommendation framework of educational resources based on pedagogics and semantic web is proposed by (Wu et al., 2020). Authors, also, made the set of reasoning rules based on pedagogics from the synthesis of the

internal structure of knowledge, the type of the knowledge, and learning performance of learners. In the case study, learners were recommended different learning materials according to the different learning performance and different knowledge structure. Study showed that this framework can be used as a guide for resource designers and teachers. Sambe& Base (2020) proposed an ontology-based framework to improve and facilitate the practice of algorithmic skills and help students gradually acquire a methodology for building algorithms. The paper (Ganapathi, Lourdusamy, &Rajaram, 2011) discusses an approach to the development and design of ontology for teaching JAVA programming. A Java ontology was created that can be integrated with any e-learning platform for teaching purposes. The role of knowledge structuring for fast, professional and successful ontology development is highlighted. Such a paradigm used to support the teaching process not only helps teachers to focus on problems and allows students to process and understand a large amount of information. At the basic level of knowledge representation, it should be easier for teachers to simply draw ontology. However, for more complex knowledge representation, it is necessary to master the appropriate programming and language or use well-known ontology editors. This approach can be applied to the development of those teaching systems where general understanding is more important than factual details.

4 Ontology Modelling Example

In this section, we present the ontology we created in aim to represent basic programming structures. The OWL ontology, as we noted in Section 2, is composed of entities, properties, and classes that have their own static and dynamic properties (Horridge, 2009). Our ontology contains basic structures from the field of programming – conditional branching (IF, IF-ELSE,IF-ELSEIF, SWITCH-CASE) and loops (FOR, DO, DO-WHILE). For the listed structures, classes and individuals were created that represent those structures, commands, and branches were established between parts of the commands - individual commands and blocks of commands. Ontology representing basic programming structures is created by utilization of Protégé tool (Figure 1).

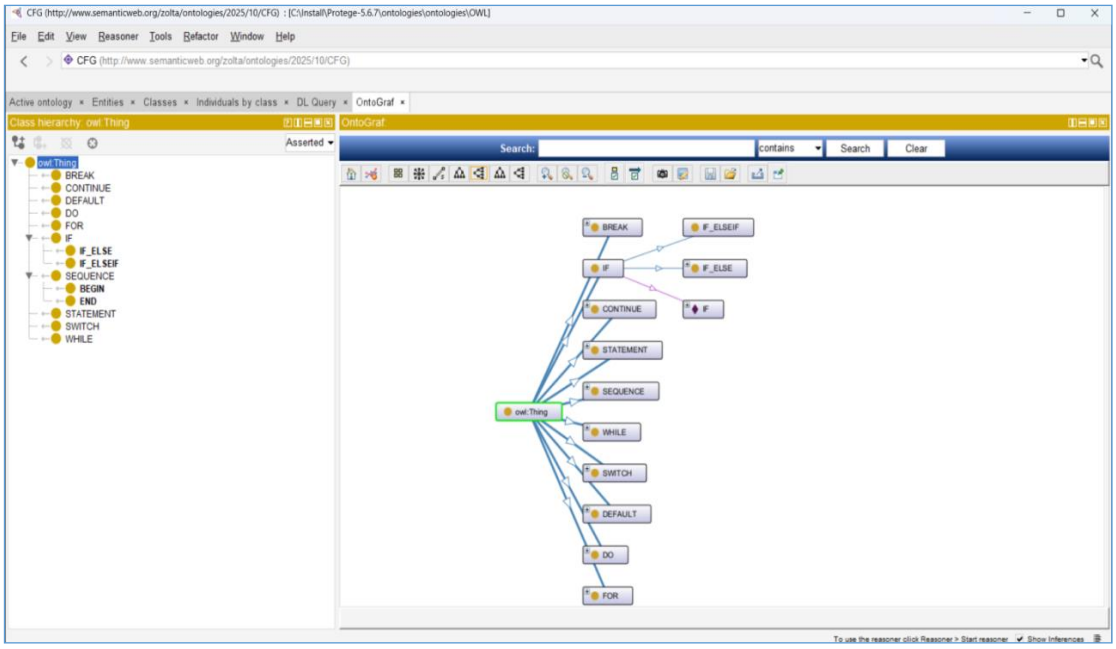


Figure 1. Ontology for presenting knowledge from programming structures in Protégé

Particular elements of each basic programming structure is presented with Protégé and exported in specific XML-like textual form, according to OWL language syntax.

Let's take the IF THEN statement and its various forms in programming as an example. It consists of the official word IF followed by a condition. If the condition is satisfied, i.e. true, only one statement can be executed, or a larger number of statements in the form of a sequence. There is also a form of this statement that also contains an ELSE block. If the specified condition is not true, the ELSE block is executed, one or more statements are skipped, and everything specified in the else part is executed (a single statement or a

sequence of commands). This structure is known in a number of programming languages such as C, C++, C#, Java, Basic,and Python etc.

- If Condition STATEMENT;
- If Condition SEQUENCE_OF_STATEMENTS;
- If Condition STATEMENT Else STATEMENT;
- If Condition SEQUENCE_OF_STATEMENTS Else SEQUENCE_OF_STATEMENTS;
- If Condition STATEMENT ElseIf Condition STATEMENT;
- If Condition SEQUENCE_OF_STATEMENTS ElseIf Condition SEQUENCE_OF_STATEMENTS.

Figure 2. presents the most complex variant – with if, else, elseif elements.

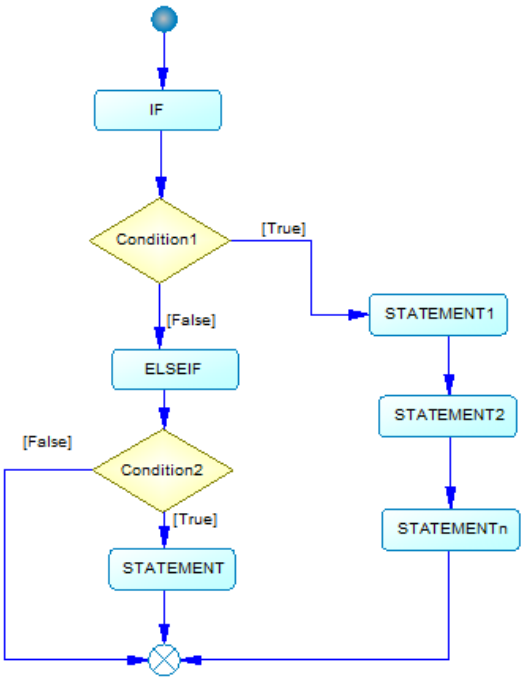


Figure 2. IF-ELSEIF statement with sequence of statements

Part of ontology created in Protégé tool related to the IF-ELSEIF statement is exported from this tool to a special XML form aligned with OWL syntax. This part of the textually presented ontology is listed below:

```
    <Declaration>
    <Class IRI="#IF_ELSEIF"/>
</Declaration>
    <Declaration>
    <Class IRI="#SEQUENCE"/>
    </Declaration>
    <Declaration>
    <Class IRI="#STATEMENT"/>
</Declaration>
    <Declaration>
    <NamedIndividual IRI="#IF_ELSEIF"/>
    </Declaration>
    <SubClassOf>
    <Class IRI="#BEGIN"/>
    <Class IRI="#SEQUENCE"/>
    </SubClassOf>
    <SubClassOf>
    <Class IRI="#END"/>
    <Class IRI="#SEQUENCE"/>
    </SubClassOf>
```

```
    <SubClassOf>
    <Class IRI="#IF_ELSEIF"/>
    <Class IRI="#IF"/>
</SubClassOf>
    <ObjectPropertyAssertion>
    <ObjectProperty IRI="#execute"/>
    <NamedIndividual IRI="#IF"/>
    <NamedIndividual IRI="#SEQUENCE"/>
</ObjectPropertyAssertion>
    <ObjectPropertyAssertion>
    <ObjectProperty IRI="#execute"/>
    <NamedIndividual IRI="#IF_ELSEIF"/>
    <NamedIndividual IRI="#STATEMENT"/>
</ObjectPropertyAssertion>
```

5 Approach to Programming Language Ontology Utilization in Software Quality Assurance

Ontology could be used in broad areas. It could be created to represent all essential elements of a programming language, as a meta representation. Generally speaking, any source code can be loaded in a tool that could be developed in aim to support software quality assurance in terms of particular programming language grammar or coding conventions. Figure 3. presents the proposed the approach that could be supported by creating a tool (named OntoSQA tool). This tool could be used for evaluation of

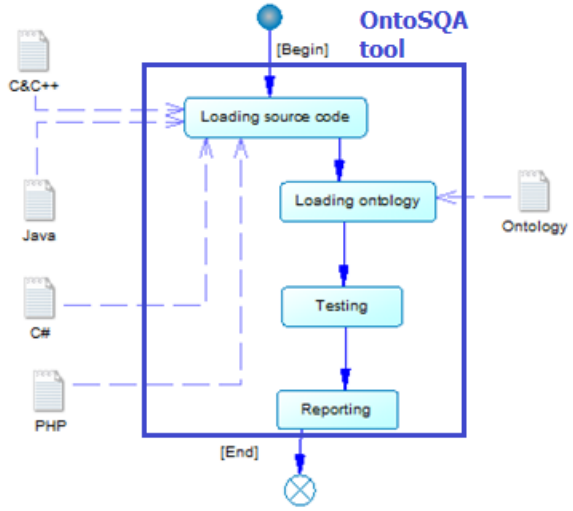


Figure 3. Ontology based testing model

6 Conclusion

Ontologies can be used in various areas of software engineering and information technologies, especially in artificial intelligence, software development, and as a support to semantic web.

Our paper presents an ontology created with the utilization of Protégé ontology tool, in aim to represent a model of basic programming structures. We have shown example of IF THEN ELSE ELSEIF programming structure represented with textual form of OWL ontology equivalent. Other programming structures could be formalized similarly, but they are not presented in this paper.

We proposed creating OntoSQL tool that can be used in software quality assurance activities. This tool could be used in educational environment in teaching programming, as well. In further research we intend to create OntoSQL tool, in aim to establish utilization of creating ontologies that support different programming languages. This tool could be used in source code evaluation regarding grammar and coding conventions aspect.

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The Use of Extended Reality (XR) in Industrial Robotics Training

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Abstract. Innovative teaching approaches are essential in preparing the workforce for the demands of modern industries. The rapid evolution of Industry 5.0 which emphasizes human-centricity and sustainability is driving the demand for a highly skilled workers capable of managing advanced robotic systems. Workforce training in the industrial robot programming domain requires significant time and financial resources, and is limited by safety risks and restricted opportunities for repeated experiential learning. Extended Reality (XR) technology enables higher-quality perception and interaction with the real and virtual world, and creates new ways of human engagement and productivity. In this study, advantages and challenges of the integration of XR-supported human-machine interfaces for training of robot programmers are identified, and an XR-supported training framework designed to complement traditional robot training methods is proposed. The proposed framework provides a foundation for future research on effective, scalable, and safe robotics training in Industry 5.0 contexts.

Key words and phrases: XR, VR, AR, robot programming, training.

1 INTRODUCTION

The development and integration of a new generation of robotic systems are key goals for the realization of highly flexible production systems. Industry 4.0 (I4.0) aims to transform the industrial sector into intelligent spaces through the integration of the Internet of Things (IoT), Artificial Intelligence (AI), and robotics. Industry 5.0 (I5.0) emphasizes human-centricity, social sustainability, and sustainable development, redefining work dynamics and career paths (Caterino et al., 2025). The increasing use of robotic systems in industry, together with the changing environment in the workplace with industrial robots, has increased the demand for a highly skilled workforce capable of programming, monitoring, and maintaining these systems. Consequently, training for these workers must be further developed (Moore, Field, Roth, & Kirchain, 2021). Workforce training is crucial for the success of manufacturing enterprises, especially in the new era of Industry 5.0, as it ensures the preservation of productivity and competitive advantages (Caterino et al., 2025). By 2030, approximately 59% of the global workforce is expected to require reskilling or upskilling due to evolving skill demands, particularly in technical and adaptive skills (World Economic Forum, 2025).

In the industrial robotics domain, vocational education and training (VET) plays an important role in preparing professionals for robot programming by developing practical skills, applied knowledge, and industry-relevant competencies. Workforce training for industrial robot programmers typically requires significant time and financial resources. The high cost of industrial robotic systems remains (Leach Mitre, 2025), which together with the need for highly skilled labor, represents a significant obstacle to broader adoption, particularly in educational settings and small-scale industries which must frequently reconfigure and reprogram robots to adapt to constantly changing production processes (Zhang, 2024).

The challenges in implementing workforce training, nowadays more than in the past, include the rapid pace of technological advancements and skill gaps to overcome (Caterino et al., 2025). The vast majority of

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engineering education and training systems, which have remained largely static and underinvested for decades, are somewhat inadequate for the emerging I4.0 and I5.0 labour markets (Bühler, Jelinek & Nübel, 2022). The debate between traditional learning methods and experiential learning had long been a topic of discussion in educational circles (Huber, 2025). Trainers and educators today face the challenge of providing training and learning environments that are natural for digital natives (Kaarlela, Padrao, Pitkäaho, Pieskä, & Bobadilla, 2022). Digital natives prefer browsing graphical and video content over reading text documents (Muszyńska, 2019). Finding simple ways for people to continually learn and update their skills is crucial (Muszyńska, 2019).

Experiential learning, which involves learning through experiences and errors, leads to better retention and can make training more effective and engaging (Scott, Sayre, & Clark, 2014). However, in industrial robot programming, training through trial and errors using traditional hands-on methods on real robots is limited or unsafe due to potential hazards associated with robot operation.

Industrial robots have been traditionally programmed using teaching pendants, although offline programming, a long-established approach, has recently become more widely used in industrial practice recently (Zhang, Lai, Simic, & Ding, 2020). Traditional robotics training methods often rely on on-site instruction, learning through direct interaction with industrial equipment, non- recurring knowledge transfer, and the need for trainees to be in the same place at the same time. Such approaches are typically time-consuming, costly (if training is performed in industrial settings, they also may require production downtime), and limited by safety concerns. In addition, access to real robotic systems during training is often restricted, which can limit opportunities for repeated practice, slow down skill acquisition, and reduce training flexibility. These limitations highlight the need for alternative training approaches that can provide realistic, repeatable, and safe learning environments without interrupting industrial operation. Novel approaches to engineering education are moving toward providing distinctive, technology-enhanced, personalized, student-centred curriculum experiences within an integrated and unified education system (Bühler et al., 2022). In light of these challenges, Extended Reality (XR) technology presents itself as an effective approach to overcome the limitations in industrial robot programming education.

XR, consisting of Augmented Reality (AR), Virtual Reality (VR) and Mixed Reality (MR), represents a technology with great potential for the development of a new generation of human-machine interfaces (HMI). With the recent advances in XR technologies and ease of availability of high-end, commercially available hardware, the manufacturing industry has seen a rise in the use of advanced XR technologies to train its workforce (Doolani et al., 2020). The XR experience can be realized using specialized HMI devices called HMDs (Head-mounted displays), as well as using smart portable devices (smartphones, tablets, etc. for AR). By enabling immersive and interactive training environments, enabling superior visualization capabilities in 3D space, XR technologies can allow users to practice robot programming, operation, and troubleshooting in simulated or augmented settings that closely resemble real-world scenarios. XR environments can support experiential learning, allow trainees to safely explore hazardous situations, enable cost-effective student-centered curriculum and individualized pace of learning, and consequently facilitate the transition from low-skill manual tasks to high-skill conceptual roles.

Despite the growing interest in XR-based training solutions, there is a lack of literature that addresses the overall challenges and advantages of integration of XR-based solutions in robot programming training. The comparison of traditional learning methods with XR-based approaches must be performed carefully, because the effectiveness of XR-based approaches depends on the quality of the designed XR-supported training system itself, the quality of XR devices, the level of knowledge of students, etc. Issues such as simulation fidelity, system integration, user acceptance, and implementation costs can limit the effectiveness and adoption of XR solutions in industrial contexts.

This paper examines the use of Extended Reality technologies in robotics training in industrial applications, focusing on their key advantages and associated challenges with regard to their efficiency, cost-effectiveness, and practical deployment in industrial settings. Building on these findings, a general XR-supported framework as the complementary component of robotics training is proposed, which provides students with a structured XR-based learning experience that shortens the transition from theoretical knowledge to practical skills, allowing subsequent hands-on training on real robots to be significantly shortened.

2 ADVANTAGES AND CHALLENGES IN INTEGRATION OF XR TECHNOLOGIES IN INDUSTRIAL ROBOT PROGRAMMING

2.1 Advantages of integration of XR-supported solutions into industrial robot programming training

VR is emerging as a valuable tool for offering immersive environments that simulate real-world scenarios to enhance training, planning, and execution of various operational tasks in industry. The use of 3D modeling and VR technology allows for better spatial understanding of the industrial plant, leading to better decision-making (Huber, 2025). The motivation and engagement of students are increased when classes are conducted in a VR environment (Wong et al., 2024). Training using VR-supported tools can increase the efficiency of procedural knowledge transfer. It is much easier to repeat tasks, and no dangerous situations are involved (Caterino et al., 2025). The introduction of VR into training of handling robots offers a promising solution (Hurtado, Valerio, & Sánchez, 2010).

In industrial settings, AR, which overlays digital information onto the user's real-world view, can provide contextual guidance and data visualization, enhance situational and spatial awareness, and facilitate faster decision-making. A major benefit of AR is that it can be experienced using smartphones, and there is increasing accessibility to other smart devices, such as tablets. This increases the scalability of the training method, where AR applications can be distributed relatively easily (Moro, Mills, Phelps, & Birt, 2023).

Academically, VR and AR environments have shown effectiveness in increasing students' learning capabilities as higher conceptual understanding was noted for concepts that were hard to imagine or hard to teach (Wong et al., 2024), which is applicable to robot programming education. In general, VR environments can be more useful for the earlier stage of the training program, whereas AR can support more advanced stages of the training program when the trainees only need support (Caterino et al., 2025), (Santos et al., 2022).

A learning curve can be defined as a mathematical description of workers' performance in repetitive tasks, where increased repetition typically leads to faster task completion (Caterino et al., 2025). Rapid learning through repetition, and experiential learning involving learning through experiences and errors are limited in real robot training due to safety and operational constraints, however, XR-based environments make both approaches feasible in a safe manner. These processes, in turn, facilitate skill transfer, providing an easier transition from theoretical knowledge to practical application and better preparing learners for the real robot environment.

Scalability is defined as the ability to handle increased workload without adding resources to a system (Weinstock and Goodenough, 2006). XR-supported training programs enable scalability in training in many industries, including industrial robotics, where XR tools can be used as advanced distance learning tools, enabling cost-effective and environmentally oriented knowledge transfer.

The development of human-robot interfaces using XR technology refers to the integration of software development platforms supported by XR technology with software for offline programming, control and simulation of robot operation (Devic, Vidakovic, & Zivkovic, 2024). In Fig. 1, robot programming HMIs using AR and VR interfaces developed at Lola Institute are presented (Devic et al., 2024), (Devic, Vidakovic, Zivkovic, & Lazarevic, 2024).

a) b)



Figure 1. a) AR-supported robot programming system, b) Robot programming in VR environment

The integration of XR-supported tools in robot programming training, in terms of instructional design, skills acquisition, and training transfer, enables the following advantages:

- experiential learning,
- a personalized approach,
- rapid skill acquisition through repetition and recurring knowledge transfer,
- flexible distance learning,
- scalability.

In addition to improving cost efficiency by minimizing production line downtime due to the lack of need for real robots, and improving the effectiveness of the training, XR-based training can also contribute to environmental sustainability by reducing the need for physical materials, travel, and energy-intensive hands-on sessions with real robots.
Impact on safety and security is another aspect that should be considered when integrating XR technologies into robotics training. Specialized safety training sessions can be designed to educate staff on best practices for working alongside robots, using advanced safety practices in hazardous environments, using advanced interfaces for remote monitoring, VR-based training enhances safety awareness by simulating potential errors and their consequences and provides a risk-free setting for trainees to immerse themselves in realistic construction scenarios, refining their skills without compromising safety (Li, Wang, Wei, & Chen, 2024), (Huber, 2025).

2.2 Challenges

From the perspective of the design of XR-supported industrial robot programming tools, the key challenges can be grouped into the following categories:

- technical challenges,
- training design and development challenges,
- economic and organizational barriers.

Technical challenges primarily relate to achieving realistic physical simulation, system integration issues, hardware limitations, minimizing system latency, and ensuring the accuracy of robot models within XR training environments (Coronado, Itadera, & Ramirez-Alpizar, 2023), (Devic et al., 2024), (Dević, Vidaković, Slavković, Živković, & Stepanić, 2025). Current VR technology may not have fully replicated the tactile feedback and subtle cues experienced in real-world operations, which could have limited the training's ability to fully prepare operators for all aspects of real-life scenarios (Huber, 2025).

Training design and development challenges encompass human factors, such as cyber sickness (Coronado et al., 2023), as well as cognitive issues, including variations in learning styles (Degeng and Triretnoningrum, 2025) and over-reliance on simulation, which may limit exposure to real-world variability and practical errors.

Developing high-quality training content demands a significant investment of both resources and time, which can be challenging. Organizational challenges also arise, including the need to train instructors to effectively deliver XR-based training and to align the new methods with existing workflows and curricula.

3 XR-BASED ROBOTICS TRAINING FRAMEWORK

Effectively utilizing XR technology in industrial robotics training remains a significant challenge, which has motivated the development of the framework to bridge theoretical knowledge and practical skills proposed in this section. In the framework proposed herein, Fig.2, XR does not replace, but complements traditional robot programming training, taking advantages of XR-supported robot programming training given in Section 2 of this study such as experimental learning, rapid skill acquisition through repetition and recurring knowledge transfer, as well as identified training design and development challenges. It consists of five modules taking advantages of XR technology superior visualization capabilities for robot programming training: XR visualization of geometric concepts, robot systems training in XR, basic programming in XR, geometric troubleshooting in XR, and advanced programming in XR. To enhance scalability, online resources from an

e-learning platform should be provided. The framework progresses from theoretical lessons to on-machine robot training, allowing learners to gradually build competence, using an XR environment, with reduced risk and downtime.

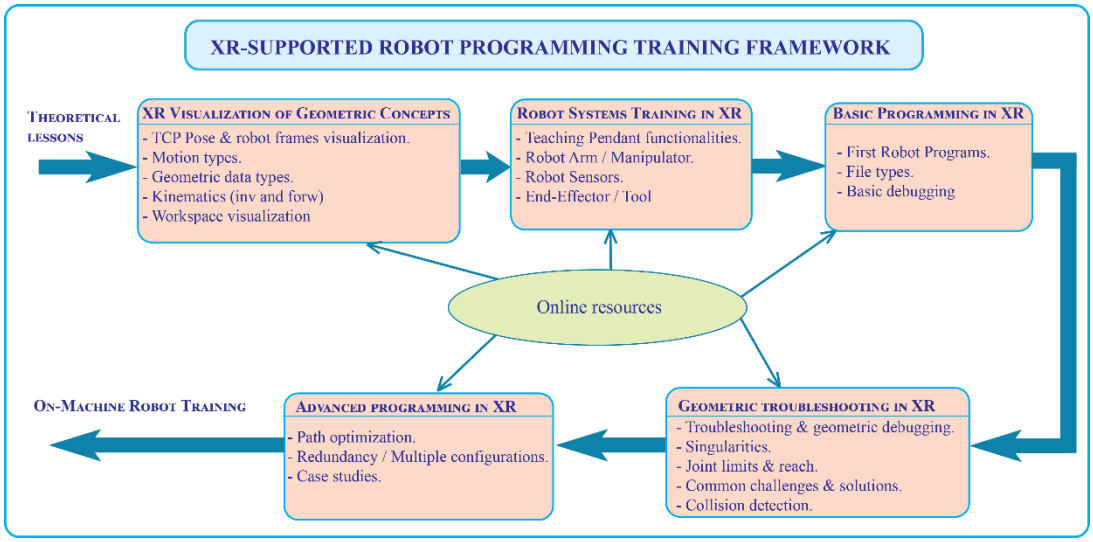


Figure 2. XR-supported robot programming training framework

4 CONCLUSION

The transition toward Industry 5.0 is redefining the industrial workforce, with its emphasis on human-centricity, sustainability, and the need for highly skilled labor capable of managing advanced robotic systems. Traditional approaches to industrial robot programming training, while effective in some respects, are limited by safety concerns, high costs, accessibility issues, and the inability to support repeated experiential learning. Extended Reality technologies present a promising approach to improving the safety, efficiency, and cost-effectiveness of robotics training. Within development of XR-supported robot training methods, technical limitations, cognitive and human factors, as well as organizational and economic barriers, have to be taken into account to achieve effective implementation. In this study, a framework for industrial robot programming training in an XR environment, as a complementary training tool to traditional training methods, is proposed. Further research is necessary to evaluate the effectiveness of the proposed framework in diverse industrial contexts and to refine it based on practical implementation outcomes. In addition, careful consideration of evaluation approaches will be required in order to reliably measure the framework's impact on learning outcomes.

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Automated Test Generation Based on User Requirements Specification: Preliminary Review

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Abstract. Software testing represents a key activity to provide and preserve software quality. Automated test cases generation has a significant role in this process, since it lowers the manual work, increases tests coverage and minimizes software errors. It is of a special interest to relate test cases creating with user requirements specification, since software testing is focused on identification of the level that software aligns with expectations. This paper explores various methods and approaches to automated test generation based on user stories, UML use cases and textual user requirements. Key findings are related to techniques and tools of natural language processing (NLP), model-based testing and formal specifications, including application of large language models (LLM). Further challenges in this area are related to automated user specification formalization as part of the system for automated test cases generation, change management context of automated test generation and evaluation of created test cases coverage.

Keywords and phrases: software requirements specification, automated test case generation, model-based testing, natural language processing, large language models

1 INTRODUCTION

Software testing is the process of identifying defects and verifying that the software meets user requirements and expectations, with the goal of ensuring quality and reliability before deployment (Björkman, 2024). Manual testing is useful when human judgment is needed, such as usability evaluation or testing new functionalities that frequently change. However, this testing method can be slow and prone to errors, especially in repetitive tests. Therefore, automated testing uses software tools and scripts that quickly and accurately execute tests, significantly increasing efficiency and reducing the risk of errors (Asfaw, 2015). Given the complexity of development and the challenges of aligning requirements with testing, automatic test case generation has become an indispensable part of the process, enabling faster and more systematic testing in accordance with user requirements, thereby contributing to the improvement of software product quality (Karhapää et al., 2017).

This paper analyzes contemporary approaches to automatic test case generation based on models and natural language processing (NLP) techniques, including the application of large language models (LLM). The aim is to present current methods and tools, identify key challenges, and indicate directions for future development in this field.

The following section presents the research methodology defining the selection of relevant literature, followed by a detailed analysis of methods for automatic test case generation based on natural language processing (NLP), large language models (LLM), and Model-Based Testing (MBT) approaches. Additionally, an overview of the most significant tools implementing these techniques in practice will be provided. The paper will conclude with a summary of key findings, identification of existing challenges, and recommendations for future research and development.

2 RESEARCH METHODOLOGY

For this research, a literature review was conducted with the aim of identifying and analyzing approaches to automatic test case generation. Google Scholar was used as the primary data source, with searches performed

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using key terms such as "automated test case generation," "model-based testing," "natural language processing for software testing," and "LLM-based test generation."

With using these keywords, 100 papers were retrieved. Based on titles and abstracts, papers that were not directly related to automatic test generation or focused on manual testing were excluded. Through detailed analysis of the texts, 33 papers were selected. These papers analyzed in aim to systematize and compare methods, tools, and challenges in the field and grouped into three categories (focusing on studies that used model-based approaches, natural language processing techniques, and modern methods applying large language models approaches to automated test generation). Finally, the selected papers were included in a thorough review of the full texts.

3 METHODS

3.1. Model based testing

Model-Based Testing (MBT) is an approach in software testing that is becoming increasingly important, especially in complex and safety-critical systems, where manual test writing is often not precise or efficient enough. This approach relies on automatically generating test cases based on formal or semi-formal models of the system. MBT addresses the problems of ambiguity and inconsistency in requirements expressed in natural language (Löffler et al., 2010; Farooq & Tahreem, 2022). UML models play a key role in this process, particularly use case diagrams and sequence diagrams, as they enable detailed and precise modeling of the system's functional behavior and interactions between users and the system. Use cases abstract the system's responses to external requests by defining functionalities visible to users or other actors. Combining UML use case, sequence, and activity diagrams, along with various algorithms, improves automated test generation (Swain et al., 2010).State machine diagrams are also important as they allow analysis of transition coverage and testing of different object states (Samuel et al., 2008). Additionally, BPMN 2.0 business process models are transformed into more formal state graphs to increase coverage and reduce testing costs (Yazdani Seqerloo et al., 2019). The combination of UML state diagrams with statistical and optimization techniques, such as genetic algorithms, enables more efficient identification of critical transitions in the system and achievement of optimal test coverage (Chevalley & Thevenod-Fosse, 2001).As the complexity of activity diagrams grows due to loops and parallel executions, the concepts of basic and simple paths are introduced to facilitate the selection of representative tests (Mingsong et al., 2006).

Key challenges of MBT include the lack of complete solutions for traceability between requirements and test cases, limited support for non-functional requirements, and efficient management of changes during software development (Ahmad et al., 2019; Farooq & Tahreem, 2022). Due to the informal and often imprecise semantics, formal methods are increasingly used as a complement to model-based approaches. Formal languages such as Z notation and the B method provide precision and semantic clarity that enable effective test automation but require additional expertise and resources (Lee, 1999; Kaur et al., 2012).

3.2. NLP-based test generation

Automatic generation of software test cases from requirements written in natural language has become a key research area. Natural Language Processing (NLP) techniques are used to extract key information and create control flows that cover all possible execution paths, where each path represents a separate test case. This approach enables systematic and acceptance testing already in the requirements analysis phase, reducing time, costs, and errors while increasing test coverage, without relying on unit tests or large language models (LLMs) (Lafi et al. , 2021). Deep learning models such as BERT significantly contribute to precise requirement classification and automatic creation of structured test documentation, thereby improving the quality and traceability of tests in agile and Continuous Integration/Continuous Delivery (CI/CD) environments. Evaluations on datasets show a high level of accuracy, with plans to extend to multiple languages and integrate with LLM technologies (Fatima et al., 2025; Sivaraman).Literature reviews highlight the wide application of basic NLP techniques such as tokenization, POS tagging, parsing, and semantic analysis, which improve requirements interpretation and test generation, although further validation and support for more complex and multilingual requirements are needed (Ayenew & Wagaw, 2024; Ahsan et al., 2017; Garousi, Bauer, & Felderer, 2020). Hybrid approaches combining rule-based extraction and machine learning methods, such as Named Entity Recognition (NER), demonstrate good results for complex systems by balancing accuracy and flexibility (Medeshetty et al., 2025; Jang & Kim, 2025). Formal specification languages like RTCM, together with tools such as aToucan4Test, enable automatic conversion of natural language requirements into

executable test scripts, increasing testing efficiency in industry (Yue et al., 2015) Additionally, the use of domain-specific ontologies and formal languages (SCR, ASSERT) helps detect ambiguities and generate optimized tests in safety-critical domains (Moitra et al., 2019; Carvalho et al., 2014)

Although NLP brings significant advantages in test automation, challenges remain such as ambiguities in unstructured requirements, lack of standardization, and the need for human verification for complex requirements. Future work should focus on enhancing multilingual support, integrating NLP with classical test design methods, and developing accessible tools for full test automation (Belsare & Bhate, 2020; Garousi, Bauer, & Felderer, 2020).

3.3. LLM-based test generation

Generating test cases based on user stories represents a key step in ensuring software quality. Large Language Models (LLMs), such as GPT-4, bring significant advantages in automating this process. LLM-based generation of test scripts significantly accelerates the process but requires continuous human oversight and validation due to possible errors, especially in critical areas, while optimal results require continuous tuning and improvement of prompts (Kavuri, 2022).

By using prompt engineering techniques and multi-step approaches, these models automatically analyze requirements and transform them into detailed user stories with clearly defined acceptance criteria, from which they then generate precise and comprehensive test cases in formats suitable for integration with test management tools. Such automation considerably speeds up test production, reduces manual work, and increases test coverage, leading to earlier bug detection and more efficient software development (Mollah & van den Bos, 2023; Rahman & Zhu, 2024; Sabarish & Chinnaswamy, 2023).Research confirms that LLMs improve the efficiency and quality of the testing process, especially in agile and CI/CD environments (Kavuri, 2022). Besides direct generation of test scripts, multi-agent systems are being developed to monitor and enhance tests during development, achieving adaptive and scalable automation (Kumari, 2025). In certain specific domains, such as finance, LLMs are combined with algorithmic methods for greater coverage and test efficiency (Xue et al., 2024).

The application of LLMs brings certain challenges. Issues of scalability, ethical dilemmas, as well as dependency on the quality of input data require human validation to avoid errors and model hallucinations (Celik & Mahmoud, 2025). Web tools that use LLMs to convert user stories into test cases often face high API costs and inaccuracies (Sami et al., 2024). Due to these challenges, a hybrid approach is proposed that combines large language models with traditional methods to improve the efficiency and coverage of testing, particularly addressing challenges of non-functional testing through additional validation and domain-specific adaptation (Shaikh et al. 2025)

4 TOOLS

This section presents a brief analysis of various tools for automated test case generation, covering approaches from model-based methods to those based on natural language processing and large language models. Among the model-based tools, notable examples include Fastest, which uses Z notation and the Test Template Framework for semi-automatic and flexible testing (Javed et al., 2016); PTGTP, which generates test cases based on control flow diagrams with optimization via a genetic algorithm (Alrawashed et al., 2019); and TDE/UML, which automates test generation from UML activity diagrams using algorithms to reduce the number of tests, with plans for further enhancements and integration with other UML models (Hasling et al., 2008).

NAT2TESTSCR and ASSERT combine formal methods with controlled natural language and formal logic—NAT2TESTSCR uses the SCR model for precise testing of critical systems without requiring deep formal knowledge, while ASSERT from General Electric applies domain ontologies and automated theorem provers to analyze and generate optimized tests for critical industries (Carvalho et al., 2014; Moitra et al., 2019).

Among the tools based on natural language processing, Litmus uses the Link Grammar parser to analyze informal requirements and create positive and negative tests (Dwarakanath et al., 2012), while US2Test, based on GPT-4, automatically generates tests from user stories and integrates with test management tools. AutoUAT and Test Flow

combine large language models to automatically create acceptance test scenarios in Gherkin format and convert them into executable automated test scripts, supporting agile methodologies and Acceptance Test Driven Development (ATDD).

All of these tools significantly contribute to automation, increased efficiency, and improved quality of software testing through the application of various techniques and approaches.

Table 1. presents a comparative overview of the most relevant tools for automated test case generation, classified according to their methodological approaches, including Model-Based Testing (MBT), Natural Language Processing (NLP) and Large Language Models (LLMs).

Table 6. Test Case Generation Tools

No.	Tool Name	Description	Domain (MBT/NLP/LLM)	Reference
1	NAT2TESTSCR	Automated test case generation for critical reactive systems using SCR model and controlled natural language.	NLP	(Carvalho et al., 2014)
2	ASSERT	Requirements analysis and test generation using formal logic and theorem provers.	NLP	(Moitra et al., 2019)
3	Litmus	Automatic generation of functional tests from informal requirements using Link Grammar parser.	NLP	(Dwarakanath et al., 2012)
4	US2Test	System test generation from user stories using the GPT-4 model.	LLM	(Cavalcanti et al., 2025)
5	AutoUAT	Generation of acceptance test scenarios from user stories in Gherkin format using LLM.	LLM	(Ferreira et al., 2025)
6	Test Flow	Conversion of Gherkin scenarios into automated Cypress tests for web applications.	LLM	(Ferreira et al., 2025)
7	Fastest	Model-based testing tool based on Z notation and Test Template Framework.	MBT	(Javed et al., 2016)
8	PTGTP	Test generation based on control flow diagrams with genetic algorithm optimization.	MBT	(Alrawashed et al., 2019)
9	TDE/UML	Test generation from UML activity diagrams.	MBT	(Hasling et al., 2008)

5 CONCLUSION

This paper presents a preliminary review of methods and techniques for automatic test case generation from software requirements, with a special focus on model-based testing, natural language processing approaches, and the application of large language models. The literature analysis shows that model-based testing is a widely accepted approach that enables early testing, high coverage, and better traceability of requirements, especially in domains where software reliability is critical. At the same time, NLP techniques contribute to reducing manual effort and improving the understanding of textual requirements, while LLM-based approaches bring a new level of automation and flexibility in generating test cases and test scripts.

However, the review results also point to numerous challenges. Ambiguity and incompleteness of requirements written in natural language, limited support for non-functional requirements, scalability issues, as well as the occurrence of errors and inaccurate information in LLM models, represent significant obstacles to wider industrial adoption. Additionally, the creation and maintenance of formal models require additional time, expertise, and appropriate tools, which in some cases limits the practical use of these approaches.

This study is limited by its reliance on secondary sources and a qualitative literature review approach. The selection of studies was based on availability in Google Scholar, which may introduce publication and indexing bias. In addition, the analysis does not include empirical validation or experimental benchmarking of the reviewed methods. As a result, the findings provide a conceptual synthesis rather than quantitative evaluation.

Based on the analyzed studies, it can be concluded that future development in this field should focus on hybrid approaches that integrate MBT, NLP, and LLM techniques, with clearly defined formal models and necessary human validation. Further research is needed to improve support for non-functional requirements, increase the accuracy and reliability of LLM models, and strengthen industrial evaluation of proposed solutions. Such approaches have the potential to significantly improve software quality and testing efficiency in modern development processes.

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Cryptography Techniques and Challenges for IoT and Embedded Systems: A Brief Analysis

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Abstract. The rapid expansion of the Internet of Things (IoT) has integrated embedded devices into critical infrastructure, healthcare, and personal domains, making security a critical concern. In this paper, we review existing cryptography techniques and encryption algorithms along with their pros and cons. Our focus is on the practical challenges of implementing strong security on devices with very limited processing power, memory, and battery life.

Key words and phrases: Cryptography, Encryption, Algorithms, IoT, Embedded Devices.

1 Introduction

Technologies of great significance have been widespread in the recent years, including the mobile computing, wireless networks as well as advertising networks. Development is commonly based on the internet and embedded technologies, which made it possible to connect the things around us everywhere.(Thabit et al., 2023)

The Internet of Things is a modern concept, related to network of physical devices embedded with sensors and software that mutually connect and exchange data over the internet. These devices commonly include industrial sensors, medical implants and smart home gadgets, whose systems collect and share information frequently. Due to handling of large amounts of data, they are suitable targets for cyber-related attacks and because of that, strong security is an important feature to make sure these devices can be used reliably. One of the common problems for securing these devices is their limited processing power and available memory. Many of IoT related devices run on small batteries and they need to have stable power supply, while maintaining secure, reliable and stable communication functionality. Traditional security methods which are designed for powerful computers are often too heavy for microcontrollers to handle, and standard cryptographic algorithms can drain device's battery very quickly, or run too slow to be useful. This challenge has led to development of specific encryption algorithms, crafted to satisfy the needs of IoT systems and devices. This paper aims to perform a survey and analysis of cryptographic algorithms commonly found in IoT systems, and point out their strengths and weaknesses.

2 Related Work

When observing the field of the Internet of Things, major challenges are focused around trust and security issues such as privacy, authentication, configuration management, access control, authorization, data storage and system administration. As Internet of Things applications range from smartphones to embedded devices, their goal is to create a digital environment that improves the quality of everyday life, according to human needs. Considering all that, cryptography represents one of the main tools for ensuring data security, as it enables secure communication by converting plaintext into cipher text, using specific algorithms and keys that protect information from unauthorized parties.(Thabit et al., 2023)

Goal of lightweight cryptography is to effectively incorporate encryption features that are suited for resource-constrained devices. Those devices usually have limited amount of available memory and weak processing power followed by low power consumption, while keeping real-time response capabilities.(Aljaedi et al., 2025)

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According to (Khairnar & Bodra, 2025), lightweight cryptography techniques can be separated into four distinct categories, which are:

- Symmetric Key Cryptography (followed by Block Ciphers and Stream Ciphers)
- Hash Functions (followed by SPONGENT and PHOTON)
- Authenticated Encryption (followed by ASCON and AEGIS)

According to (Aljaedi et al., 2025), challenges of applying conventional cryptography techniques for Internet of Things devices can be categorized by following problems:

- Key management (followed by key generation and key storage)
- Implementation Complexity
- Resource Consumption (followed by memory usage and power consumption)
- Performance Overhead (followed by computational complexity and latency)

3 Cryptography Techniques and Challenges

3.1 Symmetric Cryptography

Symmetric cryptography is considered to be a common choice for low-power consumption models, especially when implementation considers the resource-constrained Internet of Things devices.(*A Survey of Efficient Lightweight Cryptography for Power-Constrained Microcontrollers*, n.d.) While asymmetric encryption uses public key to perform encryption, and private key for decryption, symmetric encryption uses a single key for both, thus performing much faster and making it ideal for Internet of Things devices.(*SuPOR: A Lightweight Stream Cipher for Confidentiality and Attack-Resilient Visual Data Security in IoT - ScienceDirect*, n.d.) Two commonly applied symmetric encryption algorithms are block cipher and stream cipher algorithms.(*A Survey of Efficient Lightweight Cryptography for Power-Constrained Microcontrollers*, n.d.)

In practice, Internet of Things systems often adopt a **hybrid approach** to combine efficiency with strong security. **Elliptic Curve Cryptography (ECC)** or **Elliptic Curve Diffie-Hellman (ECDH)** is typically used to securely exchange or derive a **session key** between devices. The session key is then employed for fast symmetric encryption, ensuring secure communication without the computational overhead of using asymmetric algorithms for all operations.

3.2 Block Cipher

Symmetric block cipher performs encryption and decryption of data by using the same key and is commonly used for Internet of Things devices due to strong security. However, challenges of creating a lightweight block cipher that balances aspects of performance, cost and security exist to this day.(*Access: SLIM: A Lightweight Block Cipher for Internet of Health Things. :: Katalog Der Universitätsbibliothek Leipzig*, n.d.) Therefore, the goal of light-weight block cipher is to provide security in real-time scenarios, with ability of being implemented in Internet of Things devices.(*IASC | Light-Weight Present Block Cipher Model for IoT Security on FPGA*, n.d.) Considering the practical use of block ciphers in IoT environment, PRESENT block cipher is a widely accepted and implemented algorithm characterized by optimal performance, low-cost implementation and simple design.(*DNA-PRESENT: An Improved Security and Low-Latency, Lightweight Cryptographic Solution for IoT*, n.d.)

3.3 Stream Cipher

Symmetric stream cipher is an encryption algorithm that is highly efficient compared to block cipher. Its practical usage varies from digital communication all the way up to real-time transmission. The encryption technique of stream cipher is performed by utilizing a pseudorandom byte generator. Long binary sequence (also known as keystream) is generated. After generation of keystream, the plaintext is combined with it by performing an XOR operation to produce cipher text.(*A Lightweight Keystream Generator Based on Expanded Chaos with a Counter for Secure IoT*, n.d.) Considering the stream ciphers, their biggest advantage is that their memory usage, complexity and operational requirements are significantly lower in comparison to block ciphers. (*Adding an Avalanche Effect to a Stream Cipher Suitable for IoT Devices*, n.d.)

3.4 Hash Functions

Hash functions are represented as fundamental components, found both in cryptographic and non-cryptographic systems, and they support many aspects of security, such as data integrity and secure authentication.(Gladis Kurian & Chen, 2025) These functions are designed to perform one-way operation which maps arbitrary-length input to a fixed-length output.(*Hash Functions | Springer Nature Link*, n.d.) Two lightweight Hash Functions commonly applied in Internet of Things networks are PHOTON and SPONGENT. (Khairnar & Bodra, 2025)

3.5 PHOTON Hash Function

PHOTON is a hash function designed to be lightweight security primitive. It has sponge-based construction and is specifically designed for devices that are running with limited resources.(*IoT Edge Device Security: An Efficient Lightweight Authenticated Encryption Scheme Based on LED and PHOTON*, n.d.) Usability of PHOTON hash function can be found in the process of generating Message Authentication Code, which is used to guarantee data integrity and authenticity, thus providing secure communication between multiple devices.(*A Novel Lightweight Hybrid Cryptographic Framework for Secure Smart Card Operations | Journal on Information Security | Springer Nature Link*, n.d.)

3.6 SPONGENT Hash Function

SPONGENT is a form of hash function that uses the PRESENT-type permutation as the internal permutation. This type of hash function exists in a lightweight form that is made from 88, 128, 160, 224 and 256 bits.(*Improved Zero-Sum Distinguisher for SPONGENT-88 | Atlantis Press*, n.d.) Compared to SHA-1 and SHA-2 algorithms, SPONGENT-128 and SPONGENT-224 provided improved security.(*Power, Performance and Area Analysis of Sponge Based Lightweight HASH Function - R Discovery*, n.d.) Having a versatile configurations, it may provide balance between processing speed and security, which may be a good addition to enhance the already existing security of Internet of Things devices. By optimizing resource efficiency, SPONGENT hash function may operate on devices that are limited with computational resources, resulting in low memory usage, as well as reduced power consumption.(*Spongent: A Lightweight Hash Function for Enhancing Integrity in Resource-Constrained IoT Environments | IEEE Conference Publication | IEEE Xplore*, n.d.)

3.7 Authenticated Encryption

ASCON Encryption

Ascon represents a family of lightweight cryptographic algorithms which are designed to be very efficient and easy to implement.(*Ascon – Lightweight Cryptography*, n.d.) By having robust security, high efficiency and flexibility, ASCON-based family of symmetric key cryptographic primitives is ideal to be applied on resource-constrained environments, Internet of Things devices, as well as embedded systems and low-power sensors. It includes multiple algorithms including authenticated encryption with associated data as well as hash functions and more.(*NIST Publishes SP 800-232 | CSRC*, n.d.) (*Securing the IoT Ecosystem: ASIC-Based Hardware Realization of Ascon Lightweight Cipher | International Journal of Information Security | Springer Nature Link*, n.d.) Besides ASCON hash variants, Ascon-Hash256, Ascon-XOF128 and Ascon-CXOF128 adopted the sponge-based structure, thus having a compact, hardware friendly design. By relying on this type of structure, they preserve both structural integrity and lightweight implementation.(Gladis Kurian & Chen, 2025)
According to (Kaur et al., 2026), ASCON design itself, relying on a sponge-based MonkeyDuplex construction consists of four stages which are:

- Initialization Operation
- Processing of the Associated Data
- Processing of the Plaintext
- Finalization Operation

Mechanism that keeps these four stages updated is based on 320-bit permutations, where permutation is bit-sliced into five 64-bit register words that make up the 5-bit internal state. When observing the full 12-round ASCON, this permutation iteratively apply a substitution-permutation network (SPN)-based round transformation, that is made up of adding round constants, applying the substitution layer, as well as applying the linear layer for diffusion purpose to the internal state.(Kaur et al., 2026)

AEGIS Encryption

AEGIS represents a family of authenticated encryption type, with associated data ciphers designed to target highly efficient implementation in a software. By utilizing AES encryption round function as its main operation, AEGIS can make full use of various cryptographic properties while keeping efficient implementation.(Liu et al., 2025) AEGIS encryption comes in three variants which are AEGIS-128, AEGIS-128L and AEGIS-256. While AEGIS-128 and AEGIS-128L achieve 128 bits of security, AEGIS-256 is made to achieve security of 256 bits.(Liu et al., 2025) (Jiao et al., 2022)

4 Performance Evaluation of AES based Cryptography

Evaluation of AES based cryptography in this experiment is a performance and functionality test of AES encryption and decryption on an ESP32, using all three common key sizes: 128, 192, and 256 bits. The experiment generates a fresh AES key for each iteration and encrypts a fixed 128-byte message in ECB mode, measuring the time taken for key generation, encryption, and decryption. It repeats this process 20 times per key size to get consistent data, while also tracking memory usage: both heap and stack. The heap measurements use ESP32-specific functions to capture free and used memory in real time, while the stack high water mark gives insight into maximum stack usage. Overall, the experiment combines cryptographic benchmarking with resource monitoring, giving a clear picture of both the performance and the memory impact of AES operations on the ESP32.

Message to be encrypted by using different AES encryption key length types is: "**This is a sample message for AES encryption testing on ESP32. It is exactly 128 bytes long, padded with spaces to fit perfectly.**"

AES-128

Results of AES-128 evaluation can be observed in the table below:

Table 1. Evaluation Results of AES-128 bit based cryptography

Number of Iteration	Key Generation(µs)	Encryption (µs)	Decryption(µs)	Heap Used(bytes)	Heap Free(bytes)	Stack Used(bytes)	Stack Free(bytes)
1.	91	104	99	15728	304936	3488	4704
2.	63	92	92	15728	304936	3488	4704
3.	63	92	92	15728	304936	3488	4704
4.	63	92	92	15728	304936	3488	4704
5.	63	92	92	15728	304936	3488	4704
6.	63	92	92	15728	304936	3488	4704
7.	63	92	92	15728	304936	3488	4704
8.	63	92	92	15728	304936	3488	4704
9.	63	92	92	15728	304936	3488	4704
10.	63	92	92	15728	304936	3488	4704
11.	63	92	92	15728	304936	3488	4704
12.	63	92	92	15728	304936	3488	4704
13.	63	92	92	15728	304936	3488	4704
14.	63	92	92	15728	304936	3488	4704
15.	63	92	92	15728	304936	3488	4704
16.	63	92	92	15728	304936	3488	4704
17.	63	92	92	15728	304936	3488	4704
18.	63	92	92	15728	304936	3488	4704
19.	63	92	92	15728	304936	3488	4704
20.	63	92	92	15728	304936	3488	4704

Table 2. Evaluation Results (Average) of AES-128 bit based cryptography

Key Generation(µs)	Encryption (µs)	Decryption(µs)	Heap Used(bytes)	Heap Free(bytes)	Stack Used(bytes)	Stack Free(bytes)
64.4	92.6	92.35	15728	304936	3488	4704

AES-192

Results of AES-192 evaluation can be observed in the table below:

Table 3. Evaluation Results of AES-192 bit based cryptography

Number of Iteration	Key Generation(µs)	Encryption (µs)	Decryption(µs)	Heap Used(bytes)	Heap Free(bytes)	Stack Used(bytes)	Stack Free(bytes)
1.	78	99	99	15728	304936	3488	4704
2.	77	100	99	15728	304936	3488	4704
3.	77	100	99	15728	304936	3488	4704
4.	77	100	99	15728	304936	3488	4704
5.	77	100	99	15728	304936	3488	4704
6.	77	100	99	15728	304936	3488	4704
7.	77	100	99	15728	304936	3488	4704
8.	77	100	99	15728	304936	3488	4704
9.	77	100	99	15728	304936	3488	4704
10.	77	100	99	15728	304936	3488	4704
11.	77	100	99	15728	304936	3488	4704
12.	77	100	99	15728	304936	3488	4704
13.	77	100	99	15728	304936	3488	4704
14.	77	100	99	15728	304936	3488	4704
15.	77	100	99	15728	304936	3488	4704
16.	77	100	99	15728	304936	3488	4704
17.	77	100	99	15728	304936	3488	4704
18.	77	100	99	15728	304936	3488	4704
19.	77	100	99	15728	304936	3488	4704
20.	77	100	99	15728	304936	3488	4704

Table 4. Evaluation Results (Average) of AES-192 bit based cryptography

Key Generation(µs)	Encryption (µs)	Decryption(µs)	Heap Used(bytes)	Heap Free(bytes)	Stack Used(bytes)	Stack Free(bytes)
77.05	99.95	99	15728	304936	3488	4704

AES-256

Results of AES-256 evaluation can be observed in the table below:

Table 5. Evaluation Results of AES-256 bit based cryptography

Number of Iteration	Key Generation(µs)	Encryption (µs)	Decryption(µs)	Heap Used(bytes)	Heap Free(bytes)	Stack Used(bytes)	Stack Free(bytes)
1.	78	107	108	15728	304936	3488	4704
2.	77	107	107	15728	304936	3488	4704
3.	77	107	107	15728	304936	3488	4704
4.	77	107	107	15728	304936	3488	4704
5.	77	107	107	15728	304936	3488	4704
6.	77	107	107	15728	304936	3488	4704
7.	77	107	107	15728	304936	3488	4704
8.	77	107	107	15728	304936	3488	4704
9.	77	107	107	15728	304936	3488	4704
10.	77	107	107	15728	304936	3488	4704
11.	77	107	107	15728	304936	3488	4704
12.	77	107	107	15728	304936	3488	4704
13.	77	107	107	15728	304936	3488	4704
14.	77	107	107	15728	304936	3488	4704
15.	77	107	107	15728	304936	3488	4704
16.	77	107	107	15728	304936	3488	4704
17.	77	107	107	15728	304936	3488	4704
18.	77	107	107	15728	304936	3488	4704
19.	77	107	107	15728	304936	3488	4704
20.	77	107	107	15728	304936	3488	4704

Table 6. Evaluation Results (Average) of AES-256 bit based cryptography

Key Generation(µs)	Encryption (µs)	Decryption(µs)	Heap Used(bytes)	Heap Free(bytes)	Stack Used(bytes)	Stack Free(bytes)
77.05	107	107.05	15728	304936	3488	4704

The AES tests on the ESP32 show consistent performance across 20 iterations for each key length (128-bit, 192-bit, and 256-bit). Key generation, encryption, and decryption times are stable after the first iteration, with only minor variations due to normal system and timer fluctuations. AES-256 has slightly longer key generation times compared to AES-128 and AES-192, reflecting the larger key size, but encryption and decryption durations are nearly identical for all three key lengths. Stack usage remains constant across all key sizes, indicating that the AES implementation does not require additional stack space for larger keys. Heap usage is also consistent because the buffers for plaintext, ciphertext, and decrypted data are fixed at 128 bytes, independent of key length. Overall, the results demonstrate predictable and uniform AES performance on the ESP32, with key size affecting only the key generation slightly and having minimal impact on encryption and decryption times.

5 CONCLUSION

Based on the reviewed literature, lightweight cryptographic techniques can be categorized into symmetric cryptography, hash functions, authenticated encryption and hybrid approaches, as shown in Table 7. While symmetric algorithms such as block and stream ciphers offer fast and efficient encryption, lightweight hash functions like PHOTON and SPONGENT ensure data integrity with minimal resource usage. Authenticated encryption schemes such as ASCON and AEGIS further enhance security by combining confidentiality and authentication in a single, efficient design. Overall, lightweight cryptography plays an important role in addressing the key management, implementation complexity, resource consumption and performance overhead challenges, as shown in Table 8. By balancing security strength with computational efficiency, these techniques provide a practical, and scalable foundation for securing modern Internet of Things environment.

Table 7. Classification of Lightweight Cryptography Techniques

Category	Description	Example
Symmetric Key Cryptography	Uses the same secret key for encryption and decryption	Block Ciphers and Stream Ciphers
Hash Functions	Produces fixed-length hash values for data integrity	SPONGENT, PHOTON
Authenticated Encryption	Provides confidentiality and authentication together	ASCON, AEGIS

Table 8. Challenges of Conventional Cryptography in IoT

Challenge Category	Sub-Problems	Impact on IoT Devices
Key management	Key generation, Key storage	Difficult secure handling of keys in constrained devices
Implementation Complexity	Algorithm design and deployment difficulty	Hard to implement on limited hardware
Resource Consumption	Memory usage, Power consumption	Drains battery and increases hardware cost
Performance Overhead	Computational complexity, Latency	Slower processing and delayed communication

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Intelligent Agents in Computer Science Education: Opportunities, Pedagogical Value, and Emerging Risks

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Abstract. Artificial intelligence is increasingly reshaping educational practice, and computer science education has become one of the most active contexts for this transformation. Recent research shows that intelligent agents are being used in programming courses as intelligent tutoring systems, automated feedback tools, and generative AI assistants that provide explanations, code suggestions, and formative support. This paper reviews the pedagogical value of intelligent agents in computer science education, with particular attention to personalized learning support, assistance in programming tasks, and automated assessment and feedback. At the same time, it addresses emerging concerns related to overreliance, cognitive offloading, error propagation, and academic integrity. The reviewed literature suggests that intelligent agents can significantly improve responsiveness, learner support, and engagement when they are integrated into instruction through clear pedagogical scaffolding. However, recent evidence also indicates that unrestricted use may weaken durable learning, especially when students treat AI systems as shortcuts rather than instructional partners. The paper concludes that intelligent agents should not be viewed as replacements for teachers but rather as pedagogically structured tools capable of extending instructional reach in computer science education.

Key words and phrases: intelligent agents, computer science education, programming education, generative AI, intelligent tutoring systems, automated feedback

1 INTRODUCTION

Artificial intelligence has moved rapidly from the margins of educational technology to the core of teaching and learning design. In STEM education, systematic reviews show that AI technologies are now used across instructional delivery, learner support, assessment, and feedback, rather than being limited to isolated analytics tasks (Xu & Ouyang, 2022). Within this broader transformation, computer science education stands out as a particularly suitable domain for intelligent agents because programming courses rely on iterative problem solving, generate rich traces of learner activity, and require timely and repeated feedback (Agbo et al., 2025; Manorat et al., 2025). As a result, recent literature increasingly treats intelligent agents not as experimental add-ons, but as practical components of contemporary computing education.

This trend is especially important because programming students often struggle with more than syntax alone. They must learn how to decompose problems, interpret compiler and runtime errors, evaluate alternative implementations, debug systematically, and transfer conceptual knowledge from one task to another. Research on automated programming feedback and AI-supported tutoring suggests that intelligent agents are well positioned to support precisely these stages of learning by providing explanations, hints, adaptive guidance, and immediate formative responses (Keuning et al., 2019; Messer et al., 2024). At the same time, the rise of generative AI has made the issue more complex:

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the same systems that can scaffold learning may also encourage superficial solution-seeking and dependency when used without instructional guardrails (Rahe & Maalej, 2025; Wu & Yu, 2024).

For this reason, the goal of this paper is not simply to present intelligent agents as beneficial innovations, but to examine their educational role more critically. The paper reviews how intelligent agents are currently used in computer science education, where they offer the greatest pedagogical value, and which emerging risks should shape their future integration into teaching practice.

2 Intelligent agents as instructional support in computer science education

In computer science education, intelligent agents should be understood as a broad category of AI-supported systems that participate in the learning process by perceiving learner input, generating responses, and adapting support to a pedagogical goal. In practice, this category includes intelligent tutoring systems, automated grading and feedback tools, conversational assistants, and generative AI systems that can explain concepts, propose code, diagnose mistakes, or prompt reflection. Reviews in both STEM education and computing education show that these systems differ in technical architecture but converge around a common instructional function: they reduce the delay between learner action and pedagogical response (Agbo et al., 2025; Létourneau et al., 2025; Xu & Ouyang, 2022).

This reduction in feedback latency is particularly important because programming is inherently iterative. Students typically write partial solutions, encounter errors, revise their reasoning, and test alternatives through repeated cycles. Keuning et al. (2019) demonstrated in their systematic review of automated feedback for programming exercises that the value of such systems lies not merely in grading correctness, but in enabling repeated improvement through targeted feedback. A more recent review of automated grading and feedback tools confirms that most systems still focus primarily on correctness, often through unit testing and static analysis, but also notes a growing interest in evaluating readability, maintainability, and broader code-quality dimensions (Messer et al., 2024). Together, these findings suggest that intelligent agents are becoming part of the pedagogical infrastructure of programming education rather than optional technical supplements.

Recent literature on AI-driven intelligent tutoring systems reinforces this interpretation. A 2025 systematic review of ITS research in education found generally positive effects on learning and performance, while also emphasizing that educational value depends on thoughtful design and evaluation rather than on the mere presence of AI (Létourneau et al., 2025). This is especially relevant for computer science education, where the instructional challenge is not simply to produce a correct answer, but to cultivate reasoning processes that students can transfer to future programming contexts.

3 Main areas of application

The strongest evidence for the use of intelligent agents in computer science education appears in three interconnected areas: personalization, programming support, and automated formative assessment. First, personalized learning support is one of the most consistently reported benefits of AI-based educational systems. Broader STEM reviews indicate that AI tools are particularly effective when they adapt support to learner performance, prior knowledge, or patterns of interaction (Xu & Ouyang, 2022). In computer science education, where students often enter the same course with very different levels of prior experience, this adaptive capacity is especially valuable. Intelligent agents can recommend different examples, explanations, or levels of task difficulty, allowing support to vary across learners instead of remaining fixed for the entire class (Agbo et al., 2025; Manorat et al., 2025).

Second, intelligent agents increasingly function as programming guides. The recent systematic review by Agbo et al. (2025) shows that generative AI tools are now being explored not only in introductory programming, but also across a broader range of computing subjects, including upper-level courses. This expansion is important because it suggests that intelligent agents are no longer limited to drill-based assistance; rather, they are being used to support conceptual clarification, debugging, design exploration, and code interpretation. Empirical studies on students' use of generative AI in programming courses similarly show that learners commonly turn to such tools to understand examples, debug code, and resolve task-specific difficulties (Lepp & Kaimre, 2025).

Third, intelligent agents remain highly relevant in assessment and feedback. Automated grading and feedback systems can return responses almost instantly, support multiple resubmissions, and reduce instructor workload in large programming classes (Keuning et al., 2019; Messer et al., 2024). From a pedagogical perspective, this matters because delayed feedback can interrupt the learning cycle in programming, whereas immediate guidance allows students to correct misunderstandings while the problem-solving context is still active. For this reason, the literature consistently positions automated formative feedback as one of the most mature and educationally valuable applications of intelligent agents in computing education (Keuning et al., 2019; Messer et al., 2024).

4 Pedagogical value and learning benefits

The educational promise of intelligent agents extends beyond efficiency. A meta-analysis published in the *British Journal of Educational Technology* found that AI chatbots had a positive overall effect on student learning outcomes across randomized studies (Wu & Yu, 2024). Although this evidence is not limited to computer science education, it remains relevant because it indicates that conversational AI can support measurable learning gains when integrated appropriately. Even more strikingly, a 2025 randomized controlled trial published in *Scientific Reports* reported that a research-based AI tutor enabled students to learn significantly more in less time than an in-class active-learning condition, while also increasing engagement and motivation (Kestin et al., 2025). These findings suggest that AI-supported instruction can be educationally meaningful when the system is pedagogically designed rather than simply deployed as a general-purpose assistant.

For programming education specifically, recent research indicates that intelligent agents are most beneficial when they scaffold thought rather than replace it. Nathaniel et al. (2025) showed that integrating generative AI with instructional scaffolding and prompt-engineering support helped sustain higher-order thinking and programming-logic development in novice learners. This is a crucial finding because it suggests that positive outcomes do not emerge from AI access alone. Rather, they emerge when students are taught how to interrogate, guide, and verify the system's output. In that sense, the strongest pedagogical role of intelligent agents is not answer generation, but structured cognitive support.

5 Risks, tensions, and limitations

Despite these benefits, recent evidence shows that intelligent agents also introduce serious educational tensions. One of the clearest concerns is that students may use generative AI as a shortcut rather than as a learning aid. Rahe and Maalej (2025) found that, while these tools can support understanding and problem solving, students also frequently rely on them to generate or repair solutions in ways that may reduce deeper engagement with underlying concepts. This concern is echoed by newer grounded-theory research in AI-assisted programming education, which frames the central issue as a tension between cognitive scaffolding and cognitive offloading: the same tool can function as a tutor, a support mechanism, or a crutch, depending on how it is used (Liu et al., 2026).

A related limitation is that students may struggle to detect and correct AI-generated errors. Recent work in the *International Journal of Artificial Intelligence in Education* found that students often perceive generative AI as useful in programming courses, but still encounter substantial difficulty when trying to evaluate or repair incorrect outputs (Kohen-Vacs et al., 2025). This is especially significant in computer science education because plausible but flawed code can reinforce misconceptions if learners lack the expertise to verify what the agent produces. As a result, the apparent fluency of AI assistance may conceal fragile understanding.

The strongest cautionary evidence comes from recent experimental research showing that generative AI can harm learning when used without guardrails. Bastani et al. (2025) found that unrestricted AI assistance in mathematics practice led students to perform worse independently afterward, even when the tool improved immediate task completion. Although the study was not conducted in programming education, its implications are directly relevant: successful task performance with AI does not necessarily translate into durable learning. For computer science instructors, this means that intelligent agents should be introduced with explicit constraints, verification routines, and reflective activities that preserve students' responsibility for reasoning.

6 Conclusion

The literature reviewed in this paper supports a balanced conclusion. Intelligent agents are becoming increasingly important in computer science education because they respond to core instructional needs of programming courses: heterogeneous learner preparation, repeated practice, and rapid formative feedback (Agbo et al., 2025; Keuning et al., 2019; Manorat et al., 2025; Messer et al., 2024). Review studies and recent empirical work indicate that such systems can improve responsiveness, engagement, and, under appropriate pedagogical conditions, learning outcomes (Kestin et al., 2025; Létourneau et al., 2025; Nathaniel et al., 2025; Wu & Yu, 2024).

At the same time, the most recent research makes it clear that the educational value of intelligent agents is not automatic. In computer science education in particular, the key issue is not whether students will use AI-supported tools, but whether instructional design will guide that use toward explanation, critique, debugging, and conceptual transfer rather than passive dependency (Bastani et al., 2025; Kohen-Vacs et al., 2025; Liu et al., 2026; Rahe & Maalej, 2025). The most defensible pedagogical position, therefore, is that intelligent agents should not replace teachers. Instead, they should extend teaching capacity within a carefully structured educational environment that preserves human judgment, supports student reflection, and treats AI assistance as part of a broader learning design.

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Types of measurements in the evaluation of knowledge acquisition during the onboarding process in software teams

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Abstract. This paper discusses the evaluation of knowledge acquisition during the onboarding process in software teams, starting from the fact that the indicators of this process contain different natures and therefore require the application of different measurement approaches. Previous research describes onboarding practices, challenges, and supports, but a clear enough framework for linking specific onboarding indicators to the appropriate types of measurements is not present. In order to solve this deficiency, the paper considers four complementary types of measurement: Binary, Numeric, Likert, and Rubric. The research is based on Design Science Research, whereby an artifact is proposed that includes a conceptual model of measurement elements, rules for choosing the type of measurement, and the basic procedure of normalizing the results in order to translate them into a certain analytical form. The proposed model connects aspect onboarding, indicator, type of measurement, and measurement results, on the basis of which a more systematic evaluation of knowledge acquisition is possible. The contribution of this work is reflected in the systematization of the type of measurement in the context of onboarding and establishes the basis for the development of more structured evaluation models and software solutions for the onboarding process.

Key words and phrases: Employee onboarding, Software engineering, Measurement instruments, Design science research, Knowledge transfer

1 INTRODUCTION

The onboarding process in software teams is a process in which a new employee gradually assumes an active role in the team while simultaneously understanding the organization's context, projects, practices, and expectations associated with the role (Gregory et al., 2022). In agile teams, this process is particularly sensitive because the new member needs to be integrated into the existing way of working without negatively affecting the flow of the project, while at the same time developing the ability to effectively contribute to the work of the team (Gregory et al., 2022). Similarly, Ju et al. (2021) show that onboarding in software teams is not limited to formal introduction to colleagues and the work environment, but also includes specific tasks through which knowledge, confidence, and socialization are simultaneously developed. Buchan et al. (2019) additionally point out that a new employee, as a new team member, needs a period of integration and learning before becoming productive, which is why well-designed onboarding is of immediate importance for team and organizational performance.

The complexity of the onboarding process increases further in environments where distributed teams, legacy systems, and significant dependency on domain knowledge are present. Britto et al. (2018) indicate that the onboarding of software engineers and teams represented in distributed legacy projects is determined by a number of related factors, including the availability of knowledge, domain specificity, and the way team collaboration is organized. These results confirm that onboarding in software engineering is a multi-layered process that includes technical training, understanding of development procedures, integration into the team, and gradual assumption of responsibility.

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Contemporary research extensively describes onboarding practices, challenges, and support that new employees encounter in software teams (Ju et al., 2021; Gregory et al., 2022; Buchan et al., 2019; Britto et al., 2018). In addition, a recent systematic review of software solutions aimed at onboarding new employees in software projects indicates that a significant part of the literature focuses on tools to support inclusion in software projects, as well as on obstacles that occur in the initial stages of work (Santos et al., 2025).

This research gap is important when it comes to knowledge acquisition during onboarding. Certain indicators can be represented in binary form, for example whether documentation has been reviewed or a development activity has been completed. Others can be represented numerically, such as the number of completed onboarding tasks, resolved issues, or accepted code review changes, while some indicators rely on the self-assessment of the new employee or on mentor assessment of the application of development procedures.

Accordingly, the aim of this paper is to consider the types of measurements that can be applied in the evaluation of knowledge acquisition during onboarding. Special focus is directed at four complementary forms of measurement: (1) Binary, (2) Numeric, (3) Likert, and (4) Rubric. The contribution of the work is reflected in the systematization of these types of measurements in the context of onboarding, in the consideration of methodological properties, and in the presentation of the possibility of their connection through a conceptual model and the basic procedure for normalizing results.

The paper is organized as follows. In the second chapter, the theoretical framework of the work is presented, with an emphasis on onboarding in software teams, constructs, indicators, and measurement operationalization. The third chapter presents a methodological approach to research based on the design science paradigm. In the fourth chapter, the types of measurements are discussed, and a conceptual model of their application in the process of evaluation of knowledge acquisition is proposed. The fifth chapter introduces the procedure of normalization of the results and an example of the application of the considered types of measurements. At the end of the paper, concluding considerations, limitations, and possible directions for future research are presented.

2 MEASUREMENT BASIS FOR KNOWLEDGE ACQUISITION EVALUATION

In order for the evaluation of knowledge acquisition during the onboarding process to be methodologically grounded, it is necessary to clearly distinguish the construct, the indicator, and the method of measurement. Lambert & Newman (2022) stated that the development of a measure involves three steps: (1) defining the construct, (2) choosing an operationalization that corresponds to the definition of the construct, and (3) providing evidence of the construct validity of the chosen measure. Accordingly, Mueller (2004) described operationalization as a transition from the abstract level of the concept to the empirical level of variables and indicators, while Ralph & Tempero (2018) warned that in software engineering, it is not enough to assume that a certain measure includes the property that is to be evaluated. Based on the above, in this paper, the acquisition of knowledge during onboarding is viewed as a construct represented through indicators of different types, while the choice of the type of measurement is based on certain characteristics of the indicator.

In this context, different types of measurement cannot be seen as mutually interchangeable. Norman (2010) states that Likert scales are ordinal response scales and are adequate for evaluating attitudes, perceptions, and self-assessments of a certain state. On the other hand, Jonsson & Svingby (2007) show that rubrics can improve assessment consistency and support the assessment of more complex competencies when criteria and levels are clearly defined. Brookhart & Chen (2015) define rubrics as a coherent set of criteria followed by descriptions of performance quality levels. In this paper, the Likert approach is considered suitable for a scaled assessment of understanding, confidence, or perceived level of readiness, regardless of whether the assessment is given by a new employee or a mentor. On the other hand, rubrics are more suitable when the indicator is evaluated on the basis of predefined criteria and a description of the level of achievement.

In addition, certain indicators of knowledge acquisition can be dichotomous or numerical in nature. Dolnicar & Grün (2007) compare binary, ordinal, and metric response formats and indicate that different formats have different practical advantages depending on the nature of the construct and the purpose of the analysis. For this reason, Binary, Numeric, Likert, and Rubric are considered as complementary measurement types in this paper.

3 RESEARCH METHODOLOGY

This research is based on the design science paradigm, which is suitable in situations where the aim of the paper is not only descriptive, but also the development of an artifact intended to solve a specific problem (Hevner et al., 2004). In this paper, a composite research artifact is proposed, consisting of a conceptual model of measurement elements, rules for selecting the type of measurement, and a basic result normalization

procedure. Hevner et al. (2004) indicate that artifacts in design science research can take the form of constructs, models, or methods, which allows the approach in this work to be viewed as a combination of a conceptual model and methodological rules for choosing the type of measurement.

The methodological workflow relies on the approach proposed by Peffers et al. (2007), which includes (1) problem identification, (2) definition of solution objectives, (3) artifact design and development, (4) demonstration, and (5) evaluation. In this sense, the initial problem of this paper is the fact that the acquisition of knowledge during onboarding in software teams is manifested through indicators of a different nature, while in the literature, there is not a sufficiently clear approach to connecting them with the appropriate types of measurements. The goal of the proposed solution is to develop an artifact that enables a systematic alignment of indicator characteristics with appropriate measurement types.

Starting from the aforementioned theoretical foundations, an artifact developed in the paper includes three components: (1) a conceptual model of measurement elements, (2) rules for choosing the type of measurement, and (3) the basic procedure of normalizing results. The rules for choosing the type of measurement are based on the nature of the indicators that represent the acquisition of knowledge during onboarding. Binary type is used when the indicator represents the fulfillment of a certain condition or the execution of a discrete activity (Dolnicar & Grün, 2007). When the indicator has a directly measurable numerical value, the Numeric type of measurement is applied (Dolnicar & Grün, 2007). Likert-type measurement is used when the indicator requires a scaled assessment of understanding, confidence, or perceived level of readiness (Norman, 2010). A Rubric-type measurement is used when the assessment requires predefined criteria and described levels of achievement (Jonsson & Svingby, 2007; Brookhart & Chen, 2015).

In software teams, indicators of knowledge acquisition may also be derived from real development activities, such as issue resolution, code review, documentation use, repository activity, CI/CD feedback, and mentor evaluation of work on project tasks. Therefore, the selection of the measurement type depends on the nature of the indicator and on the evidence available in a specific organizational context.

4 Types of Measurements and Conceptual Model

In this paper, Binary, Numeric, Likert, and Rubric are considered as complementary types of measurement, the application of which depends on the nature of the indicator that represents the acquisition of knowledge during onboarding. Their methodological basis and the logic of choice have already been discussed in the previous section, while the way of their connection through the conceptual model of evaluation is presented below.

Based on the above, the paper proposed a conceptual model that connects the aspect of onboarding, the indicator, the type of measurement, and the result of the measurement. In this model, the starting point is the onboarding aspect that is to be evaluated, such as the acquisition of knowledge. This aspect is further presented through the corresponding indicators, where each indicator requires the choice of the type of measurement that is aligned with its nature. The result of the measurement represents the empirical expression of the indicator obtained by applying the appropriate type of measurement. In this way, the conceptual model allows different indicators of knowledge acquisition to be viewed not as unrelated elements, but as parts of a unified evaluation framework.

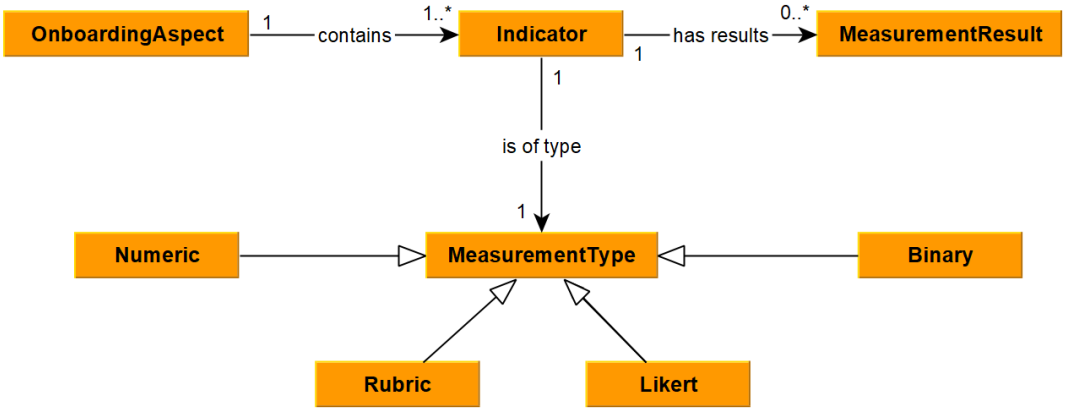


Figure 1. Conceptual model of measurement elements in onboarding evaluation

Figure 1 shows the basic elements of the proposed model and their mutual relationship. The model starts from onboarding as a broader area of evaluation, which is then operationalized through indicators. For each indicator, the appropriate measurement type is selected, and the result is obtained, which serves as the basis for further analysis and interpretation. This means that the same onboarding aspect can include indicators based on different sources of evidence, such as development activities, documentation use, system records, and mentor assessment.

The rules for choosing the type of measurement according to the nature of the indicator are presented in Table 1.

Table 7. Mapping of onboarding indicator characteristics to appropriate measurement types

Nature of indicators	Recommended measurement type	Reasoning for the choice	Typical source / example
Fulfillment of conditions or execution of activities	Binary	The indicator shows whether the required activity has been completed.	Documentation review, completed task, checklist, mentor record
Directly measurable numerical value	Numeric	The indicator can be expressed numerically	Test score, resolved issues, completed tasks, repository/system log
Scaled assessment of understanding, confidence, or readiness	Likert	The indicator requires an assessment of intensity	New employee or mentor assessment
Assessment according to criteria and levels of achievement	Rubric	The indicator requires criterion evaluation	Code review, task execution, application of development procedures

5 NORMALIZATION AND EXAMPLE

Since the results of the evaluation of knowledge acquisition during onboarding can be obtained by applying different types of measurements, their direct comparison is not methodologically justified without first being translated into a comparable form. The OECD/JRC Handbook (2008) emphasizes that normalization is required before aggregation when indicators have different measurement units or different scales, in order to make them mutually comparable. Accordingly, in this paper, a simple normalization of the results into a common range [0,1] is used, whereby the goal is to translate different types of measurements into a unique analytical form.

With the Binary type of measurement, normalization is direct because the raw value already belongs to the target interval. The normalized score s is therefore equal to the observed binary value x, where $x \in \{0,1\}$

$$s = x, x \in \{0,1\} \tag{1}$$

With the Numeric type of measurement, min–max normalization is used, which the OECD/JRC Handbook (2008) states as one of the standard ways of translating indicators into a common range. When a higher value indicates a better result, the expression is applied:

$$s = \frac{x - x_{min}}{x_{max} - x_{min}} \tag{2}$$

When a smaller value indicates a better result, the reverse form is used:

$$s = \frac{x_{max} - x}{x_{max} - x_{min}} \tag{3}$$

where x denotes the observed value of the indicator, x_{min} denotes the minimum value, and x_{max} denotes the maximum value.

With Likert and Rubric measurement types, assuming that scale levels are numbered from 1 to k, the results are translated into the range [0,1] by linear mapping of scale levels:

$$s = \frac{x - 1}{k - 1} \tag{4}$$

In the above expressions, s denotes the normalized score, x denotes the observed scale value, x_{min} and x_{max} denote the minimum and maximum values, and k denotes the total number of scale levels. This mapping was introduced to ensure analytical comparability of the results. It should be borne in mind that Norman (2010) views Likert scales as ordinal response scales, so the procedure mentioned in this paper is used as an operational solution for comparing results, and not as an assertion that the distances between adjacent levels are empirically equal. A limitation of this approach is that linear normalization simplifies the original measurement structure and should therefore be interpreted as an operational basis for comparison, not as evidence that all scale intervals have equal empirical meaning. The same logic is maintained for the rubric results, because they are also expressed through ordered levels of achievement.

To illustrate the proposed approach, Table 2 shows one aspect of onboarding related to understanding the basic development procedures. That aspect is presented through four indicators of different nature, where for each indicator, the corresponding type of measurement is applied, and the normalized result is calculated. In this way, it is shown how Binary, Numeric, Likert, and Rubric can be connected in a single evaluation framework, although they start from different measurement logics.

Table 2. Illustrative normalization example for different measurement types in onboarding evaluation

Onboarding Aspect	Indicator	Measurement type	Example result	Normalized score
Understanding Basic Development Procedures	Reviewed the mandatory documentation	Binary	1	1.00
Understanding Basic Development Procedures	Percentage of successfully completed task requirements	Numeric	78/100	0.78
Understanding Basic Development Procedures	Self-assessment of understanding	Likert	4/5	0.75
Understanding Basic Development Procedures	Mentor's assessment of the application of procedures	Rubric	3/5	0.50

The presented example shows that the results obtained by different types of measurements can be translated into a comparable analytical form, thus creating a basis for their joint interpretation in the evaluation of onboarding.

6 CONCLUSION

This paper discusses the types of measurements that can be applied in the evaluation of knowledge acquisition during onboarding in software teams. Starting from the fact that onboarding in software engineering includes various indicators, from the execution of discrete activities to the assessment of the understanding of tasks and the level of mastery of certain practices and skills, it was indicated that a single measurement format is not sufficient for a comprehensive evaluation of this process. In this sense, Binary, Numeric, Likert, and Rubric were viewed as complementary types of measurement whose appropriateness depends on the nature of the indicators that represent the acquisition of knowledge during onboarding.

The main contribution of this paper lies in connecting these types of measurements through a conceptual model, as well as in defining the basic procedure of their normalization for mutual comparability. In this way,

it was shown that indicators of different natures can be included in a single evaluation framework, without reducing all aspects of onboarding to the same form of measurement. The proposed approach is the basis for further consideration of a more structured monitoring of knowledge acquisition during onboarding, as well as for the eventual development of a broader model or software solution to support evaluation in this domain.

A limitation of the paper is that the proposed approach is shown on an illustrative example, without full empirical validation in a real organizational environment. Therefore, future research could be directed towards verifying the applicability of the proposed types of measurement in specific onboarding scenarios, as well as towards the development of more detailed rules of aggregation and interpretation of results within a wider evaluation system.

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Artificial Intelligence in Strategic Project Management Education for Industry 5.0

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Abstract. This paper provides a comprehensive review of recent literature on the application of artificial intelligence (AI) in higher education, with a focus on management and project management education. Twelve key publications from 2019 to 2026 were analyzed, highlighting the adoption of generative AI tools, adaptive learning systems, and AI-supported assessment methods. The review identifies gaps in empirical research, discipline-specific applications, and pedagogical models tailored to management and project management curricula. Based on these findings, a conceptual framework is proposed for integrating AI technologies into strategic project management education aligned with Industry 5.0 principles. The framework emphasizes human-centric approaches, responsible AI use, and sustainable pedagogical practices, aiming to improve student engagement, competence development, and learning outcomes. Methodologically, the study synthesizes empirical and conceptual findings, demonstrating the need for systematic integration of AI tools across multiple courses and programs. The proposed framework also supports curriculum design, decision-making, and governance in higher education while addressing ethical, social, and competency-related considerations. The paper concludes by suggesting directions for future research, including large-scale empirical validation, cross-disciplinary applications, and the development of AI-assisted teaching models in management education.

Key words and phrases: Artificial intelligence, management education, project management, Industry 5.0, generative AI.

1 INTRODUCTION

The rapid evolution of artificial intelligence (AI) has significantly influenced higher education and management education, creating new opportunities and challenges for teaching, learning, and curriculum design. AI technologies, including generative AI tools and adaptive learning systems, are transforming traditional instructional methods by enabling personalized learning experiences, predictive analytics, and improved decision-making capabilities (Holmes, Bialik, & Fadel, 2022; Ouyang & Jiao, 2021). In management education, these technologies offer the potential to simulate real-world project scenarios, support strategic decision-making, and improve students' competency in complex organizational contexts (Ruark & Biazzin, 2025; Zheng et al., 2024).

Despite these advancements, integrating AI into educational programs presents challenges related to pedagogical design, ethical considerations, and stakeholder acceptance (Selwyn & Gasevic, 2020; Karran et al., 2024). There is a need to develop structured frameworks that ensure AI adoption supports responsible and sustainable teaching practices while aligning with institutional goals and student learning outcomes (Holmes et al., 2022; Ruark & Biazzin, 2025). Moreover, research in AI applications for management and project management education remains limited, highlighting gaps in empirical studies, pedagogical models, and practical implementation strategies (Ali et al., 2024; Kasneci et al., 2023; Farrokhnia et al., 2024).

This paper aims to analyze recent developments in AI applications for higher education with a particular focus on project management education and to propose a conceptual framework for integrating AI technologies into strategic and human-centered teaching practices. The study emphasizes the transition toward Industry 5.0 principles, where human-centric and sustainable approaches are combined with digital innovations to improve educational outcomes and institutional effectiveness (Holmes et al., 2022; Zheng et al., 2024). In contrast to existing studies that primarily focus on general applications of artificial intelligence in education, this paper

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adopts a discipline-specific perspective by examining the role of AI in strategic project management education. The authors argue that current approaches lack structured integration of AI tools within project management curricula, particularly in alignment with Industry 5.0 principles. Therefore, the main contribution of this paper lies in the development of a conceptual framework that systematically connects AI-enabled learning, strategic project management practices, and human-centered implementation. This framework aims to bridge the gap between technological potential and pedagogical application, offering a structured approach for integrating AI into management education. The aim of this study is to develop a conceptual framework for integrating AI into strategic project management education, aligned with Industry 5.0 principles.

2 Literature Review

The integration of artificial intelligence (AI) in higher education has received increasing attention, particularly in management and project management education. AI technologies, including generative AI tools, adaptive learning systems, and predictive analytics, are changing teaching methods, assessment practices, and curriculum design (Table 1).

Table 1 Key studies on artificial intelligence in higher education and project management education

Author (Year)	*Title*	*Focus*	*Limitation*	*Research Gap*
Ouyang, F., & Jiao, P. (2021)	Artificial intelligence in education: The three paradigms	Conceptual analysis of AI integration in education through three paradigms: AI-directed, AI-supported, and AI-empowered learning	Primarily conceptual and theoretical analysis with limited empirical validation	Limited exploration of AI applications in management education and project-based learning contexts
Zawacki-Richter, O., Marín, V., Bond, M., & Gouverneur, F. (2019)	Systematic review of research on artificial intelligence applications in higher education – Where are the educators?	Systematic review of AI applications in higher education, focusing on trends, tools, and educational research coverage	Limited to published studies up to 2018; lacks empirical data from classroom implementation	Need for empirical research on AI integration in teaching practice, particularly involving educators' perspectives and discipline-specific applications
Holmes, W., Bialik, M., Fadel, C. (2022)	Artificial intelligence in education: Promises and implications for teaching and learning	Comprehensive overview of AI applications in education, including personalized learning, intelligent tutoring systems, and ethical implications	Conceptual and policy-oriented analysis with limited empirical case studies	Limited research on practical implementation of AI in management and project management education
Selwyn, N., & Gasevic, D. (2020)	The datafication of higher education: Discussing the promises and problems	Analyses datafication and digital transformation in higher education, including the use of data analytics, learning management systems, and institutional decision-making	Primarily conceptual and theoretical discussion; limited empirical evidence	Lack of focus on generative AI tools, their impact on student learning, and integration in specific disciplines such as management and project-based learning
Kasneci, E., et al. (2023)	ChatGPT for good? On opportunities and challenges of large language models for education	Analysis of opportunities and risks of large language models such as ChatGPT in educational contexts, including tutoring, assessment support, and academic writing	Conceptual analysis with limited empirical classroom implementation	Lack of empirical studies on integrating generative AI into specific disciplines such as management and project management education
Cotton, D., Cotton, P., Shipway, J. (2023)	Chatting and cheating: Ensuring academic integrity in the era of ChatGPT	Investigates generative AI use by students and implications for assessment	Focus mainly on academic integrity issues	Need to examine educational design for AI assisted learning
Ali, D., Fatemi, Y., Boskabadi, E., Nikfar, M., Ugwuoke, J., & Ali, H. (2024)	ChatGPT in Teaching and Learning: A Systematic Review	Systematic review of how ChatGPT is used in educational settings, including opportunities and challenges in teaching and learning	Focuses on summarizing existing literature; does not include new primary empirical research	Need for longitudinal empirical studies to evaluate real-world effects of ChatGPT on learning outcomes and instructor practices in diverse contexts
Rudolph, J., Tan, S., & Tan, S. (2023)	ChatGPT: Bullshit spewer or the end of traditional assessments in higher education?	Examines the impact of ChatGPT on traditional higher education assessments, academic integrity, and pedagogical practices.	Focused mainly on theoretical implications; limited empirical evidence	Need for large-scale empirical studies to understand long-term effects of ChatGPT on assessment

			across diverse disciplines.	validity and teaching strategies.
Farrokhnia, M., Banihashem, S. K., Noroozi, O., & Wals, A. (2024)	A SWOT analysis of ChatGPT: Implications for educational practice and research	Systematic analysis of the strengths, weaknesses, opportunities, and threats of generative AI (ChatGPT) in higher education	Focuses mainly on ChatGPT rather than the broader ecosystem of generative AI tools	Limited research on integrating generative AI into project management and management education contexts
Zheng, C., et al. (2024)	Charting the future of AI in project-based learning: a Co-design exploration with students	Investigates AI usage in project based learning environments	Small sample empirical study	Need for large scale studies in management education
Holmes, W., Porayska-Pomsta, K., Holstein, K., Sutherland, E., Baker, T., Shum, S. B., Santos, O. C., Rodrigo, M. M. T., Cukurova, M., Bittencourt, I., & Koedinger, K. (2021)	Ethics of AI in education: Towards a community-wide framework	Development of an ethical and responsible AI framework for education, addressing transparency, accountability, fairness, and stakeholder responsibility	Primarily conceptual framework with limited empirical validation in real educational environments	Need for empirical studies on implementing responsible AI frameworks in specific educational disciplines such as management and project-based learning
Ruark, T. I., Biazzin, C. (2025)	Teaching project management with generative AI: A pedagogical model for responsible and sustainable practice	Integration of generative AI tools in project management teaching across MBA courses	Limited number of courses analyzed	Need for broader validation across management programs

Existing studies show that AI applications in education are mainly concentrated in general or STEM-related contexts, while management education remains less explored. Zawacki-Richter et al. (2019) identified a limited presence of educators and discipline-specific applications, while Holmes, Bialik, and Fadel (2022) pointed out the lack of empirical studies in business and management programs. Similarly, Ouyang and Jiao (2021) introduced different AI learning paradigms but emphasized the need for empirical validation in project-based learning environments.

Recent research on generative AI tools highlights both opportunities and challenges. Studies by Kasneci et al. (2023), Cotton, Cotton, and Shipway (2023), and Ruark and Biazzin (2025) indicate early-stage adoption, limited empirical evidence, and the need for broader validation in management education. In addition, ethical considerations, trust, and stakeholder acceptance remain significant factors in AI-supported learning environments (Holmes et al., 2021; Farrokhnia et al., 2024).

Zheng et al. (2024) further examined AI in project-based learning, emphasizing the need for larger-scale studies. Overall, the literature indicates a clear gap in structured and discipline-specific approaches to integrating AI into project management education. These findings provide the basis for this study, which proposes a conceptual framework that connects AI technologies with strategic project management principles in alignment with Industry 5.0.

3 METHODOLOGICAL RESEARCH APPROACH

This study adopts a structured literature review approach, combining elements of systematic and qualitative comparative analysis to examine artificial intelligence (AI) applications in higher education, with a focus on management and project management education. The aim is to identify key trends, research gaps, and a basis for developing a conceptual framework aligned with Industry 5.0 principles.

The literature selection was conducted using Scopus, Web of Science, IEEE Xplore, and Google Scholar. The search included keywords such as “artificial intelligence in education”, “generative AI”, “project management education”, “management education”, and “AI-supported learning”. The review was limited to peer-reviewed publications from 2019 to 2025.

Inclusion criteria covered studies focused on AI in higher education, management or project-based learning, and pedagogical, technological, or ethical aspects of AI use. Non-peer-reviewed sources and studies not related to educational applications were excluded. The selection process included screening of titles and abstracts, followed by full-text analysis. Based on relevance and alignment with the research objective, twelve key studies were selected and analyzed (Table 1). A qualitative comparative analysis was applied to examine research focus, limitations, and identified gaps. This approach enabled the identification of common patterns

and challenges in AI adoption. In this study, "systematic analysis" refers to a structured and transparent process of literature selection and synthesis. The results of this analysis form the basis for the proposed conceptual framework integrating AI-enabled learning, project management principles, and human-centered implementation.

4 CONCEPTUAL FRAMEWORK AND PROPOSED MODEL

The proposed conceptual framework is developed through a structured synthesis of the literature presented in Table 1. The model was derived in three steps. First, key themes were identified through qualitative comparison of selected studies, including AI-enabled learning, project management practices, and human-centered and ethical aspects of AI use. Second, these elements were grouped into three dimensions: technological (AI tools), organizational (project management and educational design), and human (competencies and ethical considerations). Third, these dimensions were integrated into a unified framework aligned with Industry 5.0 principles.

The model is grounded in existing research and reflects both dominant trends and identified gaps. This approach ensures a clear link between the literature and the proposed structure, providing a basis for future empirical validation.

The framework consists of three main components. The first component, AI-enabled learning environments, includes generative AI tools and adaptive systems that support project-based learning and assessment. The second component, strategic project management practices, focuses on planning, resource allocation, and performance monitoring within educational settings. The third component, human-centered implementation, emphasizes instructor guidance, competence development, and ethical aspects of AI use.

An integration mechanism connects these components by aligning technological, organizational, and human factors. The expected outcomes include improved student engagement, better alignment with real-world project management practices, and the development of competencies relevant to Industry 5.0 environments.



Figure 1. Proposed conceptual framework for integrating artificial intelligence and strategic project management in Industry 5.0 education systems

5 RESULTS AND DISCUSSION

The proposed framework (Figure 1) provides a structured approach for integrating artificial intelligence (AI) into strategic project management education within Industry 5.0 environments. In addition to its conceptual contribution, it offers practical implications for curriculum design, teaching, and assessment. From a curriculum perspective, the framework supports integration of AI tools across multiple courses, rather than isolated use. Generative AI can be applied in project planning, risk management, and decision-making courses to simulate real-world scenarios and support analysis of alternative solutions. This approach improves alignment between academic content and industry practice.

In teaching, AI-enabled environments support a shift toward student-centered and project-based learning. AI tools can assist in case study analysis, collaborative tasks, and feedback generation, allowing instructors to focus more on guidance and higher-level learning outcomes.

Assessment can also be adapted through continuous evaluation, portfolio-based approaches, and performance analytics. These methods enable better evaluation of competencies such as problem-solving, significant thinking, and adaptability, while maintaining transparency and academic integrity.

The human-centered component highlights the role of instructors in managing AI-supported learning. This requires development of competencies related to AI use, ethics, and digital pedagogy, supported by institutional policies and training. Compared to prior studies (Table 1), the framework provides a more structured connection between AI technologies and project management education. However, implementation may be limited by institutional constraints, user acceptance, and ethical concerns. Further research should focus on empirical testing through case studies and course implementation.

6 Conclusion

A conceptual framework for integrating artificial intelligence (AI) into strategic project management education within Industry 5.0 is proposed in this study. The framework connects AI-enabled learning, project management practices, and human-centered implementation, offering a structured approach for applying AI in management education. The contribution lies in linking existing research with a discipline-specific model that supports curriculum development and teaching practice, while also providing a basis for further empirical research.

Several limitations should be noted. The study is based on a structured literature review without empirical validation, and the number of analyzed studies is limited. In addition, the focus on higher education in management and project management may restrict broader application. Future research should include empirical testing of the framework through case studies and course implementation, as well as analysis of its impact on learning outcomes and competencies. Overall, the results indicate that AI-supported project management education can support development of competencies relevant to Industry 5.0 when applied in a structured and responsible way.

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Primary School Teachers' Attitudes Toward Digital Tools and Artificial Intelligence in Nature and Society Instruction

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Abstract. The integration of digital tools and artificial intelligence (AI) into primary education represents a significant challenge for contemporary educational systems. This study examines primary school teachers' attitudes toward the use of digital tools and AI in Nature and Society instruction in the Republic of Serbia. A cross-sectional survey was conducted on a sample of 200 primary school teachers from five regions of Serbia. The instrument consisted of 12 Likert-scale items (1–5) measuring teachers' attitudes across two dimensions: digital tools competence and AI attitudes. Descriptive statistics, independent samples t-test, one-way ANOVA with post-hoc comparisons, and Pearson's correlation were used for data analysis. Results indicate moderate overall attitudes (M=3.44, SD=0.45), with teachers expressing strong agreement that AI can enhance instruction (M=3.98) and that additional training is needed (M=4.01). Significant effects of work experience (F=3.877, p=.010) and age (F=6.104, p=.001) were found for digital tools competence, with less experienced and younger teachers reporting higher competence. Education level also significantly predicted digital tools competence (F=3.380, p=.019). No significant differences were found by school type (urban vs. rural) or gender. A strong positive correlation was found between digital tools competence and AI attitudes (r=.573, p<.001). The findings suggest the need for systematic, differentiated professional development programs, particularly targeting experienced teachers, to facilitate the effective integration of digital technologies and AI in primary education.

Keywords and phrases: artificial intelligence, digital tools, primary education, teacher attitudes, Nature and Society

1 INTRODUCTION

The rapid development of digital technologies and artificial intelligence (AI) has fundamentally transformed numerous sectors of society, with education being among the most significantly affected (Darling-Hammond et al., 2020). In the 21st century, the ability to effectively integrate technology into teaching practice is no longer optional but has become a core professional competence for educators (Tondeur et al., 2012). The COVID-19 pandemic further accelerated this transformation, exposing both the potential and the limitations of digital technologies in education systems worldwide (Mayer, 2021).

In the context of primary education, the integration of Information and Communication Technologies (ICT) has become a priority in educational policies across Europe and globally. The European Commission's Digital Education Action Plan (2021–2027) emphasizes the importance of developing digital competences among both educators and learners, identifying two strategic priorities: fostering the development of a high-performing digital education ecosystem and enhancing digital skills and competences for the digital transformation (European Commission, 2020). The European Framework for the Digital Competence of Educators (DigCompEdu) further specifies six areas of competence that educators need to develop (Redecker, 2017).

In the Republic of Serbia, the Strategy for the Development of Education until 2030 identifies digitalization as a key component of educational reform, emphasizing the need for teacher professional development in the area of digital competences (Ministarstvo prosvete, nauke i tehnološkog razvoja, 2021). Nature and Society (Priroda

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i društvo) is a compulsory subject in the lower grades of primary school (grades 1–4) in Serbia. It holds particular significance for the application of digital tools and AI, given its interdisciplinary character that encompasses elements of natural sciences, geography, history, and civic education (Šaćirović, 2023). The subject requires teachers to convey complex concepts about the natural and social world, making it particularly suitable for the use of multimedia presentations, interactive simulations, virtual field trips, and other technology-enhanced approaches.

Artificial intelligence in education (AIEd) represents a rapidly evolving field that offers possibilities for personalized learning pathways, automated assessment, intelligent tutoring systems, adaptive content delivery, and learning analytics (Holmes et al., 2019). Recent developments in generative AI have brought AI to the forefront of educational discourse, raising questions about how these tools can be effectively integrated into teaching practice while addressing ethical concerns and potential risks (Zawacki-Richter et al., 2019).

Despite growing policy emphasis on digitalization, empirical research on teachers' actual attitudes and readiness to integrate digital tools and AI in primary education in Serbia remains limited. Understanding teacher attitudes is crucial because research consistently demonstrates that teachers' beliefs and perceptions significantly influence technology adoption in classroom practice (Scherer et al., 2019). The Technology Acceptance Model (TAM) proposes that perceived usefulness and perceived ease of use are key determinants of technology adoption (Davis, 1989), while the Technological Pedagogical Content Knowledge (TPACK) framework highlights that effective technology integration requires the intersection of technological, pedagogical, and content knowledge (Koehler & Mishra, 2009).

Previous research has identified several factors that may influence teachers' attitudes toward digital technologies, including age, work experience, education level, gender, and school location (Tondeur et al., 2012; Gorghiu et al., 2018). Older and more experienced teachers tend to report lower levels of digital competence, suggesting a generational divide with implications for professional development planning (Gil-Flores et al., 2017). The digital divide between urban and rural schools has also been documented in various educational contexts (OECD, 2019).

The aim of this study was to examine primary school teachers' attitudes toward the use of digital tools and AI in Nature and Society instruction, and to determine whether these attitudes differ based on demographic and professional characteristics. Specifically, the study addressed the following research questions: (1) What are primary school teachers' attitudes toward digital tools and AI in Nature and Society instruction? (2) Do these attitudes differ based on work experience, age, education level, school type, gender, and region? (3) What is the relationship between digital tools competence and attitudes toward AI?

2 METHODOLOGY

2.1 Research design and procedure

A cross-sectional survey design was employed to collect data on teachers' attitudes toward digital tools and AI in Nature and Society instruction. The questionnaire was distributed electronically via Google Forms during November–December 2024. Participation was voluntary and anonymous. Prior to completing the questionnaire, participants provided informed consent.

2.2 Sample

The sample consisted of 200 primary school teachers from all five statistical regions of Serbia. Of the 218 questionnaires received, 12 were excluded due to incomplete responses or lack of informed consent, yielding a final sample of N=200. The sample was predominantly female (92.0%), consistent with the demographic composition of primary school teachers in Serbia. By age, 34.0% were 41–50, 31.5% over 50, 25.5% aged 31–40, and 9.0% up to 30 years. Regarding work experience, 40.0% had over 25 years, 28.5% had 16–25 years, 21.5% had 6–15 years, and 10.0% up to 5 years. By school type, 47.5% worked in urban schools, 27.0% in rural schools, and 25.5% in urban schools with rural branch departments. All five regions were represented: Novi Pazar region (30.5%), Šumadija and Western Serbia (24.0%), Belgrade (19.0%), Southern and Eastern Serbia (16.5%), and Vojvodina (10.0%).

2.3 Instrument

The research instrument consisted of a structured questionnaire with two sections. The first section collected demographic data (gender, age, education, work experience, school type, region). The second section contained

12 items measuring attitudes toward digital tools and AI in Nature and Society instruction, rated on a 5-point Likert scale (1=strongly disagree to 5=strongly agree). Based on content analysis, the 12 items were grouped into two conceptual sub-scales: (a) digital tools competence (items 1, 2, 6, 7, 8, 9), assessing actual use, perceived competence, and institutional support; and (b) AI attitudes (items 3, 4, 5, 10, 11, 12), measuring familiarity with, willingness to use, and beliefs about AI. The internal consistency of the total scale was acceptable (Cronbach's α=.675 for 12 items).

2.4 Data analysis

Data were analyzed using descriptive statistics (mean, standard deviation, median, frequency distributions), independent samples t-test for comparing two groups (school type, gender), one-way ANOVA for comparing multiple groups (work experience, age, education, region) with post-hoc pairwise t-tests, and Pearson's correlation coefficient. Effect sizes were calculated using Cohen's d. All analyses were conducted with a significance level of α=.05.

3 RESULTS

3.1 Descriptive statistics for attitude items

Table 1 presents the descriptive statistics for all 12 items measuring teachers' attitudes toward digital tools and AI in Nature and Society instruction.

Table 1. Descriptive statistics for attitude items (N=200)

No.	Statement	M	SD	Mdn
1	I use digital tools (presentations, video) in N&S instruction	3.21	0.91	3
2	I use educational applications/platforms in N&S instruction	3.44	1.05	3
3	I am familiar with AI capabilities in education	2.84	1.12	3
4	I am willing to use AI tools in instruction	3.38	0.98	3
5	AI can enhance Nature and Society instruction	3.98	0.94	4
6	My school provides adequate technical support	3.31	1.09	3
7	I have participated in training for digital tools	2.74	1.05	3
8	Digital tools help students understand the material	3.64	0.89	4
9	I feel competent to use digital tools in instruction	3.59	0.96	4
10	AI can help adapt instruction to individual needs	3.87	0.79	4
11	I am concerned about negative effects of AI	3.34	0.94	3
12	I need additional training for digital tools and AI	4.01	0.83	4

The highest-rated item was the need for additional training (item 12: M=4.01, SD=0.83), indicating that the vast majority of teachers recognize gaps in their own competences. This was followed by the belief that AI can enhance instruction (item 5: M=3.98, SD=0.94) and that AI can help personalize instruction (item 10:

M=3.87, SD=0.79). The lowest-rated items were participation in training programs (item 7: M=2.74, SD=1.05) and familiarity with AI capabilities (item 3: M=2.84, SD=1.12).

The composite scores for the two sub-scales were: digital tools competence (M=3.32, SD=0.55) and AI attitudes (M=3.57, SD=0.47). The overall mean across all 12 items was M=3.44 (SD=0.45). The response distribution analysis revealed that for item 5, no teacher selected "strongly disagree" and 70.5% selected "agree" or "strongly agree." For item 12, 72.5% selected "agree" or "strongly agree." In contrast, for item 3, 38.5% selected "disagree" or "strongly disagree," confirming low AI literacy among teachers.

3.2 Differences by work experience (ANOVA)

One-way ANOVA revealed a significant effect of work experience on digital tools competence, F(3, 196)=3.877, p=.010. Results are shown in Table 2.

Table 2. Digital tools competence and AI attitudes by work experience

Work Experience	n	Digital Tools M (SD)	AI Attitudes M (SD)	Total M (SD)
Up to 5 years	20	3.46 (0.45)	3.63 (0.49)	3.55 (0.38)
6–15 years	43	3.46 (0.64)	3.58 (0.43)	3.52 (0.48)
16–25 years	57	3.38 (0.52)	3.65 (0.42)	3.52 (0.42)
Over 25 years	80	3.16 (0.52)	3.49 (0.51)	3.33 (0.46)
		F=3.877, p=.010*	F=1.512, p=.213	F=3.143, p=.026*

Post-hoc pairwise comparisons revealed that teachers with over 25 years of experience scored significantly lower on digital tools competence compared to all other groups: 6–15 years (t=2.779, p=.006), up to 5 years (t=2.315, p=.023), and 16–25 years (t=2.427, p=.017). The overall composite score also showed a significant effect (F=3.143, p=.026). No significant effect was found for AI attitudes (F=1.512, p=.213).

3.3 Differences by age (ANOVA)

A significant effect of age was found for digital tools competence, F(3, 196)=6.104, p=.001. Teachers aged 31–40 reported the highest competence (M=3.50, SD=0.61), while those over 50 reported the lowest (M=3.10, SD=0.51). Teachers up to 30 years scored M=3.44 (SD=0.47) and those aged 41–50 scored M=3.36 (SD=0.51). The difference for AI attitudes approached but did not reach significance (F=2.631, p=.051).

3.4 Differences by education level (ANOVA)

One-way ANOVA revealed a significant effect of education level on digital tools competence, F(3, 196)=3.380, p=.019. Teachers with doctoral degrees reported the highest scores (M=3.83, SD=0.44), followed by Master's degree holders (M=3.38, SD=0.55), Bachelor's degree holders (M=3.28, SD=0.53), and those with higher school education (M=2.94, SD=0.57). No significant effect was found for AI attitudes (F=1.492, p=.218) or the total composite (F=2.579, p=.055).

3.5 Differences by school type and gender (t-test)

Independent samples t-test comparing urban schools (n=146, including those with rural branches) and rural schools (n=54) found no significant differences in digital tools competence (t=1.285, p=.200, d=0.205), AI attitudes (t=1.143, p=.255, d=0.182), or total scores (t=1.375, p=.171, d=0.219). Although urban school teachers scored slightly higher on all three measures, the effect sizes were small.

No significant gender differences were found for digital tools competence (t=−1.397, p=.164, d=−0.364), AI attitudes (t=0.969, p=.334, d=0.252), or total scores (t=−0.348, p=.728, d=−0.091). It should be noted that the gender comparison is limited by the highly unequal sample sizes (16 males vs. 184 females).

3.6 Differences by region (ANOVA)

One-way ANOVA revealed no significant regional differences for digital tools competence (F=1.652, p=.163), AI attitudes (F=0.454, p=.769), or total scores (F=1.140, p=.339). Teachers from Belgrade reported the highest digital tools competence (M=3.50, SD=0.58), while those from the Novi Pazar region reported the lowest (M=3.21, SD=0.55), but these differences were not statistically significant.

3.7 Correlation between sub-scales

A significant strong positive correlation was found between digital tools competence and AI attitudes (r=.573, p<.001), indicating that teachers who report higher competence with digital tools also tend to have more favorable attitudes toward AI in education.

4 DISCUSSION

The findings of this study provide a comprehensive picture of primary school teachers' attitudes toward digital tools and AI in Nature and Society instruction in Serbia. Several key patterns emerge from the analysis that have important theoretical and practical implications.

Perhaps the most striking finding is the juxtaposition of the highest-rated item — the need for additional training (M=4.01) — with some of the lowest-rated items — participation in training programs (M=2.74) and familiarity with AI (M=2.84). This training gap suggests a significant mismatch between teachers' recognized professional development needs and the availability or accessibility of relevant training opportunities. Similar findings have been reported in other Central and Southeastern European contexts (Gil-Flores et al., 2017; OECD, 2019), suggesting that this is not unique to Serbia but reflects a broader regional challenge in educational digitalization.

Teachers demonstrated considerable openness toward AI in education, with 70.5% agreeing or strongly agreeing that AI can enhance instruction. This finding aligns with the generally optimistic outlook reported in international studies (Holmes et al., 2019; Zawacki-Richter et al., 2019). The moderate level of concern about negative effects (M=3.34) suggests that teachers maintain a balanced perspective, recognizing both the promise and the potential risks of AI integration.

The significant effects of work experience (F=3.877, p=.010) and age (F=6.104, p=.001) on digital tools competence reveal a clear generational pattern. Teachers with over 25 years of experience and those over 50 consistently reported lower digital competence. This finding is consistent with the broader literature on the digital divide among teachers (Tondeur et al., 2012; Gorghiu et al., 2018) and can be interpreted through the lens of TAM (Davis, 1989) — more experienced teachers may perceive lower ease of use due to having developed their teaching practices in a pre-digital era. From the TPACK perspective (Koehler & Mishra, 2009), these teachers may possess strong pedagogical and content knowledge but lack the technological knowledge component.

This finding has direct implications for professional development policy. Rather than offering uniform training programs, educational authorities should consider differentiated approaches that acknowledge the specific needs of teachers at different career stages. For experienced teachers, training should emphasize the pedagogical value of technology (perceived usefulness) and provide extensive hands-on practice (perceived ease of use), aligned with TAM principles.

The significant effect of education level (F=3.380, p=.019) indicates that teachers with higher academic qualifications tend to report greater digital competence, possibly reflecting exposure to technology during academic studies. The absence of significant urban-rural differences is encouraging and may reflect Serbia's efforts to provide technology infrastructure across school types, or the widespread availability of personal digital devices that reduce dependence on school-based infrastructure.

The strong positive correlation between digital tools competence and AI attitudes (r=.573, p<.001) suggests that building teachers' digital competence may serve as a pathway to more favorable AI attitudes and AI readiness. This supports the idea that digital literacy is a prerequisite for AI literacy (Holmes et al., 2019), and that professional development should adopt a sequential approach — first strengthening digital competence, then introducing AI applications.

5 CONCLUSION

This study examined primary school teachers' attitudes toward digital tools and AI in Nature and Society instruction based on a sample of 200 teachers from all regions of Serbia. The main conclusions are: (1) teachers express moderate overall attitudes (M=3.44) with strong recognition of the potential of AI to enhance instruction (M=3.98) and an equally strong expressed need for additional training (M=4.01); (2) work experience and age are the strongest predictors of digital tools competence, indicating a generational digital divide; (3) education level significantly predicts digital tools competence; (4) no significant differences were

found by school type, gender, or region; (5) digital tools competence and AI attitudes are strongly positively correlated (r=.573).

The practical implications point to the need for systematic, differentiated professional development programs that specifically target experienced and older teachers, address the gap between recognized training needs and available opportunities, and adopt a sequential approach building digital competence as a prerequisite for AI integration. Future research should employ longitudinal designs to track changes in attitudes, investigate the relationship between attitudes and actual classroom practice, and examine the effectiveness of specific professional development interventions.

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Learning through interaction: Educational Games in Modern Education - Troll Forest

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Abstract. As we are exposed daily to the internet and short, fast-paced content, it has become increasingly difficult to capture attention and maintain concentration during learning. The digital world is more colourful and engaging for both young and older users, which makes it necessary to adapt learning approaches to the demands of the modern age. New methods, such as delivering concise content through gameplay and gradually introducing new knowledge, contribute to improved learning outcomes.
Interactive educational applications represent one of the most effective responses to these challenges, as they combine learning with active participation, motivation, and continuous feedback. They incorporate elements such as rewards, levels, and challenges that motivate users and support consistent progress.
This paper presents the key concepts of educational applications and their practical implementation through the example of Troll Forest. The focus is on how interaction, gamification, and adaptive content can enhance engagement and support more effective knowledge acquisition in contemporary digital environments.

Key words and phrases: Interactive, Learning, Education, Games.

1 Introduction

The traditional way of learning is often passive and requires little engagement from participants, usually limited to listening or reading, which can quickly become monotonous. Gaining knowledge in this way demands significant effort and dedication to achieving good results. Today, it is much more natural to use interactive content and a hybrid approach to education. This method combines entertainment with learning, which in turn increases the desire to engage further and foster continuous motivation.

Educational applications can be applied in various fields, including medicine, the military, law enforcement, and industry, where they simulate processes and teach what is correct. They enhance motivation, visual skills, interaction, engagement, and collaboration. Additionally, they improve players' focus and attention, problem-solving abilities and contribute to the development of long-term knowledge (Arsenijevic, J. M. & Arsenijevic, O. M., 2022).

Digital games are fundamentally built around a specific problem that the players strive to solve. Motivated by the goal, the player invests time and effort to complete complex tasks, while simultaneously developing logic, memory, and strategic thinking. In multiplayer games, social skills are also enhanced. Numerous studies have shown that many mainstream games, originally designed primary for entertainment, can have highly beneficial educational effects. Also, there is a serious game that is specifically designed to help players acquire new knowledge, adopt new values and change behavioral patterns (Arsenijevic, J. M. & Arsenijevic, O. M., 2022).

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In the following sections, the key concepts of a knowledge-based interactive application will be presented (*2. Interactive Learning*), and the practical example of application (*3. Related Work*, 4. *Troll Forest – Game Concept*). At the end of paper is conclusion with features improvements (*4. Conclusion*).

2 INTERACTIVE LEARNING

Interactive learning methods complement traditional approaches while introducing an element of fun, making the learning process much easier. Through games and engaging activities, tasks are solved in a way that stimulates thinking, helping learners retain information more naturally and effortlessly (Yacob et al., 2016). This type of learning introduces material gradually, in well-structured stages, allowing students to build knowledge step by step. By breaking down complex concepts into manageable parts, it reduces cognitive overload and helps learners develop a deeper understanding over time (de Freitas, S.,2018).

2.1 Game-based Learning

In pedagogy today, game-based learning approaches are widely applied to explain and practice educational content (Anastasiadis, T., Lampropoulos, G., & Siakas, K.,2018). In this approach, learners acquire knowledge and skills by engaging with a game from start to finish, learning different content through interactive play (Kapp, K. M., 2014).

Games that are specifically designed for educational purposes primarily serve learning and implement the principles of game-based learning are called serious games (Anastasiadis, T., Lampropoulos, G., & Siakas, K.,2018). In addition to serious games, the principles of game-based learning are also applied in edutainment games, simulations, and adaptive learning platforms, which provide interactive and engaging learning experiences tailored to learners needs.

2.2 Gamification

Gamification is a principle that applies game-based elements, mechanics, and principles to non-game activities to motivate learners and enhance their engagement (Israel, M., 2017). Learners don't play entire game but use games elements like points, badges, levels. Also, they bring elements of story, challenge and feedback (Kapp, K. M., 2014).

2.3 Educational Component

Educational Component is game design. It includes learning objectives and contents, tasks, activities, interactions and mechanisms that enable the learner to gain knowledge. This is pedagogical and educational part of the game (Pivec, M., Dziabenko, O., & Schinnerl, I., 2003).

2.4 Level of Interaction

Interaction is a process in which an action or change elicits a response or reaction in another action or system. In game – based Learning applications there are four levels of interactions (Bonnat, C., & Sanchez, E. (2022): *First Level*– interactions between the player and the game or his opponents; *Second Level*– interactions between the players themselves; *Third Level*– exchanges between the game master and players; *Four Level*– debriefing.

2.5 Scaffolding

Scaffolding refers to guidance or support offered during the learning process to help students reach levels of understanding they would not be able to achieve on their own (Chen, C.-H., & Law, V., 2016). Scaffolds can either simplify a task by structuring it and reducing its complexity, or they can challenge learners to focus on critical concepts and connections that might otherwise be overlooked. While making the content more complex may initially increase difficulty, it also creates opportunities for deeper understanding and more effective learning (Barzilai, S., & Blau, I., 2014).

2.6 Consequence as a Mechanism

To solve a game challenge, the player uses strategies based on prior experience. By testing these strategies, they observe outcomes and reflect on the results. Feedback from the game directs the player's attention to relevant learning points, leading to knowledge synthesis, hypothesis validation, or the development of new strategies for further testing (Kiili, K., & Ketamo, H., 2007).

3 Related Work

Interactive Educational applications are present across all fields and disciplines, with numerous examples of their use in learning. One such example is the MultiCountry Game, which focuses on economics. It helps students master key terms and theoretical models through gameplay. By simulating real-world scenarios in real time, it clearly demonstrates the outcomes of their decisions. The game combines active learning with realistic model simulations and immediate feedback providing both a strong theoretical foundation and practical understanding (Calcagnini, G., Hester, D. D., & Sorini, L., 2025).

Another example is interactive web application for teaching information technologies. The application providing lection, training and testing. The students earn points at each game level. Compared to traditional learning methods, game-based learning has proven to be far more effective. Students tend to be more engaged and motivated, making this approach significantly more efficient and impactful (Vishtaka et al., 2022).

There are more Games for learning Accounting presented and described in (Yacob et al., 2016). Financial Statement Bingo – that teach to classify accounts in the financial statements; The Budget Simulation Game – that gives a scenario to prepare a budget; and more.

4 Experience and Limitations

Some researchers have examined this topic and concluded that this approach has both advantages and disadvantages, and that its practical application is still under-researched. The paper (Çelik, B., Bilgin, R. & Yıldız, Y. (2022)) reports that Educational games can boost motivation, engagement, and learning by providing interactive experiences. They also have limitations, including higher time demands, classroom management challenges, and negative social effects such as competition or frustration. Studies show they can improve learning outcomes compared to traditional methods, but may also create pressure and reduce motivation in some students. Overall, their effectiveness depends on careful design and balanced implementation aligned with learning goals.

Other Researchers in paper (Doğan-Keskin & Aral, 2022) shows that digital games can improve reflexes, strategic thinking, language skills, and motivation, but may also cause physical strain, attention issues, conflicts, and potential addiction. In education, their effectiveness depends on thoughtful design and controlled use, as poor implementation can lead to distraction and reduced academic focus. While educational games can enhance engagement and learning, they also raise challenges such as time demands, classroom management, and unequal student experiences.

The paper (Nadeem, M., Oroszlanyova, M. & Farag, W., 2023) shows that Digital game-based learning can increase student motivation and engagement, but its effects are not uniform. Some elements, such as leaderboards, may motivate certain students while discouraging others, especially those with lower performance or higher anxiety. A key limitation is the shift from intrinsic to extrinsic motivation, where students focus on points or rankings rather than understanding. The impact of gamification may also decline over time as novelty fades. Technical constraints and differences in digital literacy can further affect implementation. Results indicate that game-based activities lead to higher engagement than traditional approaches, with higher completion rates and more positive feedback. Leaderboards showed a potential motivational effect, but their impact was mixed. Overall, game-based learning is effective for increasing engagement and satisfaction, but requires careful design, as its benefits depend on context and individual student differences.

Although the results in paper (Lampropoulos et al., 2023) show that combining augmented reality, gamification, and serious games can improve motivation, engagement, and learning outcomes, several limitations remain. The sample mainly included IT students, which may bias results toward more positive acceptance. Long-term effects were not evaluated, so the durability and transfer of outcomes are unclear. Implementation can also be constrained by technical factors such as device compatibility and hardware requirements. Overall, educational games show strong potential to enhance learning, but require careful pedagogical and technical design and should complement, not replace, traditional teaching.

5 Troll Forest – Game Concept

Troll Forest is an educational game in which the player controls a forest troll who collects mushrooms. Through interaction with different types of mushrooms, the player learns to recognize, differentiate, and understand the

effects of different types of fungi. Table 1 shows how the described concept is applied to a game example. Gamification in the presented game is implemented through points awarded for edible mushrooms and challenges involving poisonous mushrooms, which motivate exploration and learning. The educational component involves learning about different types of mushrooms, their effects, and how to safely identify them. The level of interaction involves actively controlling the troll, moving through the forest, collecting mushrooms, and immediately observing the consequences of actions. Scaffolding is implemented through two levels: the first provides guidance and a safe learning environment, while the second challenges the player to apply their knowledge independently in order to progress. Consequence as a mechanism ensures clear outcomes, with edible mushrooms providing rewards and poisonous ones introducing challenges.

Table 1. Concepts on Troll Forest

Gamification	Educational Component	Level of Interaction	Scaffolding	Consequence as a Mechanism
Points for edible mushrooms challenges with poisonous mushrooms motivates exploration and learning	Learning about different types of mushrooms, their effects, and how to safely identify them.	actively control the troll, move through the forest, collect mushrooms, immediately see the consequences of their choices.	**1st Level** – guidance and safe environment for learning about mushrooms. **2nd Level** – challenges the player to apply their knowledge independently to continue the game	Every action the player takes has a clear effect: **Edible mushroom** – reward the player with points and heal, reinforcing safe choices **Poisonous mushroom** - create challenges, trigger countdown timer and force them to get typical type of item to survive

The project is organized into four types of scenes: the player, collectible items, collection log and levels.

The Player Scene - Troll

The player scene defines the main character and its behavior. The player character is a troll controlled using the arrow keys (Figure 1). The player explores the forest, discovering different types of mushrooms and their effects. Each type of mushroom provides new knowledge and introduces unique impact on gameplay. Currently, two types of mushrooms are included, as shown in Figure 2.



Figure 1. Player scene - Troll



Figure 2. Collectible items scene – Edible and Poisonous mushroom

The Collectible Items Scene - Mushroom

Collectible items are interactive objects that player can collect. In this game this are mushrooms. Currently, it is possible to collect two types of mushrooms: edible and poisonous.

- *Edible* – grant points to the player and can heal them if they have consumed a poisonous one. They teach the player that they are safe, even desirable to collect, as they provide only benefits.
- *Poisonous* – It has a negative effect on the player, as they become poisoned and have a limited time to recover. If they fail to heal in time, the game ends.

The Collection Log Scene – Mushroom Book

The Collection Log displays the items the player has collected. It serves as a mushroom encyclopedia, providing detailed information about each mushroom picked up, including its appearance and habitat. For each mushroom, the log shows the common Name, Latin name, Description, Cap, Flesh, Stipe, and Habitat. The design of the mushroom book is illustrated in Figure 3.



Figure 3. Collection Log Scene – Mushroom Book

Not only can the player learn about the effects and consequences of each mushroom, but they can also gain additional knowledge about its appearance and natural environment. This feature combines gameplay with educational value, encouraging players to explore and learn more about the mushrooms they encounter.

The Level Scene – Forest

The game has two levels. The first is the Basic Forest (Figure 4), where the player moves around and collects mushrooms. In this level, the layout of game elements is always the same. Collecting edible mushrooms grant points, and the player continues collecting until all mushrooms in the forest are gathered. However, if the player collects poisonous mushrooms, they are immediately transferred to next level.



Figure 4. The Level Scene – Basic Forest

The second level is Poisonous Forest (Figure 5). From the moment the player enters, a 30-second timer begins, during which they must find an edible mushroom to heal and come back to first level. Collecting another poisonous mushroom reduces the remaining time by 5 seconds. In this level, the layout is randomized: each time levels start, mushrooms and trees are arranged differently, making it more challenging to find a healing mushroom. Additionally, moving fog elements obscure parts of the forest, reducing visibility. If the player fails to find edible mushroom before the timer reaches zero, the game ends.



Figure 5. The Level Scene – Poison Forest

6 CONCLUSION

The current version of the game serves only as an introduction to what it could eventually become. The game consists of two basic levels, which can be easily expanded. The first level is easy and gradually introduces the player to the game mechanics. It focuses on exploration and learning through a system of consequences and Reward. The second level is faster-paced and requires the player to apply what they learned in the first level, as time is limited. The sooner the player chooses the correct mushroom, the sooner the danger is neutralized.

Feature development and expansion of the game could include adding other types of edible and poisonous mushrooms, as well as new categories, with each new category unlocking a new level. Particularly interesting possibilities include medical mushrooms, zombie mushrooms, psychoactive mushrooms, and many others.

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Personalizing learning with artificial intelligence tools

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Abstract. The integration of artificial intelligence (AI) into education has enabled the development of adaptive learning systems that support personalized learning experiences. Adaptive learning uses data-driven technologies to adjust instructional content, pace, and delivery according to individual students' needs, preferences, and performance. This paper examines the role of AI tools in facilitating personalized learning and improving educational outcomes. The study reviews key benefits of personalized AI integration in education, including real-time feedback, personalized content recommendations, and AI tutors that provide adaptive guidance and support. These technologies allow educators to create more flexible learning environments while increasing student engagement, motivation, and academic performance. At the same time, the paper discusses several challenges associated with implementing AI-based personalization, including ethical concerns, technological infrastructure requirements, digital inequality, and resistance to technological change among educators. Despite these challenges, AI-driven adaptive learning systems have significant potential to transform traditional education into more learner-centered environments. The findings highlight the importance of responsible and human-centered implementation of AI technologies to ensure equitable access and effective integration into educational practice.

Key words and phrases: personalization, AI, education, adaptive learning, change.

1 Introduction

Adaptive learning is a teaching approach that uses technology to provide personalized instruction tailored to each student's needs, preferences, and developmental stage. It utilizes artificial intelligence and data-driven algorithms to automatically modify the content, delivery, and pacing of lessons based on students' performance and engagement. Adaptive learning increases engagement, improves educational outcomes, and promotes effective, efficient learning by meeting each student's individual needs. Authors emphasize the importance of adaptive learning in online education and its advantages (Gligorea et al., 2023). The integration of AI into education marks a new chapter of personalized, flexible learning (Hariyanto et al., 2025). It is also stated that AI's transformative potential enables innovative approaches to sustainable education, transforming traditional teaching into dynamic, learner-centered experiences (Strielkowski et al., 2024).

Personalized learning models help students meet their individual needs and goals by enhancing their knowledge, perspectives, skills, and understanding of the educational system (Farhood et al., 2025; Kamalov et al., 2023). The core concept of personalized learning is that each student has unique learning styles and paces, which require adaptive methods to maximize their potential (Ejjami, 2024). Artificial intelligence-based technologies, including chatbots and virtual assistants, enable the customization of exercises, information, and feedback based on each student's performance and specific needs (Labadze et al., 2023). In the similar vein, Merino-Campos (2025) states that artificial intelligence in education can completely transform personalized learning by adjusting the pace, content, and teaching strategies to suit each student's individual needs. AI supports personalized learning by tailoring instructional materials to meet each learner's needs. Research indicates that students in individualized learning environments have higher self-efficacy and a more positive outlook on their education (Vieriu & Petrea, 2025). AI can identify the most appropriate learning task for each

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learner, based on their context and current needs, enabling tailored suggestions (Halkiopoulos & Gkintoni, 2024).

Additionally, it is explained in existing literature that tools such as chatbots and virtual tutors provide on-demand, adaptive support, helping students understand complex ideas and offering personalized explanations (Younas et al., 2025). Tapalova and Zhiyenbayeva (2022) describe how a personalized learning environment includes a variety of services, educational resources, and apps tailored to each learner's needs. They develop less expensive training, improve the user experience, and create customized student profiles using technologies such as Web 2.0 and Web 3.0. Adaptive systems can be adjusted to meet each student's needs by focusing on specific subjects and revisiting lessons that students have not fully grasped. As it is established that personalized learning can be achieved through AI application, some of the most significant benefits are addressed.

2 BENEFITS OF AI TOOLS INTEGRATION FOR PERSONALIZED LEARNING

Improved learning environments, greater scheduling flexibility, instantaneous feedback, more flexible management of students' learning experiences, and faster student development are among the benefits of AI-enabled learning systems. Large volumes of data may be processed by AI systems, which can also learn from patterns and experiences and generate recommendations or predictions. AI enables the use of a range of teaching strategies while respecting each student's skills, abilities, and academic challenges (Gligorea et al., 2023; Lin & Chen, 2024). Adaptive learning technologies provide tailored support, focused feedback, and optimized learning pathways to improve student engagement and results by continuously analyzing data on student interactions (Strielkowski et al., 2024). In more detail: feedback, personalized content and AI tutors are addressed.

2.1 Feedback

Providing students with adequate feedback is crucial for enhancing learning with chatbots, enabling self-regulated learning. Feedback helps students reduce uncertainty during the learning process. It has been demonstrated that chatbot-based corrective feedback can improve the English learning experience and increase retention (Younas et al., 2025). Students receive targeted support where they need it most through our personalized approach. As they observe real progress, students become more motivated and engaged in their learning (Strielkowski et al., 2024). This individualized strategy enhances overall learning outcomes and boosts student engagement. Furthermore, AI-driven educational systems offer real-time feedback and assessment capabilities that exceed those of traditional teaching methods (Strielkowski et al., 2024). Immediate AI feedback is a critical mechanism for reducing uncertainty during complex tasks, clarifying expectations, and enabling learners to focus their mental effort on deeper conceptual understanding rather than on administrative navigation (Yin et al., 2025). Kaliisa et al. (2025) compared the feedback provided by the teachers and AI and explored the effectiveness of each. While there are no significant differences in the results, the research direction is valuable.

2.2 Personalized content

Students have access to a wider range of sources of inspiration and knowledge because I can select and recommend relevant materials from large libraries of educational content. AI can identify content that matches students' interests, passions, and learning goals using natural language processing algorithms, sentiment analysis, and recommendation systems. This promotes intrinsic motivation and curiosity-driven discovery (Lin & Chen, 2024). Still, it is important to note that Holmes, Bialik, and Fadel (2019) critique many current AI tools for personalizing only the pace at which students move through a fixed, traditional curriculum. Instead, they advocate for AI to help deliver a personalized curriculum that adapts the actual content, core concepts, and interdisciplinary themes to make learning more relevant to a student's life.

2.3 AI tutors

By enabling students to take control of their education, intelligent tutoring systems promote independent learning. AI facilitates the automatic creation of learning materials tailored to students' comprehension levels, ensuring content relevance and alignment with their progression. The personalized guidance and adaptive instructional strategies work in real time, similar to human tutors, by leveraging learner interaction data

(Fortuna et al., 2025). Given that traditional "one size fits all" models do not engage students or address such differences, it is important to examine the role of AI robots. On the other hand, teachers deliver content, set pacing, and administer assessments dynamically in response to real-time student feedback. One of the most important benefits of AI tutors is their accessibility, which democratizes education for students in underserved or remote areas (Shoukat et al., 2025). Intelligent tutoring systems include recommendation, personalized learning, and adaptive learning systems. AI tutoring systems can enhance students' academic performance (Mohamed et al., 2024). The results of the study by Saha (2025) show that students' anxiety levels decreased statistically significantly when they interacted with AI-powered chatbots. This was explained by the chatbots' capacity to offer rapid access to resources, personalized assistance, and real-time emotional support. These findings highlight the potential of AI chatbots as scalable, affordable therapies for psychological distress in online learning settings (Saha, 2025).

3 Pitfalls of AI tool application for personalization

Significant ethical, technological, and pedagogical issues are recognized when it comes to the application of AI tools in education, and there is a real chance that the education system will not be able to adequately comprehend, manage, and integrate the rapid improvements in AI goods and services (Kovalchuk et al., 2025). AI has great potential to revolutionize education through adaptive systems and personalized learning. However, its implementation must be approached with caution. It is crucial to address ethical and pedagogical issues and to understand better how AI interacts with educational theories. By adopting a human-centered, balanced approach that promotes fair access, it can be ensured that AI empowers students rather than excluding them (Vieriu & Petrea, 2025).

Teachers, legislators, and IT developers must work together to implement AI-driven personalized learning. Policymakers must establish supportive settings, educators must be equipped with the necessary knowledge and resources, and tech companies must ensure AI tools are ethical, open, and easy to use. Although AI has significant potential to improve the customization of educational experiences, many obstacles remain regarding technological infrastructure, pedagogical flexibility, and psychological acceptability (Paola et al., 2025).

Significant relationships among academic level, learning mode, technology use, and faced hurdles are identified in the quantitative analysis of personalized learning implementation across educational levels. These relationships offer important insights into the strategies and challenges associated with the uptake of personalized learning across the educational spectrum (Paola et al., 2025).

Many AI-based learning systems in use today can only suggest specific courses or activities without considering students' cognitive and emotional needs (Fortuna et al., 2025).

The possibility that adaptive learning technology would exacerbate the digital divide is another serious worry. Although new technologies have the potential to greatly improve educational outcomes, if access to them is not distributed fairly, they may worsen existing disparities. Students from low-income households, rural areas, or underprivileged backgrounds might not have the devices, internet access, or digital literacy skills needed to use adaptive learning resources. These children may become even more marginalized due to their limited access, widening the distance between them and their classmates with greater access to technology (Strielkowski et al., 2024).

In contrast to this idea, Plooy et al. (2024) argue that personalized learning shows promise in fostering equity in learning and enhancing student success by emphasizing that personalized content can help overcome these differences.

Teachers accustomed to traditional teaching techniques may be resistant to change and doubt the efficacy of new technologies. A lack of knowledge about how these technologies operate, or concerns about the extra time and effort needed to incorporate them into current curricula, may be the cause of this opposition. Second, sophisticated technological tools may not be supported by the infrastructure of traditional schools, necessitating substantial investments in hardware, software, and reliable internet connectivity (Strielkowski et al., 2024).

It can be concluded that although there are obstacles to overcome, including difficulties in measuring learning variables, a lack of theoretical direction for interventions based on these variables, and ethical concerns, personalized learning has the potential to improve learning outcomes (Plass & Froehlich, 2025).

4 Conclusion

Artificial intelligence is becoming an important tool for enabling personalized learning in modern educational environments. Using adaptive learning systems, AI technologies can adjust instructional materials, feedback,

and learning pathways to individual students' needs and learning styles. The integration of AI tools such as chatbots, intelligent tutoring systems, and recommendation systems allows students to receive real-time feedback, personalized content, and continuous learning support. These capabilities contribute to increased engagement, improved learning outcomes, and more efficient learning processes.

However, implementing AI-based personalization in education faces several challenges. Ethical issues, technological limitations, unequal access to digital tools, and resistance from educators may hinder the effective use of these systems. Additionally, current AI systems often prioritize academic outcomes over students' cognitive and emotional needs. Therefore, the successful integration of AI in personalized learning requires collaboration among educators, policymakers, and technology developers. Educational institutions must ensure adequate infrastructure, training, and ethical guidelines to support the responsible use of AI tools. When implemented in a balanced and human-centered way, AI technologies have the potential to transform education by creating more adaptive, inclusive, and student-centered learning environments.

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Teachers'perspectives on the introduction of artificial intelligence tools into teaching

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Abstract. The integration of artificial intelligence (AI) in education is transforming teaching practices and enabling new opportunities for personalized learning and instructional support. However, the successful implementation of AI technologies largely depends on teachers' attitudes, competencies, and willingness to adopt innovative teaching approaches. This paper examines science teachers' perspectives on the use of AI in education and explores the key factors influencing its adoption in classroom practice. The study reviews existing literature on teachers' perceptions of AI, highlighting both the potential benefits and the challenges associated with its integration. AI tools can support teaching through administrative automation, real-time feedback, personalized learning opportunities, and enhanced access to educational resources. At the same time, concerns remain regarding ethical risks, data privacy, overreliance on technology, and the potential decline in students' critical thinking and creativity. Additional barriers include insufficient technological infrastructure, limited professional development, and teachers' uncertainty about their changing role in AI-supported classrooms. The findings emphasize that teachers' attitudes, digital competencies, and institutional support play a crucial role in determining the effectiveness of AI implementation. Therefore, improving AI literacy, providing targeted professional training, and addressing ethical and pedagogical concerns are essential for enabling responsible and effective integration of AI technologies in education.

Key words and phrases: Teachers, AI, benefits, challenges, attitudes.

1 INTRODUCTION

The widespread use of AI in science education might not ensure that teachers can use it effectively in the classroom, nor does it guarantee instructional quality. Teachers may not yet be fully prepared to implement AI-based teaching despite AI-supported learning's enormous potential. Moreover, science teachers' opinions about innovative teaching methods are directly linked to the extent to which they implement them successfully (Tripathi, 2025). Some educators still hold negative views of using technology in the classroom and prefer more traditional teaching methods and resources. Teachers' efforts to incorporate technology into their work may be hindered by concerns about adopting new methods (Al Darayseh, 2023). Originally, teachers used AI mainly for administrative tasks as efficiency tools with simple applications. However, their pedagogical use of AI varies greatly in complexity, ranging from basic content creation to advanced instructional design that combines AI skills with educational theory and practice. Understanding teachers' perspectives is crucial for developing professional development programs that boost their confidence in using AI and provide them with the skills needed to incorporate it effectively into their teaching strategies (Kashif et al., 2025).

Science teachers' opinions about new teaching methods directly influence how effectively they are adopted. Some educators still hold negative views of using technology in the classroom and prefer to stick with traditional teaching methods and resources. Teachers' efforts to integrate technology into their teaching may be hindered by concerns about these new approaches (Al Darayseh, 2023).

The study by Erdem and Atmaca-Aksoy (2025) examines computer science teachers' views on AI integration in classrooms, highlighting the potential for enhanced personalized learning and administrative efficiency,

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alongside concerns about ethical risks, data privacy, and reduced student critical thinking. While AI is viewed as a tool for increased engagement and data-driven instruction, educators emphasize the importance of balancing technology with human pedagogy. According to Mandal and Mete (2023), teachers generally hold positive attitudes toward AI as a transformative, complementary tool, with up to 90% recognizing its potential to improve productivity and tailor education. However, educators also express significant concerns about potential loss of human connection (60%), issues with academic integrity (71%), and data security risks. These complexities point to the need for further examination of teachers' attitudes, identification of factors influencing them, and evaluation of arguments for and against implementing AI in teaching.

Studying teachers' attitudes is crucial because the effectiveness of AI in education depends significantly on teachers' willingness and positive perceptions of the technology. Additionally, recent research shows that teachers often lack a proper understanding of AI technologies and may feel powerless when using them, which can lead to decreased self-efficacy and reluctance to integrate these tools into the classroom (Filiz et al., 2025).

2 FACTORS THAT INFLUENCE ACCEPTANCE OF AI

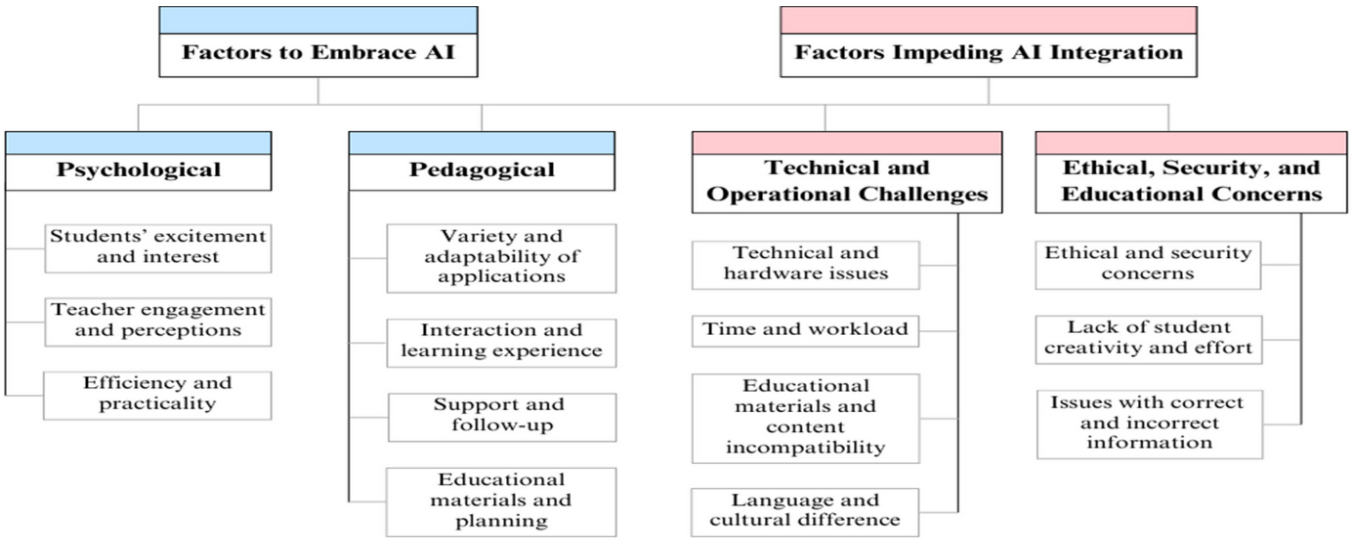
Teachers' perceptions of the value of AI-assisted instruction can be improved, and its adoption encouraged, by making it easier for them to integrate AI applications into science lessons (Al Darayseh, 2023). The teacher's attitude is mostly shaped by the training they receive. The study shows that combining technical AI concepts with specific teaching strategies, as outlined by the TPACK (Technological pedagogical content knowledge) framework, greatly boosts teachers' confidence and ability to teach artificial intelligence (Sun et al., 2022). Velander et al. (2023) highlight the need for greater AI literacy and specialized training for educators adapting to rapid technological changes. While AI has the potential to personalize learning, teachers face significant challenges in understanding, adopting, and managing the ethical issues associated with these tools in the classroom.

Teacher adoption of AI is guided by a three-part framework consisting of Teacher Agency (performance expectancy), Teacher Affection (emotional orientation), and Teacher TPACK (knowledge-based integration). While Agency and Affection influence willingness and motivation to use AI, Teacher TPACK provides the essential skills to integrate technology with teaching goals. For successful integration, initiatives need to address perceived value, emotional comfort, and cognitive coherence simultaneously (Kashif et al., 2025).

While teachers are shifting toward a facilitator role, significant barriers persist, including fears of being replaced, distrust in AI's reliability, and the need for higher levels of digital skills to mitigate perceived threats (Tan et al., 2024). Similarly, Stoicov (2025) observes that educator resistance is fueled by fears of role replacement, loss of pedagogical autonomy, and ethical concerns about AI’s reliability and academic integrity. Moreover, inadequate institutional infrastructure, limited resources, and the necessity for improved digital literacy and TPACK skills strongly contribute to these negative attitudes.

Educators' perceptions of AI's advantages and drawbacks are strongly influenced by their personal cultural beliefs. More perceived benefits of AI were specifically predicted by higher uncertainty avoidance (i.e., the degree to which people feel threatened by ambiguous and uncertain situations), stronger long-term orientation (i.e., the degree to which people orient toward future rewards), and lower masculinity (i.e., the degree to which people adhere to distinct emotional gender roles). On the other hand, greater concerns about AI were predicted by higher levels of masculinity and collectivism (i.e., the degree to which individuals feel incorporated into strong, cohesive in-groups) (Viberg et al., 2024). Teachers with more years of experience are less concerned about AI, but they do not see greater advantages in it. Furthermore, we found no evidence that teachers' perceived advantages or worries about AI are explained by their age, gender identity, educational background, or the subject they teach (Viberg et al., 2024). The main factors recognized by Filiz et al. (2025) as significant for teachers' integration of AI in teaching are presented in Figure 1. Figure 1 shows the wide range of factors that may influence teachers' acceptance and integration of AI in teaching. The list of factors shows that diverse aspects may influence the integration of AI. Each of these factors must be further addressed.

Figure 1: Factors Affecting Teachers' AI Adoption (Filiz et al., 2025).



3 ADVANTAGES OF AI INTEGRATION IN TEACHING

Artificial intelligence is used for administrative tasks such as tracking student attendance and grading, freeing up more time for teacher-student interactions. It can also improve classroom management by reducing teachers' administrative workload. Moreover, AI can support students in real time through chatbots and virtual assistants to handle tasks, answer questions, and provide feedback. Teachers familiar with these tools might incorporate them into their lesson plans to provide ongoing support even after school hours (Güneyli et al., 2024). Although the teachers in this study generally supported AI literacy education and praised AI educational tools individually, these positive attitudes were not consistently translated into implementation (Gamlem et al., 2025). Although teachers in the study by Heung & Wegerif (2024) generally supported AI literacy education and praised AI educational tools individually, these positive attitudes often did not translate into actual implementation.

The advantage of quick access to information and resources, as well as the ease of obtaining answers, is noted as one of the arguments for incorporating AI in teaching. Providing opportunities for personalized learning. Rather than relying solely on teachers, they said AI could meet diverse students' learning needs by providing appropriate materials or assisting with learning at an individual's unique pace (Bae et al., 2024).

4 CHALLENGES AND RISKS OF AI INTEGRATION

Although educators generally view students' use of AI tools positively, several concerns were raised, including limited technological resources and the risk that students may become overly dependent on easily accessible information. Some educators emphasized that students' ability to solve problems independently and think critically could decline if they consistently rely on pre-made solutions (Pınar, 2026). There were also worries that widespread AI use in education might suppress original thought, foster a generation lacking empathy, and pose ethical challenges. These concerns highlight the importance of supporting educators in ensuring the responsible and effective integration of AI technologies in the classroom (Pınar, 2026). Computer science teachers identify key barriers to integrating AI, including significant disparities in technological infrastructure, a lack of professional development, and tight curriculum constraints. Furthermore, educators expressed concerns about ethical risks, including algorithmic bias, assessment challenges posed by generative AI, and a potential loss of the human connection in teaching (Mahon et al., 2026). Teachers' expectations of AI-based technologies were characterized by their complete compliance with their own opinions and the provision of perfect truth. Even a small disagreement was seen as proof that the tool was ineffective, unreliable, and unsuitable (Nazaretsky et al., 2021). Concerns were also raised about how the widespread use of AI in education might suppress original thinking, lead to a generation that lacks empathy, and pose moral dilemmas. These

findings highlight the importance of supporting educators to ensure the careful and effective use of AI technologies in the classroom (Mahon et al., 2026). Students' specific worries from this perspective include blind dependence, ethical ignorance, and a notable decline in the development of their creativity and critical thinking (Sharmin et al., 2026).

Additionally, teachers are concerned about several issues, including algorithmic unfairness, data security, and the possibility that AI could be used maliciously, such as to spy on children (Sharmin et al., 2026). In Tripathi's (2025) study, teachers noted that in AI-integrated classrooms, their professional validity was increasingly being put to the test. They believed that a broader shift in authority and knowledge was reflected in students' increasing reliance on AI technologies rather than on instructors. Many thought that students' expectations for AI-based instruction and their ability to use AI independently were gradually replacing the instructor's conventional role, nearly at the expense of "traditional education."

5 Conclusion

Artificial intelligence has the potential to greatly transform educational practices by supporting personalized learning, enhancing classroom management, and assisting teachers with administrative tasks. AI tools such as chatbots, intelligent tutoring systems, and recommendation systems can boost student engagement, provide real-time support, and enable instruction to be tailored to individual learning needs. However, the successful adoption of AI in education largely depends on teachers' perceptions, skills, and willingness to incorporate these technologies into their teaching.

The literature emphasizes that while many teachers see the potential benefits of AI, significant concerns about ethical risks, data security, academic honesty, and the potential reduction of human interaction in learning remain. Furthermore, challenges such as inadequate technological infrastructure, limited training opportunities, and low levels of AI literacy may hinder teachers from effectively using these tools.

For AI to be successfully integrated into education, it is crucial to provide teachers with appropriate professional development, strengthen institutional support, and encourage a balanced approach that integrates technological innovation with pedagogical principles. AI should be seen as a complementary tool that aids teachers rather than replaces them. By addressing existing challenges and boosting educators' confidence and skills, AI technologies can lead to more effective, inclusive, and personalized learning environments.

From the authors' perspective, the most important prerequisite for effective AI integration is not the availability of AI tools alone, but the preparedness of teachers to use them critically, creatively, and pedagogically meaningfully. AI should be introduced gradually, with continuous professional support and clear institutional policies. Only in this way can artificial intelligence contribute to the improvement of teaching while preserving the essential human, ethical, and pedagogical dimensions of education.

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Digital Competencies of Teachers

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Abstract. Modern technologies has transformed knowledge transmission, requiring the education to adapt to the digital age. Digital competencies have become an essential part of their professional profile, enabling the effective use of information and communication technologies in planning, implementation and evaluation of teaching. This paper examines the impact of teachers' self-esteem on the development of their digital competencies. The hypothesis was tested on a sample of 56 primary school teachers in Vojvodina using a combined questionnaire integrating the Rosenberg Self-Esteem Scale, relevant items from the ICILS 2023 teacher survey and the SELFIE for Teachers instrument. Pearson's correlation coefficient was used as the main statistical method. Results showed a solid level of basic digital skills (78.6% of teachers reported high proficiency in finding educational resources and 71.4% in creating presentations), but proficiency in advanced areas was considerably lower (LMS - 32.1%, video editing - 48.2%). Correlation analysis revealed strong positive correlations ($r = 0.80 – 0.94$) between self-esteem and digital competencies, the strongest links ($r > 0.90$) were related to teachers' sense of personal worth and self-efficacy. These findings indicate that higher self-esteem is significantly associated with greater confidence and engagement in using information and communication technologies.

Key words and phrases: digital competencies, information and communication technologies, professional development, self-esteem.

1 INTRODUCTION

The rapid development of modern technologies also changed the ways in which knowledge is acquired and transmitted, demanding that the educational system be adapted to the demands of the digital age (Živković, 2011; Ilić, 2020; Dumitrašković, 2014). Just a decade or two ago, traditional tools like blackboards and chalk dominated classrooms while teaching was primarily teacher-centered and frontal in nature (Viduka et al., 2016; Jakšić et al., 2021). Today, information and communication technologies (ICT) offer interactive, individualized teaching and student-centered learning, making teaching content more accessible and motivating for students (Fu, 2013; Raja and Nagasubramani, 2018; Šikl-Erški, 2023).

In this context, teachers' digital competenices have become a very important part of their professional development. These competencies do not only include technical skills for using digital tools, but also refer to pedagogical skills for effective application of technologies, delivery and evaluation of lessons (Digital Competence Framework, 2023; European Commission/EACEA/Eurydice, 2019; Ministry of Education, Science and Technological Development, 2017). However, despite strategic documents and reforms, schools in Serbia still face numerous challenges, including insufficient technical equipment, different levels of digital readiness of teachers and limited continuous professional development (Government of the Republic of Serbia, 2013; Ilić and Purić, 2022; Matović, 2021; Marić and Jevtić, 2015).

The level of development of digital competencies of teachers also represents their willingness to modernize teaching through the introduction of modern ICT tools and to engage in continuous professional development in the field of digital competencies (Ilić and Purić, 2022). Traditional teaching fails to meet the demands of modern society, which requires students to independently acquire, manage, analyze and apply knowledge (Živković, 2011; Viduka et al., 2016; Lasić-Lazić, 2014). Empirical findings indicate that while teachers demonstrate solid basic digital skills, proficiency in advanced areas such as learning management systems and

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video editing remains significantly lower (Ilić and Purić, 2022; Institute for Quality Evaluation of Education and Training, 2024).

Self-esteem can be defined as the way in which an individual evaluates and values himself. It also represents the assessment that a person forms about himself, which reflects the degree of acceptance or rejection of his own personality and indicates the degree to which a person considers himself capable, successful, significant and valuable. People with high self-esteem express a positive evaluation of themselves and perceive themselves as valuable, while people with low self-esteem are more prone to self-rejection, self-dissatisfaction and negative self-evaluation (Jelić, 2012). The level of self-esteem can be a significant predictor of professional competencies (Ceylan, 2023).

Previous studies have examined teachers' digital competencies and the barriers to technology integration, most of them have focused on external factors such as infrastructure, access to equipment, and the quality of training programs. Far less attention has been paid to internal psychological factors that may influence teachers' motivation and willingness to develop these competencies. In particular, the potential role of self-esteem as a predictor of digital competence development remains largely unexplored in the Serbian educational context.

This study focuses on connecting and understanding the concepts of digital competencies and teachers' self-esteem. The central research question is: Does teachers' self-esteem affect the development of their digital competencies? The research problem that this study aims to address is the extent to which individual psychological characteristics — specifically the level of self-esteem — act as an obstacle or an incentive for teachers' professional development and their motivation to master new information and communication technologies. Based on the defined research problem and research question the following hypothesis is formulated: there is a statistically significant positive relationship between teachers' self-esteem and the level of their digital competencies.

2 METHODOLOGY

The research was conducted using a convenience sampling method, as participants were selected based on their availability and willingness to participate in the study. The sample included teachers from several primary schools in the territory of Vojvodina (N = 56). Due to the applied sampling method and the relatively small sample size, the results cannot be considered fully representative of the entire population of primary school teachers, but they provide valuable insights into the examined relationships. The questionnaire is composed of three validated instruments: the Rosenberg Self-Esteem Scale, selected items from the international teacher survey ICILS 2023, and the SELFIE instrument for teachers, designed to assess teachers' digital competencies. The main goal of the research was to examine whether teachers' self-esteem affects the development of their digital competencies. To examine the relationship between these variables, Pearson's correlation coefficient was applied. According to the authors' recommendations, all negatively worded items on the Rosenberg Self-Esteem Scale were reverse coded before analysis. An anonymous questionnaire was used to collect data, and all participants were informed about the purpose of the study. The results obtained were processed using statistical software SPSS.

3 MAIN RESULTS

Analyzing the demographic structure of the respondents, it was determined that 56 primary school teachers participated in the research. The sample consisted mostly of female population (f = 49, 87,5%), while men were represented in significantly smaller numbers (12,5%, f = 7). The largest number of respondents belong to the age group of 30 - 49 years, which indicates that the sample is teachers with significant professional experience.

In order to assess the level of digital competencies of teachers, respondents performed a self-assessment of their skills in various areas of application of digital technologies in education.

Table 1. Self-assessment of digital competencies

Self-assessment of digital competencies (N=56)	**Frequency (f)**	**Percentage %**
Finding useful information	44	78.6
Make presentations	40	71.4

Assessment of the quality of teaching resources	39	69.6
Assessment of students' knowledge using IC	33	58.9
Preparing lessons that require the use of ICT by students	32	57.1
Preparing tests that record students' answers	32	57.1
Using programs for spreadsheet calculations in the function of keeping records	30	53.6
Use of shared resources in the function of cooperation	27	48.2
Editing video content for teaching	27	48.2
Contribute to the forum discussion	23	41.1
Using the LMS system	18	32.1

The results shown in Table 1 indicate that teachers have developed basic digital competencies, especially in the area of finding information on the Internet (78.6%; f = 44) and creating presentations (71.4%; f = 40), which confirms the wide use of digital technologies in the preparation of the teaching process. Also, a high level of self-assessment was recorded in the assessment of the quality of teaching resources (69.6%; f = 39). On the other hand, lower levels of self-assessment are evident in more complex competencies, such as using the LMS system (32.1%; f = 18) and participating in online discussions (41.1%; f = 23), which indicates a limited use of digital tools in the context of collaboration and interaction. These findings suggest that, despite a solid foundation of digital skills, there is a need for further development of competencies involving more advanced and pedagogically focused use of ICT.

The results of the data analysis reveal a significant difference between teachers' awareness of the importance of digital technologies and their actual engagement in professional development. Significant number of participants showed a high level of awareness of the role of digital tools in education, their practical application and participation in continuous professional development remain limited. Only 32.1% of respondents (f = 18) stated that they had never participated in activities aimed at developing digital skills, while 39.3% (f = 22) believed that additional training in this area was not needed. Regarding the integration of ICT in the teaching process, 17.9% of teachers (f = 10) never participated in such activities, while 35.7% (f = 20) stated that they participated on several occasions. These findings indicate a clear need to strengthen the professional competences of teachers, especially through greater practical application of digital tools and more active exchange of experiences within the teaching community.

By analyzing the adapted questions of the SELFIEforTEACHERS survey, which refers to the professional engagement of teachers, the author comes to the conclusion that communication is the strongest point of the surveyed teachers, while the biggest challenge is mentoring and knowledge sharing, which can be seen in Table 2.

Table 2. Professional engagement

Digital competence	**Consciousness / Initial level (%)**	**Active usage (%)**	**Leadership / Mentoring (%)**
Organizational communication	39,3%	44,7%	14,2%
Digital technologies and infrastructure at the school level	39,3	37,5%	19,6%
Professional learning (through digital technologies)	48,2%	46,5%	5,4%
Professional learning (about digital technologies)	66,1%	25%	7,2%

By analyzing communication as a digital competence, we come to the knowledge that this is the area where teachers feel most competent in their daily work. Digital technologies and infrastructure at the school level have the highest percentage in the part of leadership (mentoring), which tells us in favor of the fact that teachers, in addition to knowing how to use, also help others to manage with school equipment. In the area of

professional learning through digital technologies, we can conclude that although teachers actively use digital technologies, they rarely share their experiences with their colleagues. Competence professional learning about digital competencies tells us that although there is a high awareness that teachers need to learn about digital technologies, only 25% of respondents actually do it.

Based on the analyzed mean values of Rosenberg's self-esteem scale, it is concluded that the respondents (N = 56) have a stable basic sense of personal worth M = 3.55. A high percentage of them agree that things can work as well as others M = 3.43. The item "I feel that I have many good qualities" has the largest standard deviation (SD = 1.006), which indicates the disagreement of the respondents - some teachers are very sure of their virtues, while others are significantly more doubtful.

To examine the relationship between self-esteem and the digital competencies, Pearson correlation coefficient was applied, in which all items of the Rosenberg self-esteem scale were compared (the Rosenberg self-esteem scale consists of 10 items, 5 positively constructed and 5 negatively constructed statements, which required negative statements to be coded separately) and adapted questions about teachers' digital competencies from ICILS 2023 teacher surveys. For the purposes of this research, question number eight was used, which originally contains 14 items, eight of which were taken over for the purpose of this research. The analysis was conducted on a sample of N = 56 respondents. Values shown represent two-tailed tests of statistical significance. Significance levels are indicated by the $p < .05$ symbol (*) indicating that there is less than 5% probability that the correlation is random and the result is considered statistically significant, while $p < 0.01$ by the symbol (**) indicating that there is less than 1% probability that the correlation is random and the result is considered highly statistically significant.

Table 3 shows the most significant correlation between individual items of self-esteem and teachers' digital competencies.

Table 3. The strongest correlations between self-esteem items and digital competencies (N=56)

Self-esteem item	Digital competence	r	Connection strength	Direction
I feel that I am a person of worth, at least as much as others.	General approaches (relevant to all subjects) to using ICT to improve teaching and learning	0.805**	Strong	Positive
I feel that I have many good qualities.	General approaches (relevant to all subjects) to using ICT to improve teaching and learning	0.893**	Very strong	Positive
I am capable of doing things just as well as most other people.	Use of productivity applications (eg, word processor, presentation software, Internet use)	0.906**	Very strong	Positive
I have a positive attitude towards myself.	Use of productivity applications (eg, word processor, presentation software, Internet use)	0.844**	Very strong	Positive
Overall, satisfied with myself.	Use of productivity applications (eg, word processor, presentation software, Internet use)	0.323*	Weak	Positive
Overall, I tend to feel like a failure.	Use of productivity applications (eg, word processor, presentation software, Internet use)	0.906**	Very strong	Positive
I feel like I don't have much to be proud of.	General approaches (relevant to all subjects) to using ICT to improve teaching and learning	0.843**	Very strong	Positive
I wish I could respect myself more.	Subject-specific approaches to the use of	0.910**	Very strong	Positive

	ICT for the improvement of teaching and learning			
Sometimes I really feel useless.	Use of productivity applications (eg word processor, presentation software, Internet use, spreadsheet programs)	0.943**	Very strong	Positive
Sometimes I think I'm not good at all.	General approaches (relevant to all subjects) to using ICT to improve teaching and learning	- 0.920**	Very strong	Negative

The conducted Pearson analysis indicates that most of the correlations are statistically significant because very strong positive correlations dominate (r = 0.84 - 0.94). Such results show a strong connection between perceptions of own values and digital competencies. The strongest correlations (r > 0.90) between digital competencies and self-esteem are for the following items: Sometimes I really feel useless (r = 0.943); I wish I could respect myself more (r = 0.910); I am able to do things as well as most other people (r = 0.906); I tend to feel that I am a failure (r = 0.906), which means that digital competencies are strongly related to feelings of personal worth and efficacy. Pearson's correlation showed that there is also one negative item, related to the following statement - sometimes I think I am not good/good at all (r = – 0.920), which can be interpreted so that a higher level of digital competencies leads to less agreement with negative self-evaluation. The only weak connection was found with the item "On the whole, satisfied with myself" (r = 0.323) and this result suggests that global self-satisfaction is a broader construct and does not depend directly on specific digital skills or on the assessment of competence in that area.

Overall, the results clearly indicate a strong connection between self-esteem and teachers' digital competencies. However, given the correlational nature of the analysis, these findings do not allow for causal inferences. They say that self-esteem can be an important psychological factor that affects the motivation and willingness of teachers to develop digital competencies, further research is needed to better understand the nature of this connection and its possible implications for professional development programs.

4 CONCLUSION

The problem that this paper deals with concerns the under-researched role of teachers' self-esteem when developing their digital competencies. Previous research was mainly focused on external factors such as technical equipment, training or organizational conditions, while this paper examined whether teachers' self-esteem can represent a significant prerequisite for the development of digital competencies.

The results of the research show that teachers possess a solid level of basic digital competencies, while their training for more advanced areas of application of digital technologies is still limited. At the same time, a very strong and statistically significant positive correlation was found between self-esteem and digital competencies (r = 0.80–0.94). These findings suggest that teachers with a higher level of self-esteem show greater self-confidence and willingness to actively use information and communication technologies in educational work.

From a theoretical point of view, this research contributes to the understanding of the relationship between the personal characteristics of teachers and their professional development in the context of the digital transformation of education, the significance of the obtained results goes beyond theoretical frameworks and offers concrete guidelines for practice. In addition to improving the technical infrastructure and organizing professional trainings, professional training programs for teachers should include psychological factors, primarily strengthening self-esteem because this factor stands out as a key driver of internal motivation; a teacher who is confident in his own abilities will be more ready to adopt new digital competencies and, what is more important, to actively and consistently apply them in direct work with students. The results confirm the proposed hypothesis, indicating a statistically significant positive relationship between teachers' self-esteem and digital competencies.

The results obtained should be interpreted with some caution due to the limitations of the study, including relatively small sample size and territorial constraints, as well as use of a convenience sampling metod. Therefore, the findings cannot be fully generalized to the broaded population of primary school teachers in Vojvodina or beyond. Future research should include larger and more heterogeneous samples, as well as

longitudinal designs, in order to more precisely examine the direction, strength, and stability of the relationship between self-esteem and the development of digital competencies and to improve representativeness and generalizability of the findings.

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Artificial Intelligence in Modern Education: A Review of AI Assistant Tools and Their Role in the Learning Process

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Abstract. Artificial intelligence represents one of most important technological innovations in modern society, and its use finds itself in field of education. Artificial intelligence like educational tool brings young people knowledge, skills and tools that helps them to innovate and positively transform the society in which we live. This paper represents a narrative review of existing literature and publicly available information on the application of artificial intelligence in education. Sources were selected based on relevance to the topics of AI assistants, educational automation, and personalized learning. In addition to academic literature, the paper presents five AI tools currently used in educational practice — Gradescope, Fetchy, Dragon Speech Recognition, Cognii, and Century Tech — selected as representative examples of distinct AI applications in teaching and assessment.

Key words and phrases: Artificial intelligence, Educational AI tools, Software.

1 INTORDUCTION

Artificial intelligence (AI) has emerged as one of the most transformative technologies of the 21st century, with applications spanning medicine, finance, transportation, and education. At its core, AI refers to computer systems capable of performing tasks that typically require human intelligence, such as reasoning, learning, problem-solving, and decision-making (Russell & Norvig, 2020).

The rapid growth of AI has been driven by three converging factors: the exponential increase in available data, significant improvements in computational power, and advances in machine learning algorithms. These developments have enabled AI systems to move beyond narrow, rule-based functions toward more flexible, adaptive behaviour across diverse domains (Zawacki-Richter et al., 2019).

In the field of education, AI presents both significant opportunities and notable challenges. On one hand, it enables personalized learning, automated assessment, and broader access to educational resources. On the other hand, it raises important questions about data privacy, the appropriate role of technology in teaching, and the risk of over-reliance on automated systems (Luckin et al., 2016). Understanding how AI tools are currently being applied in educational settings is therefore essential for educators, policymakers, and researchers alike.

This paper is a narrative literature review aimed at examining the current applications of artificial intelligence in educational settings, with particular focus on AI assistant tools. Sources were selected through a review of academic literature and relevant professional publications on the topics of AI in education, personalized learning, and educational automation. The five AI tools presented — Gradescope, Fetchy, Dragon Speech Recognition, Cognii, and Century Tech — were selected as representative examples of distinct AI functionalities in teaching and assessment contexts. Sources were analyzed thematically, grouping findings around the key topics of AI advantages in education, automation, data analysis, and tool-specific capabilities.

2 AI ASSISTENT

AI assistant can be defined as a software program that relies on technologies such as natural language processing (NLP) to interpret and respond to voice and text commands. These systems are capable of performing many of the same tasks as humans, including reading text, dictation, making calls and more (ITNetwork, 2024). With the evolution of chatbots and generative artificial intelligence, various types of AI assistants have gained prominence. However, they serve different purposes for users and provide varying levels of assistance:

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- Chatbots. Chatbots are computer programs that function as AI assistants and communicate with users through a text interface on websites, social media platforms and messaging applications. These systems can assist users, respond to prompts or initiate conversations. AI chatbots utilize natural language processing (NLP) and machine learning (ML) algorithms to interpret user input, generate relevant responses and improve their performance over time by learning from interactions.
- Conversational agents. Besides text-based chatbots, conversational agents enable AI assistants to communicate in a human-like manner through both text and voice interfaces. These systems are designed to understand complex linguistic patterns, recognize user intent and provide appropriate responses in various contexts. Conversational AI technology can be used to develop more sophisticated AI assistants which are capable of performing various tasks and offer more intuitive and natural user experience.
- AI digital assistants. These advanced AI digital assistants are capable of performing a variety of tasks, often across multiple devices and platforms. They frequently interact with users through voice-based communication. With such AI digital assistants, users can efficiently and rapidly access information, control smart home devices and manage their calendars through integration with various services and applications (TechTarget, 2024).

3 ADVANTAGES OF AI IMPEMENTATION IN EDUCATION

Integrating AI in education from the very beginning of learning process offers dual benefits:

- It reduces time spent on administrative and repetitive tasks, allowing teachers to dedicate more attention to direct student interaction and mentoring;
- It equips students with digital and AI literacy skills essential for navigating an increasingly technology-driven world responsibly (Luckin et al., 2016).

Research consistently shows that AI integration in education yields measurable benefits for both students and teachers. When implemented thoughtfully, AI tools can support more equitable and effective learning environments by adapting to individual student needs and reducing the administrative burden on educators (Zawacki-Richter et al., 2019). Developing AI literacy among students from an early age is increasingly regarded as essential preparation for participation in a technology-driven society (Luckin et al., 2016).

The following benefits of AI in education are widely documented in the literature (Holmes et al., 2019; Zawacki-Richter et al., 2019):

- More accurate and objective assessment**:** AI-assisted grading tools can evaluate student work with greater consistency than manual marking alone, reducing subjective bias and providing students with faster, more actionable feedback (Holmes et al., 2019).
- Efficient, low-stress testing: Thanks to AI, testing becomes more effective and less stressful. After each lesson, students can assess their knowledge, receiving results that indicate both their mastery of the material and any areas requiring additional attention.
- Enhanced knowledge retention: AI supported learning is more effective because content is divided into units and adapted to individual learning styles, with numerous interactive examples and functions. This approach enables students to master the material more thoroughly and retain it for longer periods.
- Student motivation: Detailed AI-generated analytics on each student. AI provides valuable insights into each student's progress and performance. Consequently, teachers can offer targeted support and encouragement to those who need it. (Luckin et al., 2016).
- Personalized learning: AI algorithms can analyze each student. Algorithms that deliver key information about each student's learning patterns allow teachers to tailor instruction and recommend personalized educational tools suited to individual learning styles. Personalized learning is widely recognized as one of the most significant contributions AI makes to modern education (Holmes et al., 2019).

4 ADVANTAGES OF IMPLEMENTATION AI ASSISTENTS IN EDUCATION

Automation in the Educational Process:
Artificial intelligence provides tools for automating various educational tasks, such as grading tests, creating personalized learning programs, and monitoring student progress. These tools not only simplify teachers' work but also enable faster evaluation, freeing up more time for student interaction. For example, essay grading software can automatically analyze grammatical errors and provide feedback, while assessment systems allow for more precise tracking of student progress.
Data Analysis in Education:
Another important aspect of AI in education is its ability to analyze large volumes of data. Based on grades, test results, attendance, and other educational parameters, schools can make informed decisions that enhance the teaching process. This approach enables educators to identify educational trends and anticipate areas that require additional attention or resources.
AI enables access to educational content from around the world, making education more accessible and tailored to the individual needs of students.

5 AI assistents used in education

The Gradescope AI tool enables students to peer-assess while providing feedback, tasks that are often time-consuming without AI technology. Gradescope leverages a combination of machine learning (ML) and artificial intelligence to streamline grading, saving both time and effort.
By delegating these tasks to external collaborators, teachers can focus on more critical activities. Gradescope can be used by instructors to grade paper-based exams, online homework, and to organize project preparation all in one platform.
Key features of Gradescope:

- Manual grouping of questions assisted by AI
- Extended time for students
- AI-assisted grading
- Increased efficiency and fairness

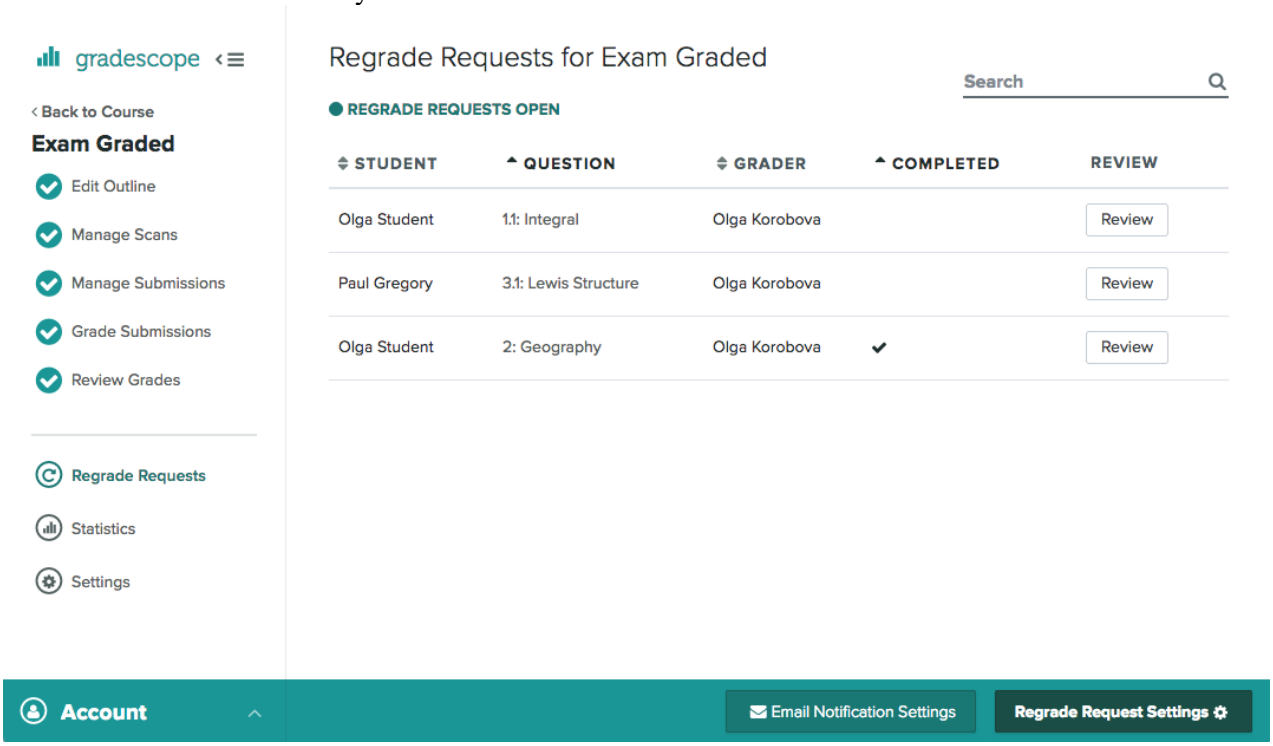


Figure 1. Gradescope application (Source: gradescope.com)

Fetchy is a generative AI platform specifically designed for educators. It enables teachers to unlock their full instructional potential by simplifying and modernizing the countless tasks they face, including creating engaging lessons, generating newsletters, composing professional emails, and much more. Leveraging the

power of artificial intelligence, Fetchy empowers educators to enhance their teaching methods, optimize time management, and make confident, well-informed decisions.
Fetchy specializes in tailoring generated content to meet teachers' specific needs. Since it does not require complex instructions, it is user-friendly for educators. By using Fetchy's customized solutions, teachers can expect relevant outputs aligned with their particular educational requirements.
Key Features of Fetchy:

- Generates lesson plans
- Reviews history from multiple perspectives
- Identifies mathematical or scientific experiments

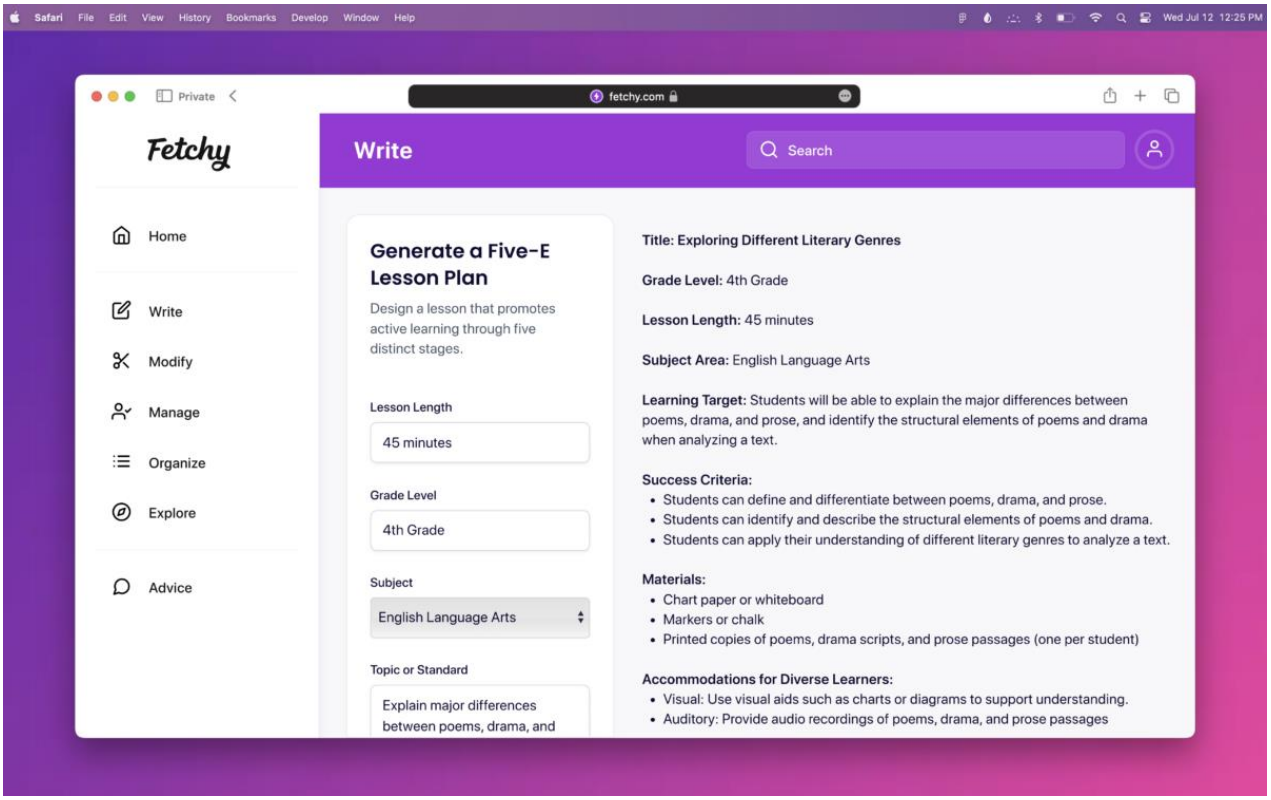


Figure 2. Fetchy application (Source: fetchy.com)

Nuance's Dragon Speech Recognition is a speech-to-text software that can be used by both students and faculty. The Dragon Speech Recognition product can transcribe up to 160 words per minute, assisting students who have difficulty writing or typing. The tool also supports voice commands for navigating documents, which is essential for learners with accessibility needs.

- Dragon offers many additional features, including the ability to dictate lesson plans, curricula, worksheets, reading lists, and more three times faster than typing while achieving 99% accuracy.
- Key Features of Nuance's Dragon:
- Accessibility functions supporting voice commands
- Voice-assisted student work assessment
- Classroom dictation with 99% accuracy

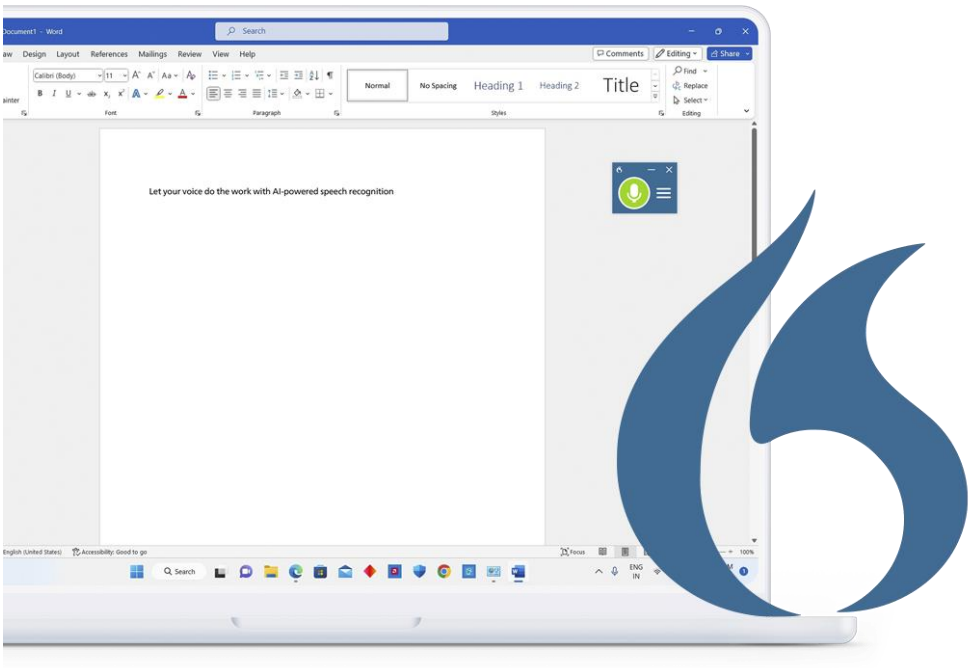


Figure 3. - Nuance's Dragon Speech Recognition application(Source: https://dragon.nuance.com/en-us/dragon)

Cognii is another Boston-based company that develops AI-powered products for K–12 and higher education institutions, as well as corporate training environments.

One of Cognii's main AI tools is its virtual learning assistant, which leverages conversational technology to help students construct open-ended responses and improve critical thinking skills. Additionally, the virtual assistant provides individualized tutoring and real-time feedback tailored to each student.

- Key Features of Cognii:
- Assists students in formulating open-ended responses
- Provides one-on-one tutoring
- Offers personalized adaptation for each student

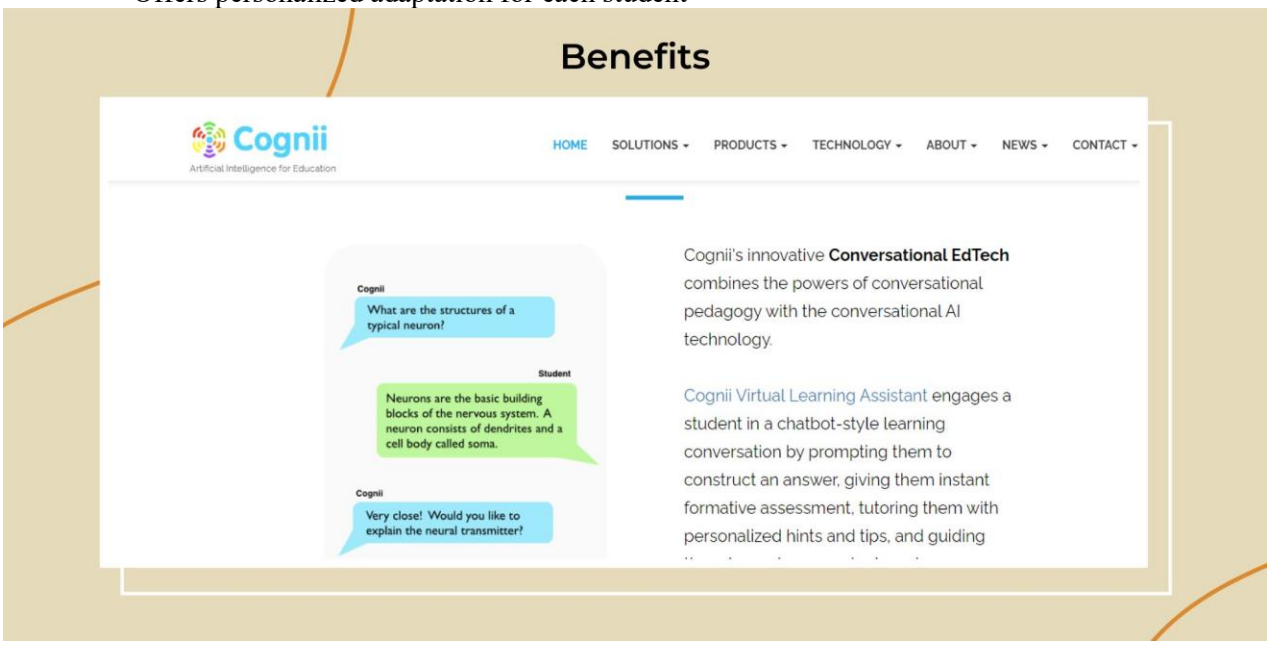


Figure 4. – Cognii application(Source: www.cognii.com)

Century Tech, a London-based company, offers an AI platform that leverages cognitive neuroscience and data analytics to create personalized learning plans for students. These tailored plans, in turn, reduce the workload for instructors, allowing them to focus on other areas.
The AI platform also tracks student progress, identifies gaps in knowledge, and provides personalized study recommendations and feedback for each user. For teachers, Century assists in accessing new resources that minimize the time required for routine tasks such as planning and grading.
Key Features of Century:

- Accelerates learning and enhances student engagement
- Reduces teacher workload
- Provides actionable insights from data (ITNetwork, n.d.)

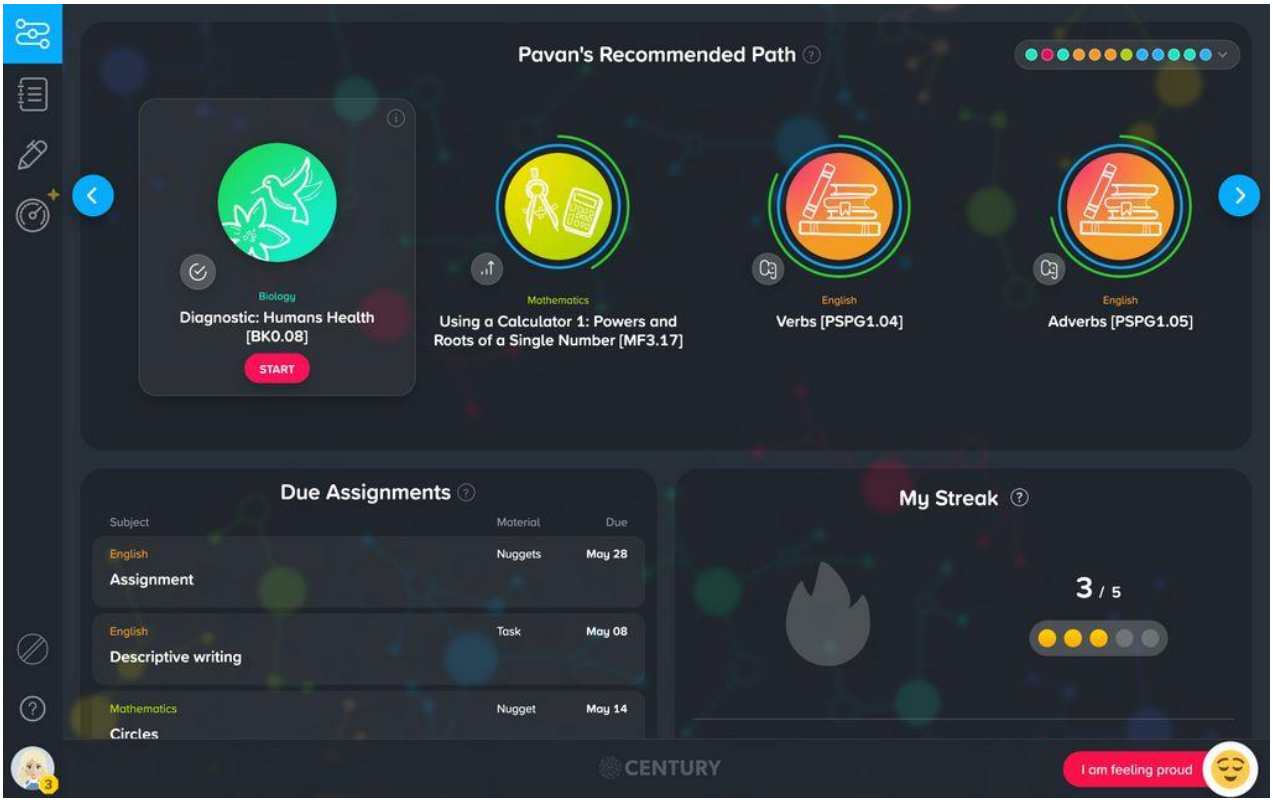


Figure 5. – Century application(Source: www.century.tech)

6 LIMITATIONS AND ETHICAL CONSIDERATIONS

Despite its considerable potential, the integration of AI in education raises several important ethical and practical concerns that must be addressed for responsible implementation.
Data privacy is among the most pressing concerns. AI educational tools typically collect large volumes of data about student behaviour, performance, and learning patterns. The storage and use of such data — particularly for minors — must comply with legal frameworks such as the General Data Protection Regulation (GDPR) and requires transparent communication with students and parents (Holmes et al., 2019). Without adequate safeguards, there is a risk that sensitive personal data could be misused or inadequately protected.
Teacher training represents another significant challenge. The effective use of AI tools requires educators to develop new technical competencies alongside a critical understanding of how these systems work and where they may fail. Without adequate professional development, there is a risk that AI tools will be adopted superficially or inappropriately, undermining rather than enhancing the quality of education (Luckin et al., 2016).
Finally, over-reliance on AI poses a risk to the development of critical thinking and independent learning skills. If students become accustomed to receiving instant AI-generated answers and feedback, they may struggle to develop the problem-solving abilities and intellectual resilience needed for higher education and professional

life (Zawacki-Richter et al., 2019). It is therefore essential that AI tools are used to complement, rather than replace, pedagogically sound teaching practices.

7 Conclusion

This paper has examined the application of artificial intelligence in educational settings, with a focus on AI assistant tools and their practical benefits. The reviewed literature and tools demonstrate that AI has significant potential to improve the quality, efficiency, and accessibility of education through personalized learning, automated assessment, and data-driven decision-making. Tools such as Gradescope, Fetchy, Dragon Speech Recognition, Cognii, and Century Tech represent concrete examples of how AI is already being applied across diverse educational tasks. At the same time, responsible implementation requires careful attention to data privacy, adequate teacher training, and the avoidance of over-reliance on automated systems. Teachers remain irreplaceable in providing emotional support, fostering critical thinking, and building meaningful relationships with students. Future research should focus on long-term evaluations of AI tool effectiveness across different educational contexts, as well as on developing ethical frameworks to guide their use (Holmes et al., 2019).

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Students' Creativity in Higher Education

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Abstract. Creativity is increasingly recognised as a key competence in higher education, as it supports problem-solving, critical thinking, adaptability, and innovation. This paper examines the extent to which higher education encourages or suppresses students' creative potential. The study combines a theoretical overview of student creativity, the role of the higher education environment, and factors that foster or hinder creative development, with an empirical investigation conducted among 55 students of Engineering Management at the Technical Faculty "Mihajlo Pupin" in Zrenjanin. The findings indicate that students generally perceive creativity as being valued within their academic environment, particularly through supportive classroom atmospheres, encouragement of diverse solutions, and constructive feedback. However, the results also reveal important limitations, especially the burden of academic obligations and the insufficient dominance of creative and practice-oriented tasks. Based on these findings, higher education institutions should reduce perceived workload pressures and systematically increase practice-oriented, open-ended, project-based tasks, supported by formative feedback and assessment criteria that explicitly reward originality.

Key words and phrases: Creativity, Students, Education**.**

1 INTRODUCTION

Creativity is now regarded as one of the key competencies of the contemporary individual, as it implies the ability not only to acquire knowledge but also to apply it creatively in new circumstances. In higher education, it is particularly important because students are expected to solve complex problems, connect different sources of knowledge, and shape innovative solutions (Alvarez-Icaza et al., 2024). However, one question remains open: do universities truly develop creative potential, or do they often constrain it through formalism, reproductive learning, and rigid academic patterns (Georgiou et al., 2022)? This dilemma is further significant because today's labour market and social challenges increasingly value originality, adaptability, and the ability to create new solutions (Avcı & Durak, 2022).

Enhancing creativity in higher education requires a redesign of pedagogical approaches and assessment models in order to move away from predominantly reproductive learning and create space for active, inquiry-based, and problem-oriented student engagement (Peters & Angelov, 2025). This implies a greater reliance on creative pedagogy, process-based assessment, project work, simulations, presentations, and multi-stage tasks through which students demonstrate their way of thinking rather than merely the final result (Chan & Colloton, 2024). Such approaches not only foster originality and critical thinking, but also reduce the scope for superficial use of artificial intelligence and academic dishonesty.

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2 Students' Creativity

Creativity is most commonly defined as the ability to produce new, original, and contextually valuable ideas, responses, or products (Creely & Blannin, 2023). It implies not only novelty, but also an assessment of an idea's usefulness, its applicability, and its potential contribution to problem-solving (Carceller, 2024). In the educational context, creativity is associated with the development of critical thinking, problem-solving, interdisciplinary integration, and adaptability, which is why it is regarded as one of the fundamental skills of the twenty-first century (Nurita et al., 2024). Its important dimensions include originality, fluency, flexibility, curiosity, willingness to take risks, and the ability to connect seemingly distant ideas (Ameen & Wahhab, 2023).

For students, creativity is not an additional but a developmentally and professionally important competence. It enables them to move beyond the framework of reproductive learning, to explore independently, evaluate ideas, and arrive at solutions in situations that are not clearly defined in advance (Mahama, 2024). It is particularly important because it contributes to the development of divergent and convergent thinking, self-confidence when working on new tasks, and readiness for a labour market that increasingly demands innovation and adaptability (Gajda, 2025;). For this reason, contemporary higher education should create conditions in which students not only acquire content but also reshape it through project work, experiential learning, and problem-solving.

3 Factors that Encourage and Suppress Creativity During Study

During the course of study, creativity develops most strongly in an environment that prioritises active learning, collaboration, problem-based tasks, and authentic situations drawn from practice. Students are then given the opportunity not to absorb knowledge passively, but to test, reshape, and apply it through inquiry and experimentation. Such an approach can be further strengthened through the thoughtful use of artificial intelligence, especially when it supports brainstorming, research, and design without displacing independent thinking (Costello et al., 2024; Jiao et al., 2024). An additional stimulus is the development of AI literacy, as it enables students to understand the possibilities, limitations, and ethical dilemmas of contemporary digital tools (McGuire, 2023).

Creativity may be weakened when the education system insists on rote learning, rigid curricula, and standardised forms of assessment (Habib et al., 2025). In such an environment, students often become accustomed to searching for the 'correct' answer rather than exploring several possible solutions, thereby narrowing the space for divergent thinking. Additional problems include fear of mistakes and pressure to succeed, as these reduce students' willingness to experiment, take risks, and develop original ideas (Wazan et al., 2023).

4 The Role of Higher Education in the Development of Creativity

Higher education institutions play an important role in the development of creativity because they can provide an environment that encourages inquiry, the exchange of perspectives, and interdisciplinary collaboration (Rana et al., 2025). Such a role requires a carefully designed curriculum, contemporary teaching strategies, and a willingness to use technology as support for the creative process rather than as its substitute (Sarıtepeci & Durak, 2024; Montenegro, 2024). In this sense, it is especially important that students learn to use artificial intelligence critically, thoughtfully, and ethically, so that they retain an authentic voice and develop their own thinking (Rong et al., 2025; Ma et al., 2025).

Teaching methods and assessment practices directly affect whether creativity will be encouraged or hindered. When the reproduction of facts, convergent answers, and formal accuracy are valued above all else, students have less space for innovative thinking and independent problem-solving (Urmeneta et al., 2024). By contrast, methods involving projects, open-ended tasks, case studies, and reasoned argumentation can make a substantial contribution to the development of creativity.

The role of the teacher is crucial, because their pedagogical philosophy and way of conducting teaching shape the academic climate in which students work. A supportive environment that encourages reflection, dialogue, and personal development increases the likelihood that students will express ideas more freely and develop original solutions. By contrast, rigid approaches and insistence on predefined outcomes may suppress imagination and creative expression (Tong, 2024). In addition, the contemporary context also requires continuous professional development for teachers, especially in relation to the responsible use of generative

artificial intelligence and the design of tasks that require analysis, synthesis, and evaluation (López-Regalado et al., 2024; Guan & Yang-xi, 2025).

5 Methodology and Research Results

The research was conducted with the aim of examining students' creativity in higher education, with particular focus on the extent to which creativity is encouraged or suppressed within the academic environment. The subject of the research encompasses students' personal assessment of their creativity, their perceptions of the teaching process, teaching practices, assessment methods and feedback, as well as the need for greater use of techniques that contribute to the development of creative thinking and behaviour.

The aim of the research was to determine how students assess their own creativity and how they perceive the conditions for the development of creativity during their studies. Particular emphasis was placed on identifying the factors that encourage creativity, as well as those that limit it, with a view to identifying specific changes in teaching practice which, in the students' opinion, could contribute to its greater development.

A quantitative approach was applied in the research. The survey method was used as the basic research method, while the research instrument was a structured anonymous questionnaire entitled Creativity in Higher Education. The research was conducted at the Technical Faculty 'Mihajlo Pupin' in Zrenjanin, within the Engineering Management study programme. The research sample comprised 55 students, ranging from the first year of undergraduate academic studies to Master's studies. It was a convenience sample, since the students included in the research were those available to the researcher and who voluntarily agreed to participate in the survey. The research lasted about a month, that is, from March 17, 2026, to April 10, 2026. The questionnaire was designed as several thematic sections. The first section referred to the general characteristics of the respondents. The second section covered students' perceptions of whether creativity at the faculty is encouraged or suppressed, taking into account such elements as the teaching climate, freedom of expression, the valuing of originality, fear of mistakes, and workload. The third section related to teaching practices that may affect creativity, including project assignments, case studies, discussions, the possibility of choosing the topic or mode of completing an assignment, as well as space for iterative improvement of work. The fourth section dealt with assessment and feedback, that is, whether the system of evaluation and teachers' comments encourage originality or favour reproduction of the material.

A five-point Likert scale was used for the closed questions, where a value of 1 indicated complete disagreement and a value of 5 complete agreement with the statements offered. The results were analysed using descriptive statistics.

The research was conducted on a sample of 55 students from the Engineering Management study programme at the Technical Faculty 'Mihajlo Pupin' in Zrenjanin. Within the sample structure, female respondents predominated, accounting for 76.4%, while male respondents represented 23.6% of the sample. According to year of study, third-year students were the most represented (32.7%), followed by second-year students (21.8%), while first- and fourth-year students accounted for 16.4% each, and Master's students for 14.5%.

The results relating to the general perception of the encouragement of creativity show a predominantly positive attitude among students. Most respondents believe that creativity is valued at their faculty as an important competence, with 61.8% expressing agreement with this statement, while 30.9% remained neutral. Similarly, 60% of respondents believe that teaching encourages inquiry and independent thinking, while almost a third are neutral.

A particularly significant finding is that 63.6% of respondents believe they have sufficient space to express an original view without fear of a negative reaction, while only a small number express open disagreement. This suggests that students largely experience the teaching environment as relatively safe for expressing their own ideas. In addition, as many as 83.6% of respondents agree with the statement that the atmosphere in class is such that ideas are considered rather than dismissed in advance, which represents one of the most positive findings in this part of the research (Figure 1).

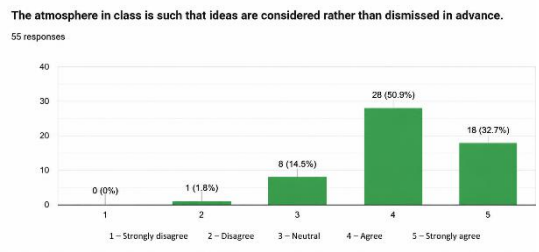


Figure 8. Atmosphere in class

A significant percentage of respondents, 72.7%, believe that teachers encourage different solutions and approaches to the same problem. However, the statement that in practice creative thinking is required more often than reproduction of the material received somewhat more moderate support: 50.9% of respondents agree with it, while as many as 32.7% are neutral (Figure 2).

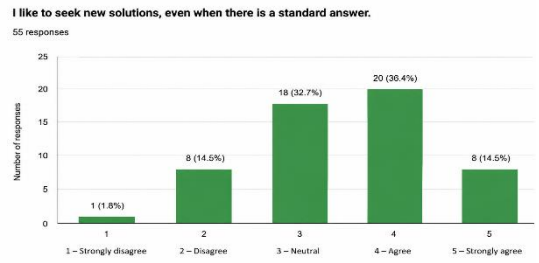


Figure 9. Creative thinking

The issue of workload deserves particular attention. The statement that workload does not reduce the possibility of creative work received the weakest support within this section. While 36.4% of respondents agree with it, 38.2% express disagreement and 25.5% remain neutral (Figure 3). Such a result actually leads to the conclusion that students perceive the number of subjects, deadlines, and other obligations as a significant obstacle to creative work.

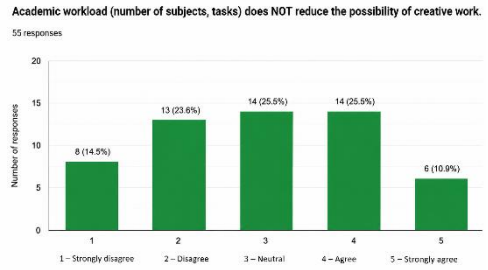


Figure 10. Academic workload

Within the teaching practices that affect creativity, the results likewise show a predominantly positive picture, albeit with some reservation. More than half of the respondents, 56.4%, state that they are given tasks that require solving real problems from practice, and the same percentage believe that they frequently work on project assignments or case studies. Nevertheless, the high percentage of neutral responses to these questions indicates that such teaching methods do exist, but are probably not equally represented across all subjects or all forms of teaching.

More favourable results were obtained for questions relating to student autonomy and the quality of teaching guidance. As many as 69.1% of respondents state that they have the opportunity to choose the topic, format, or method of completing an assignment, while 70.9% believe that they receive clear guidance as well as the freedom to arrive at a solution in their own way. These findings are particularly important, because the combination of structure and autonomy represents one of the key prerequisites for the development of creativity in education. In addition, 67.3% of respondents point out that discussions, debates, or problem-based questions are used in teaching, while 74.5% believe that teachers ask questions that stimulate thinking, such as ‘how else could it be done?’

Results in the area of assessment and feedback are particularly important and generally very positive. As many as 81.8% of respondents believe that the assessment criteria are clear and transparent. This is an important

finding, because clear criteria reduce uncertainty and may contribute to students' greater willingness to engage in more complex and original forms of work. In addition, 63.7% of respondents assess that original ideas and innovative approaches are additionally valued, which shows that students, to some extent, recognise the connection between creativity and the system of evaluation. However, the fact that more than a quarter of respondents remained neutral suggests that such valuing is not always sufficiently visible or equally present in all teaching situations. The most positive results were obtained for questions relating to feedback. As many as 89.1% of respondents believe that feedback helps them improve an idea rather than merely correct mistakes (Figure 4), while 81.8% believe that feedback is specific, that is, that it clearly indicates what is good, what should be improved, and how.

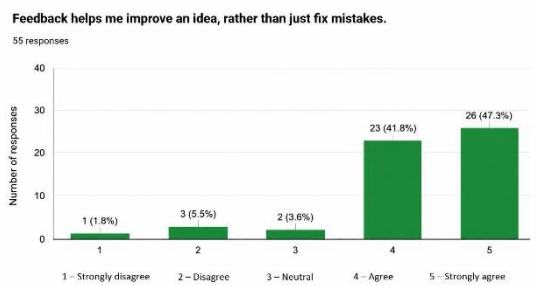


Figure 11. Importance of feedback

On the basis of all the results presented, it may be concluded that Engineering Management students do not perceive creativity in higher education as an entirely neglected dimension of teaching. On the contrary, most respondents recognise that the faculty contains numerous elements that support creativity: encouragement of different solutions, consideration of ideas without their premature rejection, the possibility of expressing an original viewpoint, the use of discussions and problem-based questions, as well as clear and development-oriented feedback. However, the results simultaneously show that there is still room for improvement. Workload stands out in particular as a limiting factor, as does the fact that creative tasks, work on real problems, and project-based teaching are not yet sufficiently dominant for students to conclude without reservation that creative thinking takes precedence over reproduction of the material.

Overall, the results indicate a moderately to strongly positive attitude towards creativity within higher education, but also a need for further strengthening of teaching practices that give students more autonomy, more time to develop ideas, and more opportunities for original contribution. In other words, students recognise a good foundation for the development of creativity, but also clearly indicate that its more systematic development would require additional changes in the organisation of teaching, workload, and the way student work is assessed.

6 Conclusion

Encouraging students' creativity in higher education requires a systemic shift from memorisation and reproduction towards teaching and evaluation practices that develop critical thinking, problem-solving, and original expression. Innovative teaching methods, a supportive academic climate, the thoughtful use of technology, and forms of assessment that value process, argumentation, and the application of knowledge play a key role in this process. Only in such an environment can students develop their creative potential as an important resource for professional development, social engagement, and dealing with the complex challenges of the contemporary world. Further research could be directed towards comparing perceptions of creativity among students from different study programmes, faculties, and levels of study, in order to determine the extent to which discipline and educational context shape opportunities for creative expression. It would also be important to examine the relationship between specific teaching methods, modes of assessment, and the development of students' creative competences through longitudinal research, in order to assess whether changes in teaching practice produce visible effects in the long term.

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Rethinking Student Identity: AI, Multilingualism, and Learning Practices in Kyrgyzstan

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Abstract. This paper examines how artificial intelligence (AI) is reshaping student identity in higher education in Kyrgyzstan within a multilingual environment where Kyrgyz, Russian, and English coexist in everyday academic life. Based on an exploratory qualitative design using semi-structured and in-depth interviews, the study investigates how students use ChatGPT and AI-supported translation tools to explain difficult concepts, draft texts, improve academic writing, organize research tasks, and navigate language barriers. The findings show that AI functions as both cognitive and linguistic support, while also reshaping how students perceive themselves as capable, legitimate, and relatively autonomous learners. Students report greater confidence and flexibility in academic work, but also express concern about dependence, shallow understanding, authorship, and the authenticity of written work. The paper argues that AI contributes to the emergence of hybrid learning identities in which thinking, writing, and problem-solving are increasingly distributed between students and digital tools. The study highlights the importance of multilingual contexts for understanding both the empowering and unequal effects of AI in higher education.

Key words and phrases: artificial intelligence, student identity, multilingualism, higher education, learning practices.

1 Introduction

Artificial intelligence is rapidly becoming part of students' everyday academic life. In higher education in Kyrgyzstan, this development is especially significant because many students move across Kyrgyz, Russian, and English while reading, writing, searching for information, and participating in class. In this multilingual setting, tools such as ChatGPT and machine translation are used not only to save time, but also to explain difficult concepts, generate drafts, translate terms, structure presentations, and provide linguistic support. AI therefore enters academic life not as an occasional experiment, but as part of routine learning practice.

This paper argues that AI should be understood not only as a technical aid, but also as a factor reshaping student identity. In this study, student identity refers to students' evolving sense of themselves as capable, legitimate, and relatively autonomous academic actors. It is related to, but not identical with, self-efficacy. Self-efficacy concerns confidence in one's ability to complete particular tasks, whereas identity concerns how students position themselves as learners, writers, and participants in academic life. When students rely on AI to clarify theory, improve writing, or support research tasks, they do not simply become more efficient. They also renegotiate what counts as their own work, what they can do independently, and what kinds of support feel acceptable in multilingual academic practice.

The Kyrgyzstani case is especially important because multilingualism is not an exception, but a normal condition of study. Students often move between Kyrgyz, Russian, and English within the same learning task: they may encounter terminology in English, discuss ideas in Russian, and seek clearer understanding through Kyrgyz or another familiar register. AI enters this already stratified linguistic environment as a mediating resource. It may help students bridge languages, but it may also reinforce hierarchy between them, especially when English and Russian are better served by digital tools than Kyrgyz. The multilingual dimension of AI use is therefore not simply background context; it is one of the mechanisms through which confidence, dependence, and perceived legitimacy are shaped.

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Against this backdrop, the paper asks three related questions: How do students use AI in their everyday academic practices? How does AI influence their confidence, language use, and perception of themselves as learners? And what tensions emerge around authorship, dependence, and authenticity when academic work is partly distributed between human and machine? By addressing these questions, the study contributes to current debates on AI in education from the perspective of a post-Soviet multilingual higher education context that remains underrepresented in existing scholarship. The argument is exploratory rather than universalizing: the paper does not claim that AI transforms all students in the same way, but that it produces patterned tensions and role shifts that become visible in this multilingual setting.

2 LITERATURE REVIEW

A growing body of scholarship treats AI as a meaningful resource for multilingual education. Donley (2024) shows that teachers use ChatGPT as a linguistically responsive tool to facilitate communication, differentiate content, and support multimodal literacy practices for multilingual learners. Akhter (2025), in a systematic review of intelligent tutoring systems, similarly argues that AI-supported systems are most effective when they combine adaptive learner modeling, linguistically sensitive feedback, multimodal instruction, and culturally responsive design. In both studies, AI is framed as a mechanism that can reduce barriers, increase participation, and broaden access to academic content in multilingual settings.

This supportive view is also visible in research on bilingual curriculum reform. Olagoke and Akande (2025), writing on English and Yoruba instruction in Nigeria, argue that AI-based multilingual education can improve learning outcomes through translation, feedback, and digital language support. Yet their study also shows that gains are unequal because English benefits from more mature tools and larger infrastructures than Yoruba. This point is highly relevant for Kyrgyzstan, where Kyrgyz, Russian, and English do not occupy equal positions in educational institutions, academic publishing, or digital resources. AI may therefore support multilingualism while still reproducing linguistic hierarchy.

Other scholars move beyond the question of access and focus instead on authorship, identity, and confidence. Davoodi (2025) is especially important because AI is analyzed not simply as a compliance issue but as a matter of pedagogical judgment in multilingual classrooms. Through narrative inquiry, Davoodi shows that AI creates tensions around language support, confidence, authorship, and ethical accountability. In one case, AI functions as a form of linguistic scaffolding that allows a multilingual student to express ideas more clearly and to trust her own thinking. In another, a student worries that AI-assisted revision may blur the line between her own work and machine-generated language. This perspective is directly relevant to the present study because it shows that AI changes not only performance but also students' sense of legitimacy and ownership.

A more process-oriented perspective is offered by Slamet et al. (2025), who examine multilingual academic literacy practices through the idea of a broader meaning-making meshwork. Their study of multilingual university writing argues that digital tools should not be understood in isolation. Rather, AI-powered translation, note-taking applications, and screen-based reading practices interact with classroom ecologies, peers, identities, previous schooling, and students' linguistic repertoires. This argument is valuable because it suggests that AI use is not a simple add-on to student work. It becomes woven into how students read, draft, revise, and make sense of academic language. In multilingual higher education in Kyrgyzstan, such a perspective helps explain why AI use is tied to both practical efficiency and deeper shifts in learner identity.

Critical scholarship warns, however, that AI is not neutral. Schneider (2022) argues that commercial language technologies often regiment language by privileging dominant, standardized, and well-resourced forms. In this view, language technologies are shaped by data availability, capitalist interests, and social hierarchies rather than by educational fairness alone. Such systems tend to privilege English and other well-resourced languages, while underrepresenting variation, fluid multilingual practice, and less dominant languages. For the present study, Schneider's argument is important because it helps explain why AI may feel empowering to students while simultaneously carrying unequal ideological effects. In Kyrgyzstan, AI support may enable participation, but it may also silently reinforce the prestige of some languages over others and strengthen narrow ideas of correct academic expression.

Taken together, the literature suggests three key points. First, AI can function as significant multilingual support by helping learners translate, draft, revise, and access academic content. Second, AI also changes how students perceive themselves, especially in relation to confidence, authorship, and legitimacy. Third, these effects are not neutral but shaped by language hierarchy, institutional norms, and uneven digital support across languages. What remains insufficiently explored is how these dynamics unfold in post-Soviet multilingual higher education settings such as Kyrgyzstan. This paper addresses that gap by examining how AI shapes both academic practice and student identity in a context where movement across Kyrgyz, Russian, and English is routine but unequally valued. In doing so, it treats identity not as a fixed psychological trait, but as a changing position that students negotiate through everyday academic practice.

3 Methodology

This study draws on an exploratory qualitative design based on semi-structured and in-depth interviews. The empirical material was collected at two universities in Kyrgyzstan and focuses on students who routinely study across Kyrgyz, Russian, and English. The purpose of the design was to examine not only how students use artificial intelligence in their academic work, but also how they interpret its influence on their confidence, learning practices, and sense of themselves as students. The study does not aim at statistical generalization; rather, it seeks analytical depth in understanding how AI is experienced in a multilingual higher education context.

The qualitative component included 70 semi-structured interviews and 10 in-depth interviews with students from the two Kyrgyzstani universities. The semi-structured interviews were used to identify recurring patterns in students' everyday uses of AI for writing, translation, exam preparation, idea generation, and academic problem-solving. The in-depth interviews made it possible to explore these themes in greater detail, especially students' reflections on dependence, confidence, authenticity, and their changing sense of themselves as learners. Together, these two forms of interview material allowed the study to move beyond general observations and examine how students narrate the role of AI in their academic lives.

The analysis is thematic rather than statistical. It focuses on five interrelated dimensions: AI as everyday academic support, AI in multilingual learning, AI and self-efficacy, AI and authorship, and students' self-positioning in AI-supported academic work. These themes were identified through iterative reading of the interview material and refined in relation to the literature on multilingual meaning-making, identity, and uneven digital support. The role model proposed later in the paper should therefore be read as an analytical heuristic derived from recurring student self-descriptions, rather than as a fixed typology. The findings presented in this conference paper are exploratory and context-bound, but they offer conceptually rich insight into how students articulate AI-related tensions in multilingual higher education.

4 Findings and Discussion

4.1 AI as Everyday Academic Support

The interview data show that AI occupies an important place in students' everyday academic practices, especially as a tool for managing information, preparing written assignments, and making complex material more accessible. Students describe AI as a familiar instrument rather than an unusual innovation. This normalization matters because it suggests that AI is not experienced as an optional add-on but as part of the ordinary infrastructure of studying.

"I use artificial intelligence quite actively in my studies. For me, it is already a familiar tool, especially when working with texts—writing essays, preparing reports, and structuring ideas. I can ask it to explain a complex theory in simple language, help me build the logic of a text, or produce the 'skeleton' of a presentation." (Female, Senior, Social Science Student)

This statement captures several features that recur across the interviews. First, AI is used to reduce cognitive overload by simplifying theory and structuring tasks. Second, it helps students work faster by turning open-ended tasks into manageable steps. Third, it functions as a kind of academic companion that is always available. In this sense, AI contributes to a more responsive and individualized academic workflow. However, the convenience it provides also begins to alter expectations about how academic labor should be done. When students can delegate explanation, structuring, or preliminary drafting to AI, the boundary between support and outsourcing becomes less clear.

4.2 AI, Multilingualism, and Language Self-Efficacy

The interview material showed that students' multilingual academic practices are shaped by unequal access to knowledge across languages. Although most participants study primarily in Kyrgyz and Russian, they noted that many useful academic sources, concepts, and explanations are more readily available in English. In this context, AI served as a mediating tool that enabled students to translate, reformulate, and interpret English-language information into Kyrgyz and Russian. As a result, AI expanded students' access to global academic content and reduced linguistic barriers that might otherwise limit participation in higher education. This finding suggests that in Kyrgyzstani universities, AI is significant not only because it supports learning directly, but also because it allows English-language knowledge to circulate more actively within Kyrgyz- and Russian-medium educational spaces.

The multilingual value of AI extends beyond literal translation. Students described using AI to translate, paraphrase, simplify, and explain terminology across Kyrgyz, Russian, and English. In many cases, AI helped transform dense academic language into more accessible forms that students could understand and later reuse in their own speech or writing. In this sense, AI becomes part of multilingual meaning-making rather than functioning merely as a digital dictionary. The interviews suggest that AI is especially useful when students must move from the formal language of academic texts to more comprehensible explanations and then back again into institutionally acceptable written forms.

One student explained this process in the following way:

"For language learning, I ask it to create a daily study plan and a list of words, sentences, and exercises according to our plan. I actively use it to search for and explain difficult topics and to work with English—for translation and checking formulations."(Female, Senior, Social Science Student)

This quotation shows that AI is not only used reactively, for example to solve immediate language problems, but also proactively, as a tool for organizing learning routines. Students use it to structure repetition, vocabulary building, and daily study plans. Such practices may strengthen language self-efficacy because they give learners a sense that progress is manageable, individualized, and within their control. Bandura (1997) argues that self-efficacy is shaped by a person's belief in their ability to organize and carry out the actions needed to achieve specific goals. In the present study, AI appears to support this belief by helping students feel more prepared to work with unfamiliar terminology, academic texts, and assignments in another language.

At the same time, the multilingual value of AI is uneven. The more smoothly the tool functions in a particular language, the more that language becomes a privileged route into academic participation. This is why multilingual support cannot be separated from questions of language hierarchy. AI may expand access, but it may also reinforce the stronger position of English as a source language of academic knowledge and the uneven technological support available across Kyrgyz, Russian, and English.

Students also reported using AI in research-related work, including conference abstracts, course papers, and statistical interpretation. One participant described how AI helped interpret the Mann–Whitney test in SPSS and explain how to formulate the results in a research report. This example is important because it shows that AI support in multilingual education extends beyond language correction. It also includes procedural and methodological explanation, which may increase confidence and reduce anxiety in technically demanding tasks. AI therefore enters the domain of academic self-efficacy not only through language support, but also through broader access to forms of expert knowledge that might otherwise feel inaccessible.

These examples suggest that multilingual AI use is not confined to sentence-level correction. It also mediates access to academic genres, disciplinary methods, and research procedures. Analytically, this matters because it shows that identity shifts are tied not only to improved writing performance, but also to broader forms of academic participation. Writing course papers, interpreting data, and presenting at conferences become more imaginable for students when AI lowers both linguistic and technical barriers.

4.3 Authorship, Dependence, and Authenticity

The positive role of AI in academic support does not eliminate ambivalence. Many students describe AI as useful precisely because it helps them perform better, write more clearly, and work faster. Yet they also worry that overuse may weaken independent thinking and produce only surface understanding. This concern appears repeatedly in the interviews and marks one of the central tensions of AI-supported learning. Students recognize that AI can improve the outward quality of a text even when their own understanding remains partial.

This ambivalence is especially visible in relation to authorship. When AI helps generate structure, reformulate sentences, or propose arguments, students may feel that the final product is partly theirs and partly not.

Importantly, this does not mean that students experience themselves as passive. Most participants emphasize the need to verify, adapt, and rewrite AI-generated material. Even so, the presence of AI complicates the notion of a singular author. Academic work becomes collaborative in a new way, but the collaborator is nonhuman, invisible, and not easily acknowledged within traditional academic norms.

The authenticity issue is therefore not only ethical but identity-related. Students want to benefit from AI support without feeling that they have lost ownership of their work. This is why many of them stress post-editing, personal adaptation, and preservation of an individual style. Such comments suggest that students are actively trying to maintain a boundary between assistance and replacement. However, the very need to draw that boundary confirms that AI has already altered the conditions under which authorship is understood.

The risk of dependence is also discussed in practical terms. Students note that AI can save time and lower cognitive load, but it can also make it easier to avoid slow and demanding intellectual work. This is particularly relevant for early-stage academic development, where struggling with theory, terminology, and argument structure is often part of learning itself. AI may reduce frustration, but it may also reduce the productive friction through which deeper understanding develops. The challenge for higher education is therefore not simply whether students use AI, but how they use it and what kinds of learning dispositions this use encourages.

4.4 A Model of Student Roles in AI-Supported Learning

Analysis of students' self-perception suggests that they do not experience AI through one fixed identity. Instead, they position themselves along a continuum of roles that emerged inductively from recurring interview patterns. The first and most common role is that of the user. Here, AI is treated as a technical instrument for searching, translating, checking, and accelerating routine tasks. The second role is that of the editor. In this role, students actively adapt, reformulate, and verify AI-generated material in order to fit specific academic purposes. The third and most autonomous role is the author with AI support. Here, students describe themselves as producing the core ideas and arguments while using AI mainly to clarify wording, structure, or presentation.

Table 1. Model of student roles in AI-supported academic work.

Role	Main Characteristics	Level of Autonomy
User	Uses AI as a technical aid for searching, translating, checking, and accelerating routine tasks.	Moderate
Editor	Revises, adapts, checks, and reformulates AI-generated material for a specific academic purpose.	Medium-High
Author with AI support	Develops core ideas independently and uses AI mainly for clarification, structure, or refinement.	High

The roles in Table 1 should not be understood as rigid or mutually exclusive categories. Students may shift between them depending on task difficulty, language demands, confidence level, deadline pressure, and prior familiarity with the topic. What matters analytically is that AI encourages new forms of self-description. Students are no longer simply writers or learners in the traditional sense; they become coordinators of human and machine resources. This role flexibility is one of the clearest signs that student identity is being reconfigured, even if that reconfiguration is uneven and situational rather than total.

The model also helps explain why AI use cannot be reduced to either empowerment or dependence. The same student may act as an autonomous author in one context and as a pragmatic user in another. For example, students often report higher autonomy in tasks where they already understand the topic but need help refining language. They report lower autonomy when encountering unfamiliar theory, technical language, or methodological procedures. AI therefore does not erase agency but redistributes it unevenly across tasks. This is also where the multilingual dimension matters most: students may appear more autonomous in one language and more dependent in another, depending on which language carries the burden of terminology, academic convention, or assessment.

This finding supports the paper's main argument that student identity under AI conditions is hybrid rather than simply weakened. Hybrid identity here means that academic work is increasingly produced through collaboration between student cognition and AI support, but the balance between the two changes from moment to moment. The important question is not whether students remain fully autonomous in a traditional sense, but how autonomy is redefined when digital support becomes a routine part of multilingual study.

4.5 Implications for Higher Education in Kyrgyzstan

The findings have several implications for higher education policy and pedagogy in Kyrgyzstan. First, AI should be recognized as part of the actual learning environment rather than treated only as an external threat. Since the overwhelming majority of participants already use AI, universities need guidance that acknowledges real practice and helps students use these tools critically and transparently. Blanket prohibition is unlikely to reflect academic reality.

Second, multilingual pedagogy needs to be addressed explicitly. Students do not use AI in a linguistically neutral environment; they use it while navigating unequal academic roles for Kyrgyz, Russian, and English. Universities should therefore encourage reflective discussion about when AI is being used for comprehension, for translation, for genre adaptation, and for substantive idea development. Such distinctions would help educators respond more precisely to both support and dependence.

Third, pedagogy should focus on critical AI literacy. Students need support in verifying outputs, identifying inaccurate information, preserving their own voice, and understanding where AI assistance ends and their own academic responsibility begins. This is especially important in research writing, data interpretation, and translation-based work, where polished language can easily conceal weak understanding. Developing these capacities would allow universities to move from reactive control toward reflective pedagogy.

Finally, the findings suggest that universities should reconsider authorship as a pedagogical issue rather than only a disciplinary one. If students increasingly work as users, editors, and authors with AI support, educators need language for discussing these distinctions openly. Such discussion may help students preserve agency while using AI productively and may reduce the anxiety that surrounds authenticity in digitally mediated academic work. At the same time, institutions should avoid overstating what this exploratory study proves: the present findings indicate emerging patterns, not a finished account of all student-AI relations in Kyrgyzstan.

5 Conclusion

This paper argues that AI is reshaping student identity in higher education in Kyrgyzstan by becoming part of everyday multilingual learning practice. Students use AI to explain difficult theories, structure writing, translate across languages, prepare presentations, interpret research procedures, and manage academic time more efficiently. These practices show that AI functions as both cognitive and linguistic support in a context where multilingual academic work is normal and often demanding.

At the same time, AI does more than support performance. It also influences how students understand themselves as learners, writers, and academic participants. Students report increased confidence, stronger language self-efficacy, and a greater sense that difficult tasks can be made manageable. Yet they also describe tensions around dependence, reduced depth of understanding, and uncertainty about authorship and authenticity. The educational significance of AI, therefore lies not only in what it helps students do, but also in how it reshapes what they believe they can do independently. This paper does not argue that AI should replace self-study or that it is better than independent learning. Rather, it shows that AI has become part of students' actual study practices and that this shift has both empowering and problematic effects. The goal is to analyze that tension, not to celebrate dependence on AI.

A central analytical contribution of the paper is the argument that AI contributes to hybrid student identities. In AI-supported academic work, students position themselves as users, editors, and authors with AI support rather than occupying one stable learner identity. This role flexibility reflects a broader transformation of academic practice in which thinking, writing, and problem-solving are increasingly distributed between human and machine. In the multilingual context of Kyrgyzstan, this distribution is shaped both by practical need and by language hierarchy. The paper does not suggest that identity is replaced by technology; rather, it shows that identity is negotiated differently when AI becomes part of routine academic mediation.

Future research could build on this study by examining disciplinary differences, language-specific uses of AI, and institutional responses across universities in Kyrgyzstan. There is also a need for more detailed analysis of how AI affects writing development over time and whether students move toward greater autonomy or stronger dependence as AI use becomes more normalized. The findings presented here are exploratory, but analytically important. They suggest that understanding AI in higher education requires attention not only to

efficiency and learning outcomes, but also to identity, multilingualism, and the unequal infrastructures through which academic life is increasingly organized.

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Explainable Intelligent Agents for Teacher Decision Support in AI-Enhanced Learning Environments

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Abstract. Artificial intelligence is increasingly present in education, but its practical value depends not only on analytical capability, but also on whether teachers can understand and meaningfully use AI-generated recommendations. In many educational settings, this remains a challenge because system outputs are often presented without sufficient explanation. This paper proposes a conceptual model of explainable intelligent agents for teacher decision support in AI-enhanced learning environments. The model includes three functional components: a Student Monitoring Agent, which observes learning-related indicators; a Recommendation Agent, which generates instructional suggestions; and an Explanation Agent, which clarifies the reasoning behind those suggestions. The paper argues that intelligent agents are more pedagogically useful when they are designed not as autonomous decision-makers, but as support mechanisms that preserve teacher oversight and professional judgment. To illustrate the relevance of the model, the paper presents a scenario from computer science teaching in which agent-based support helps identify student difficulties and makes AI-generated recommendations easier to interpret. The proposed approach highlights explainability as a key condition for the responsible and educationally meaningful use of intelligent agents in teaching.

Keywords: intelligent agents, explainable AI, teacher decision support, AI in education, educational systems, personalized learning

1 INTRODUCTION

Artificial intelligence is now firmly present in education, but its role is no longer limited to automation or content generation. In many learning environments, AI is increasingly used to identify patterns in student behavior, support adaptation, and assist educational decision-making. Even so, the literature still points out that much of the field has developed from a technical rather than a pedagogical perspective, which leaves open the question of how educators can make meaningful use of AI outputs in everyday teaching practice (Zawacki-Richter et al., 2019).

This gap becomes especially visible when teachers are presented with recommendations that may look useful but are not easy to interpret. In educational settings, a recommendation has value only if it can be understood in relation to student needs, learning goals, and classroom context. That is why recent work on explainable AI in education argues that transparency is not simply a desirable add-on, but a condition for designing AI tools that teachers and learners can realistically use and trust (Khosravi et al., 2022).

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From that perspective, intelligent agents deserve attention not only as autonomous computational components, but also as mediating structures between data and pedagogy. A more useful way to think about them in education is as systems that collect signals, generate possible actions, and help teachers understand why those actions are being suggested. This paper therefore proposes a conceptual model of explainable intelligent agents whose main purpose is to support teacher judgment rather than replace it (Farrow, 2023).

2 Intelligent Agents in AI-Based Education

In the broader AIED literature, intelligent agents are usually associated with adaptive support, tutoring, monitoring, feedback, and recommendation. Their appeal lies in the fact that they can process multiple forms of learner data and respond in ways that are more dynamic than traditional rule-based educational software. More recent reviews also show that AI-supported tutoring and adaptive systems have become one of the most visible application areas in educational research, especially where personalization and timely support are central goals (Létourneau et al., 2025).

Still, the usefulness of such systems depends on more than analytical performance. Teachers are much more likely to engage with AI tools when they understand their logic, perceive their benefits, and do not experience them as opaque or risky. Large international evidence now suggests that teacher trust in AI in education is shaped less by demographics and more by factors such as AI understanding, perceived benefits, concerns, and self-efficacy, which makes interpretability a practical issue rather than only a theoretical one (Viberg et al., 2025).

This is exactly where explainability becomes important. Research in XAI for education increasingly argues that explanations should be meaningful to the people who use the system, not only technically accurate from the perspective of the model designer. In other words, an explanation is educationally useful only when it can be connected to the language, concepts, and decisions that matter in actual teaching practice (Khosravi et al., 2022).

3 Proposed Conceptual Model of Explainable Agent Support

The model proposed here is intentionally simple. It is built around three functional components: a Student Monitoring Agent, a Recommendation Agent, and an Explanation Agent. The first component gathers indicators that may matter for teaching, such as repeated errors, time on task, completion patterns, and recent performance trends. The second transforms those indicators into a possible instructional suggestion. The third provides an explanation that connects the suggestion to the observed evidence in a form that a teacher can interpret (Khosravi et al., 2022).

The central assumption behind this structure is that AI support becomes educationally meaningful only when the recommendation and the explanation remain tied together. A system that merely flags a student as “at risk” or in need of “additional support” does not help very much if the teacher cannot see what pattern triggered that judgment. Work in XAI and educational explainability has repeatedly emphasized that explanation must be audience-sensitive, context-dependent, and understandable to non-technical stakeholders, especially in settings where decisions affect learning pathways and student opportunities (Farrow, 2023).

An important practical advantage of the proposed architecture is that it separates observation, suggestion, and explanation into distinct but connected functions. This makes the model easier to interpret from a pedagogical perspective, since the teacher is not confronted with a single opaque output, but with a sequence that can be followed and evaluated. First, learning-related signals are

identified and organized. Next, those signals are translated into a possible instructional action. Finally, the system provides an explanation that links the recommendation to observable student patterns. Such separation is useful because it supports transparency at the level of process, not only at the level of final output. In educational settings, this can make AI-supported recommendations more understandable, easier to question, and more suitable for real classroom use (Khosravi et al., 2022).

In this model, the teacher remains the final decision-maker. That point is important because current research on human-in-the-loop AI in education shows that meaningful educational use depends on how human roles are positioned in relation to the system. Rather than treating the teacher as a passive recipient of system output, the model assumes an active role in which recommendations are reviewed, interpreted, adjusted, or rejected in light of broader pedagogical knowledge (Memarian & Doleck, 2024).

4 Application Scenario in Computer Science Teaching

A practical example can be drawn from computer science teaching, where student performance often hides different kinds of difficulty behind similar scores. One student may solve programming tasks correctly, but only after many failed attempts and long delays; another may complete tasks quickly but show recurring misunderstandings in conditionals, loops, or decomposition. Research on intelligent tutoring systems for programming has long shown that this domain is especially suitable for adaptive and feedback-oriented AI support because learning difficulties tend to appear in recognizable patterns across tasks (Crow et al., 2018).

In such a scenario, the Student Monitoring Agent could register indicators such as repeated syntax or logic errors, unusually long task completion time, and instability across related programming exercises. The Recommendation Agent could then suggest targeted additional practice, simpler preparatory tasks, or focused revision of a specific concept. The role of the Explanation Agent would be to clarify why that recommendation was generated, for example by linking it to repeated mistakes in conditional logic and slower-than-expected progress across recent tasks. This kind of design is consistent with current evidence that AI-driven tutoring systems are most useful when they support personalized intervention without obscuring the reasoning behind the support itself (Létourneau et al., 2025).

5 Discussion

The main strength of this model is not technical complexity, but pedagogical positioning. It keeps the teacher at the center while giving structure to AI-generated support. That matters because recent studies on teacher-facing AI systems show that trust and acceptance improve when the system's recommendations are understandable, especially when explanations are expressed in domain-relevant language rather than abstract model terms. In other words, teachers are more likely to use AI support when it speaks to their professional reasoning instead of only displaying data features (Feldman-Maggor et al., 2025).

Another point worth emphasizing is the practical role of explainable agents in reducing the interpretive burden on teachers. In many digital learning environments, large amounts of student-related data are available, but not all of them are equally useful for instructional decision-making. A system that only presents indicators may still leave the teacher with the difficult task of deciding which patterns matter and why. By contrast, an explainable agent-based model can organize those signals into a more coherent form of support. At the same time, such support should remain advisory rather than authoritative. The educational value of the system depends on whether it strengthens

teacher judgment without narrowing it to predefined machine-generated categories (Memarian & Doleck, 2024).

At the same time, explainability alone does not solve every problem. A transparent recommendation can still be based on weak signals, biased data, or incomplete representations of student learning. This is why responsible AI in education is increasingly discussed as a broader socio-technical issue involving transparency, agency, privacy, fairness, and stakeholder acceptability. Recent multi-stakeholder evidence also shows that acceptance of AI in education changes depending on how much agency, explainability, and perceived risk are built into the use case itself (Karran et al., 2025).

There is also the broader issue of autonomy. In educational practice, teaching decisions are rarely based on measurable indicators alone. Teachers work with context, prior knowledge of students, classroom dynamics, and forms of professional judgment that are difficult to formalize in a digital system. For that reason, intelligent agents should be treated as support tools rather than independent pedagogical authorities. A human-in-the-loop approach remains necessary, especially when recommendations may affect student progression, confidence, or access to support (Memarian & Doleck, 2024).

6 Conclusion

The implications of this are straightforward. If intelligent agents are to support teachers in meaningful ways, they cannot function merely as hidden decision engines. They need to make their suggestions legible, contestable, and educationally relevant. A model that combines monitoring, recommendation, and explanation offers a more realistic foundation for classroom use because it treats AI support as something that informs professional judgment rather than bypasses it (Memarian & Doleck, 2024).

For a short conference paper, the value of this proposal lies in its conceptual clarity. It does not claim to solve the full complexity of AI in education, but it does offer a focused argument: explainable intelligent agents are more likely to be pedagogically useful when they are designed around teacher interpretation, human oversight, and context-sensitive support. That position is also in line with the strongest recent literature in the field, which increasingly treats trust, explainability, and responsible deployment as core design requirements rather than secondary concerns (Viberg et al., 2025).

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How Should English Be Taught as a General Education Course at Japanese Universities?

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Abstract. This study evaluates highly effective pedagogical strategies for teaching English as a General Education (GE) subject in Japanese higher education, specifically in accordance with current MEXT policy frameworks. This article proposes a learner-centered curriculum that incorporates the four fundamental language skills alongside academic literacy and active learning strategies, transcending conventional grammar-translation approaches. The paper proposes evidence-based methods to facilitate the transition from secondary to tertiary education by synthesizing contemporary pedagogical concepts, such as formative assessment and structured classroom routines, with insights from international teaching contexts. Some of the main strategies discussed regarding Content and Language Integrated Learning (CLIL), using global themes to encourage cross-cultural engagement, and using Information and Communication Technology (ICT) in hybrid environments in a planned way. The study ultimately concludes that university-level English instruction must transform into an environment that cultivates critical thinking, cross-cultural awareness, and communicative competencies vital for a globally interconnected society.

Key words and phrases: English as a Foreign Language (EFL), Japanese Higher Education, Active Learning, Content and Language Integrated Learning (CLIL), Communicative Competence, Academic Literacy, Intercultural Awareness, ICT Integration

1 "How Should English Be Taught as a General Education Course at Japanese Universities?"

English is now central to global communication. Particularly for university students, developing individualized English proficiency broadens global perspectives and boosts competitiveness in a world growing more interconnected by the day. English is essential across many fields due to ongoing shifts in industry and rapid advances in information technology.

According to MEXT, there is a strong emphasis on developing useful communication skills: To develop communication skills that apply perspectives and ways of thinking in foreign language communication, and enable students to accurately understand, appropriately express, and effectively convey information and ideas through language activities such as listening, reading, speaking, and writing, as well as integrated activities that combine these (MEXT, 2019, p. 12).

As mentioned, through the High School Course of Study, the University Establishment

Standards, reports on higher education reform, and suggestions from the Central Council for Education, MEXT has outlined a clear vision for English education. The three main goals of these policies are academic literacy, practical communicative competence, and curriculum continuity with secondary education reforms.
In Japanese higher education, English serves a key general education subject. While universities are still free to design their own curricula, general education English courses should help students learn how to work together and coexist in multicultural and multilingual environments.

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Before students move on to specialized fields, they should also lay the groundwork for intercultural understanding and English communication. Courses should accommodate beginner, intermediate, and advanced proficiency levels to ensure gradual progression.

This essay argues for how English should be taught as a general education course at Japanese universities, drawing on policy directions, contemporary pedagogy, and my teaching experience and philosophy.

2 Building Integrated Four-Skill Proficiency

University English courses should foster practical language use, aligning with MEXT's ongoing emphasis (MEXT, 2018). The University Establishment Standards, which indicate a move away from grammar-translation or reading-centered instruction. They instruct educational institutions offer learning opportunities that enhance students' communication skills in foreign languages.

For instance, in a unit on migration, American University of Central Asia (AUCA) students read a brief article, used sentence frames to facilitate structured small-group discussions, wrote a reflective paragraph, and then gave a brief summary presentation. This sequence reflected the integrated proficiency that MEXT envisions and reinforced usable English. This method is consistent with my teaching philosophy, which holds that students learn best when assignments build upon one another, relate to real-world problems, and enable scaffolded output. Using Teach Like a Champion 3.0 (Lemov, 2022) classroom strategies like Right Is Right, Format Matters, and Affirmative Checking, along with formative assessment principles from Black and Wiliam (1998), I place a strong emphasis on precise success criteria and regular comprehension checks. These practices make ensure that every student stays involved and accountable.

My experience at AUCA shows that when assignments integrate all four skills in meaningful ways, students flourish.

3 Developing Foundational Literacy and Academic English

University English courses must offer foundational literacy for academic study across disciplines, according to MEXT policy documents (Central Council for Education, 2012). Therefore, structured academic communication should be included in general education English in addition to conversational skills and exam preparation.

Students benefit from explicit instruction in academic conventions, as my experience teaching academically diverse groups—both at AUCA and during workshops involving students from four universities in Kyrgyzstan, as well as participants from Uzbekistan, France, Japan, Tajikistan, and the United States—has shown. In addition to improving English proficiency, tasks like summarizing lectures, deciphering charts, creating slide shows, and taking part in debates also improve logical reasoning and clarity of expression.
Important elements of this strategy consist of:

Using English as the main language of instruction to normalize English-medium communication is one of the key elements.

Promoting the expression of evidence through discussions and project-based learning. • Adopting the following expanded competencies: writing, speaking-interaction, speaking-presentation, listening, and reading.

Raising the required vocabulary to between 2,500 and 3,000 words.
Interacting with scholarly and educational texts, including conversations about social issues.

My teaching philosophy, which emphasizes academic rigor combined with emotional consistency and encouragement—a balance frequently encapsulated in the Warm/Strict approach (Lemov, 2022) is consistent

with these pedagogical approaches. Students' confidence and academic endurance are increased when they receive support while maintaining high standards.

4 How to Close the Gap Between High School and College with Active Learning

The new high school Course of Study that went into effect in 2022 has made secondary English education focus more on teaching "primarily in English," doing communicative tasks, and writing. Still, many students who attend college lack insight into how to do extended speaking, academic writing, or group work. From my MAT coursework and thoughts on formative assessment, I know how important it is to be aware of what students already know and to help them move on to more advanced academic English. No Opt Out (Lemov, 2022) and other strategies make sure that every student takes part in a meaningful way while also psychologically safe.

To close the gap between secondary school and higher education, university English classes should incorporate CLIL-based activities and active learning.

I incorporated simple English texts about sustainability and cultural exchange to teach both language and content in my global citizenship workshop. Students commented that learning through English, not just about English, made the subject more interesting and got them more involved. Active learning works really well because English communication naturally involves talking to each other and figuring out what each other is saying. I led international group discussions, problem-solving tasks, peer review, and structured debates among Kyrgyz,

Japanese, French, American university students. I saw that even students with lower levels of English were willing to take risks when the activities were clearly structured and supported by modeling.

Common active-learning activities that help students learn a language are:

- Talks in pairs and groups
- Tasks that involve solving problems or filling in gaps in information
- Learning by doing projects
- Feedback from peers and writing together
- Debates that are organized

These methods align with Black & Wiliam’s (1998) claim that students learn best with immediate, actionable feedback and opportunities to practice new skills.
This principle fits with my philosophy for the classroom: every activity should allow for ongoing interaction, feedback, and revision.

5 Placing English in the context of global mobility and learning about other cultures

English is an essential tool for academic success and intercultural engagement as Japanese universities pursue greater internationalization. My instruction emphasizes communitybased learning, cultural identity, and global citizenship, which enhance students’ preparedness for study abroad and participation in international academic settings.
I have taught students from many countries in my classes, such as France, the US, Japan, Korea,
Canada, Tajikistan, and Uzbekistan. Some of the most important strategies are:

- Exploring global themes such as sustainability, global education, cross-cultural communication, identity, and diversity. Students apply their prior study abroad experiences and their understanding of emotional intelligence and empathy to practical tasks, making their learning both meaningful and actionable.
- Engaging in reflective writing on cultural perspectives, which allows students to deepen their understanding of personal and cultural identity while practicing English. These exercises develop students' intercultural competency, widen their perspectives, and emphasize English as a bridge for significant global engagement.

6 UTILIZING HYBRID LEARNING ENVIRONMENTS AND ICT

Technology has emerged as a crucial part of contemporary English education due to the rapid development of ICT and hybrid learning after COVID-19. In order to maximize in-person time for discussion and project work, I have used hybrid models in my teaching, where students watch material or complete peer review.

Additionally, digital tools facilitate:

- Instantaneous formative feedback on writing;
- Vocabulary development via apps; and
- Multimodal assignments like video presentations.

These methods support my view that technology should complement human interaction rather than replace it, freeing up class time for more complex assignments that foster critical thinking and effective communication.

In conclusion, teaching English as a general education subject at Japanese universities necessitates respect for learner diversity, pedagogical innovation, and alignment with national policy. MEXT emphasizes student-centered learning support, ICT integration, academic literacy, active learning, internationalization, and practical communicative competence.

These national objectives are in line with my teaching philosophy, which is based on formative assessment, intercultural learning, and academically demanding but encouraging instruction.
University English can enable students to use language as a tool for inquiry, communication, and engagement in an international context through integrated four-skills instruction, structured academic English tasks, CLIL-based bridging activities, active learning, ICT utilization, and individualized support.

In the final analysis, general English classes ought to function as a transformative environment where students acquire the critical thinking, intercultural awareness, and communicative skills required for academic and professional engagement in a world growing more interconnected by the day.

7 CONCLUSION

It is very important for Japanese colleges and universities to make English a general education requirement so that students can move around the world. To achieve MEXT's goals, teachers should stop using passive, reading-heavy lessons and start using new teaching methods that help students learn how to communicate effectively. This paper demonstrates that students do better when utilizing English as a tool for learning and solving problems. This requires a balanced integration of the four language skills, the development of academic literacy, and the implementation of active CLIL methodologies.

Furthermore, incorporating hybrid learning and ICT tools optimizes classroom time for meaningful discussions, peer collaboration, and intercultural exchange. By maintaining continuous formative assessment and an instructional approach that balances academic rigor with emotional support, the divide between high school and university can be successfully bridged. Ultimately, general English courses must extend beyond basic language acquisition, functioning as catalysts that develop the collaborative skills, cultural empathy, and critical thinking necessary for success in the modern academic and professional world.

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Artificial Intelligence in Education: Applications, Challenges, and Future Directions

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Abstract - The emergence of artificial intelligence has brought significant changes, particularly in the IT sector, to which the labor market has also responded rapidly. The education system is closely linked to the labor market; however, it tends to change much more slowly than the IT sector and the evolving expectations of the labor market. In this study, the authors aim to identify current applications of artificial intelligence, examine the emerging institutional, technical, moral, and ethical challenges, and outline possible future directions based on the relationship between these three domains: the IT sector, the labor market, and the education system.

Keywords: artificial intelligence, education, future directions

1 Introduction

Pupils must be provided with knowledge and competences applicable in daily life, so that they can meet the expectations of society once they leave school. Thus, it is essential that they become adaptive, collaborative, creative, and problem-solving persons (Kovács et al., 2022).

The superior international achievements of Science, technology, engineering, mathematics STEM-focused nations reflect the mathematical literacy assessed in PISA 2012, with the focus on “meeting life needs ... through using and engaging with mathematics, making informed judgements, and understanding the usefulness of mathematics in relation to the demands of life” (Thompson et al., p. 11).

Science, technology, engineering, and mathematics (STEM) education is receiving increasing attention, and robotics education is becoming popular worldwide. STEM education can inspire children’s natural enthusiasm for exploring the unknown and give them opportunities to put their knowledge into practice (Schreiner et al., 2005). Robots are considered an essential element of STEM education because they can convey complex mathematical and scientific thinking (Kopcha et al., 2017).

In addition to computers and mobile phones, other smart devices are also emerging that influence our lives. It is important to take advantage of these new technologies, because only in this way can we fully benefit from the opportunities offered by the new information society. The information society affects every aspect of our lives. This transformation does not concern only the economy; rather, the entire social system is being reshaped according to the logic of the information society. We ourselves are an integral part of this process. (Avornicului, Seer, & Benedek, 2016, p. 70)

Technologies associated with the information society, together with the competencies required to access, acquire, evaluate, process, store, utilize, and reinterpret information, have become increasingly important. These developments shape not only the direction of technological innovation and the evolving demands of the labor market but also generate significant expectations for educational systems.

Recognizing these challenges, the European Parliament and the Council of the European Union adopted a Recommendation on Key Competences for Lifelong Learning. The development of the European Reference Framework was motivated by the recognition that globalization continuously presents the European Union

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with new challenges, requiring all citizens to develop a broad range of key competences in order to adapt flexibly to a rapidly changing and increasingly interconnected world. Among these competences, digital competence occupies a central role. The framework identifies eight key competences for lifelong learning: (1) communication in the mother tongue; (2) communication in foreign languages; (3) mathematical competence and basic competences in science and technology; (4) digital competence; (5) learning to learn; (6) social and civic competences; (7) sense of initiative and entrepreneurship; and (8) cultural awareness and expression (European Parliament & Council of the European Union, 2016).
According to the Recommendation, digital competence involves the confident, critical, and responsible use of information society technologies (IST) for work, leisure, learning, and communication. It is founded on essential information and communication technology (ICT) skills, including the use of computers to retrieve, evaluate, store, produce, present, and exchange information, as well as to communicate, collaborate, and participate in online networks via the Internet (European Parliament & Council of the European Union, 2016).
Technological advancement has continuously expanded the possibilities offered by the Internet. While Web 1.0, which emerged at the end of the twentieth century, primarily enabled passive browsing of content in the form of text, images, audio, and video, the advent of Web 2.0 in the new millennium shifted the focus toward user interaction with digital content and the collaborative creation of content accessible to everyone. The widespread adoption of Web 2.0 was characterized by content-sharing platforms, blogs and microblogs, online forums, and the rapid growth of social networking services. Web 3.0 represents the next stage in this evolution. Its defining characteristic is the establishment of semantic relationships among different sources of information through algorithms. These relationships are typically based on users' digital footprints, including their browsing histories, together with sponsored or personalized content that is likely to match their interests. As a result, Web 3.0 systems are capable of making context-aware decisions, efficiently utilizing existing databases, and retaining information from previous interactions with individual users. These technological capabilities are primarily employed to enhance the user experience; however, they also play a significant role in online marketing by enabling targeted advertising, promoting products and services, expanding online communities, and increasing user engagement. The practical realization of many of these capabilities became tangible with the emergence of artificial intelligence applications, particularly in the form of conversational agents, or chatbots. (Tóth, Námesztovszki, Horváth Futó, 2024).

2 Artificial Intelligence

Artificial intelligence (AI) has been defined and interpreted in various ways. The term was first introduced by John McCarthy in 1956 (Russell & Norvig, 2010). From an educational perspective, the definition proposed by Baker, Smith, and Anissa is perhaps the most appropriate. Rather than referring to a specific technology, they define AI as computers capable of performing cognitive tasks such as learning and problem-solving (Baker, Smith, & Anissa, 2019).
The European Commission has also paid particular attention to the opportunities offered by artificial intelligence by establishing the High-Level Expert Group on Artificial Intelligence. In addition to addressing legal and ethical issues, the group formulated a comprehensive definition of AI:
“Artificial intelligence (AI) systems are software (and possibly also hardware) systems designed by humans that, given a complex goal, act in the physical or digital dimension by perceiving their environment through data acquisition, interpreting the collected structured or unstructured data, reasoning on the knowledge, or processing the information derived from this data, and deciding the best action(s) to take to achieve the given goal. AI systems can adapt their behaviour by analysing how the environment is affected by their previous actions.” (Independent High-Level Expert Group on Artificial Intelligence, 2019).
ChatGPT is an AI-based application, commonly referred to as a chatbot, that enables interactive communication with users through text-based conversations and also supports text-to-speech online communication. The platform was developed by OpenAI, an artificial intelligence research laboratory founded in the United States. One of OpenAI’s closest partners is Microsoft, which provides the cloud infrastructure supporting the service. In addition, Microsoft has invested substantial financial resources in the development of ChatGPT, making it possible for the service to operate on one of the world's most powerful supercomputing infrastructures. Modern AI chatbots are also capable of generating images based on user-provided prompts, including specifications related to content, style, and artistic technique. These image-generation platforms have become extremely popular because the images they produce can generally be used without copyright concerns,

while simultaneously meeting the growing demand for original visual content driven by social media platforms and the culture of active content creation.

These global trends should also be examined from the perspective of the diffusion speed of technological innovations. Diffusion speed refers to the time required for a technology to spread to approximately 80% of the world's countries. Research indicates a clear acceleration in this process. Railways, for example, required approximately 125 years to achieve global diffusion, while the telephone spread within 100 years and radio within 75 years. Personal computers became widespread in only 25 years, and mobile phones reached global adoption in approximately 20 years (Rab, 2016). This trend demonstrates that acceleration is not limited to major technological revolutions but can also be observed within individual technologies, such as online platforms and AI services like ChatGPT. Following its launch on 30 November 2022, ChatGPT reached one million users within just five days and had approximately 180 million users by the beginning of 2024 (Duarte, 2024). This represented the fastest user growth ever recorded. According to data compiled by Exploding Topics, while ChatGPT required only five days to reach one million users, Instagram needed two and a half months, Facebook ten months, and Twitter two years to achieve the same milestone. These figures clearly demonstrate both the platform's remarkable popularity and the unprecedented level of public interest. However, the pace of adoption continues to accelerate, as the social media platform Threads reached one million users in just one hour (Duarte, 2024).

3 Artificial Intelligence in Education

Artificial intelligence (AI)-based solutions, particularly large language models (LLMs), offer numerous new opportunities for both teachers and students, often opening entirely new perspectives for educational stakeholders. Alongside these benefits, however, AI may also amplify existing problems while introducing previously unknown risks.

A fundamental issue associated with the use of AI—although it is often overlooked—is that primary digital inequalities (DiMaggio & Hargittai, 2001) continue to exist among members of society. People living in developed countries often take the availability of digital technologies for granted, yet even there not everyone has access to essential digital resources. In many other parts of the world, disparities in access to devices, internet connectivity, and technical support create even greater inequalities (Chanda et al., 2025). These differences frequently result in substantial, sometimes insurmountable, disparities in access to learning opportunities. Moreover, a considerable gap exists between those who can afford premium AI services and those who lack the financial resources to access them. Consequently, the rapid diffusion of AI-based technologies may not only preserve but also exacerbate existing digital inequalities (Bulathwela et al., 2024).

One of the greatest advantages of AI-based educational systems is their ability to personalize learning much more accurately than previous technologies by adapting instructional content and learning tasks to students' prior knowledge, learning pace, and patterns of errors. These systems enable continuous monitoring of learners' progress, making it possible to identify precisely where students require additional support and where they perform most successfully. AI makes highly personalized learning support possible, which is particularly beneficial for students with special educational needs (Binhammad et al., 2024). However, implementing such personalized solutions requires the collection and processing of vast amounts of learner data, including information that may be personally identifiable. Such data include learning style characteristics, approaches used to solve tasks, points at which learners encounter difficulties and the reasons for these difficulties, the timing and duration of learning activities, levels of attention and concentration and their fluctuations, and even aspects of learners' living conditions. AI systems therefore process substantial volumes of personal information. Consequently, ethical issues constitute one of the most significant challenges associated with AI in education, while concerns regarding data protection, privacy, and information security arise throughout the processes of data collection, storage, access, and use (Ismail, 2025).

Another fundamental concern is that AI algorithms inevitably reflect the values, assumptions, and priorities of their designers (Holmes et al., 2022), making the possibility of bias inherent from the outset. Furthermore, the datasets used to train AI systems may unintentionally contain patterns that reflect historical or societal prejudices. In addition, if the complex datasets required for AI applications are constructed inaccurately—for example, through the inclusion of erroneous, incomplete, or inappropriate data—measurement bias and representation bias may emerge within the system (Baker & Hawn, 2022). Whenever such biases occur, AI can no longer be regarded as making objective, value-neutral decisions or recommendations. Instead, biased

algorithms may create systemic barriers and significantly influence students' educational trajectories (Boateng & Boateng, 2025).

Students themselves may also hinder their own learning processes and cognitive development by delegating academic tasks to AI systems. While time- and effort-saving solutions are naturally attractive, the uncontrolled use of such conveniences reduces opportunities to practice independent thinking. A similar danger exists for teachers, who may become overly reliant on AI by delegating lesson planning, the selection of teaching methods and instructional strategies, the creation of learning materials and assessment tasks, or even the evaluation of students' work. If this occurs, their professional competencies and pedagogical skills will inevitably deteriorate over time (Szőke-Milinte, 2025). For this reason, perhaps the greatest educational challenge posed by AI is its potential to generate metacognitive laziness among both students and teachers (Fan et al., 2025). Paradoxically, economic inequalities may produce the opposite effect in this respect. Individuals who can afford premium AI services are able to outsource a larger proportion of their cognitive tasks, thereby reducing the need to develop their own knowledge and abilities. In contrast, those without access to advanced AI services must rely more heavily on their own reasoning and problem-solving skills, which ultimately contributes to the development of their knowledge and competencies (Szűts & Námesztovszki, 2023).

Intensive AI users are also exposed to the risk of technological dependence (Rahman et al., 2023), while frequent use may lead to digital fatigue (An et al., 2025). Another concern is that increasing time spent using digital technologies may reduce interactions both among peers and between students and teachers. Over the long term, the decline of social interactions may have serious consequences by increasing the proportion of individuals experiencing loneliness and social isolation (Bailey, 2023). A further long-term challenge associated with AI concerns its substantial energy consumption. According to some estimates, by 2030 digital technologies may account for approximately 20% of global electricity demand (Yang et al., 2021), with a significant proportion attributable to artificial intelligence. Without comprehensive advances in energy production and sustainable energy solutions, this growing demand could contribute to a global energy crisis.

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Sustainable AI Integration in Education: Opportunities, Risks, and the Central Role of Teachers

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Abstract. Artificial intelligence (AI) has rapidly become an important feature of contemporary education. It is increasingly used to support teaching, personalize learning, improve communication, and simplify administrative processes. At the same time, its rapid expansion has raised important questions concerning teacher competencies, ethics, privacy, academic integrity, and institutional readiness. The aim of this paper is to analyze the opportunities and risks of AI integration in education, with particular emphasis on teachers' competencies and institutional support. The paper applies a qualitative conceptual review method based on academic literature, policy reports, and systematic reviews published between 2020 and 2025. The findings suggest that AI can enhance efficiency, differentiated instruction, accessibility, and student engagement when implemented within coherent pedagogical and organizational frameworks. However, weak governance structures, limited professional capacity, and uncritical reliance on automated systems may reduce educational quality. As a contribution, the paper proposes a five-dimensional framework for sustainable AI integration in education.

Key words and phrases: AI in education, AI literacy, teachers' competences and institutional readiness, conceptual framework for sustainable AI integration.

1 INTRODUCTION

Artificial intelligence has moved in a remarkably short period from the margins of technological debate to the centre of educational practice. Particularly since the emergence of widely accessible generative AI systems, its presence has expanded rapidly across different levels of education. What was once discussed mainly in speculative or future-oriented terms now appears in classrooms, lecture halls, institutional platforms, and everyday professional routines. Schools and universities increasingly use AI-supported tools for lesson planning, formative assessment, communication with students, accessibility support, and administrative tasks. The rapid spread of generative AI has accelerated this shift by making sophisticated systems available to users with little technical expertise.

The public discussion surrounding AI in education is often polarized. On one side, AI is presented as a solution to long-standing challenges such as excessive teacher workload, limited personalization, or declining student engagement. On the other, it is portrayed as a threat to academic integrity, teacher autonomy, data privacy, and the human character of education. Neither position fully captures the complexity of the issue. Educational technologies rarely produce outcomes independently; their effects depend on how they are interpreted, implemented, regulated, and embedded within institutional cultures. Despite a growing body of literature, existing research often remains fragmented, focusing either on technological capabilities or on ethical concerns in isolation, without integrating pedagogical, professional, and organizational perspectives.

This paper therefore starts from a different premise. The key question is not whether AI will enter education, but under what conditions it can do so responsibly and meaningfully. This paper argues that the effectiveness of AI integration depends less on technological sophistication and more on the alignment between teacher

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competencies and institutional readiness. In that respect, two factors appear especially important: teachers' competencies and institutional readiness. Teachers remain central to curriculum interpretation, assessment, motivation, ethical judgement, and the creation of learning relationships. Institutions, meanwhile, shape the strategic, technical, and regulatory environment in which innovation either becomes sustainable practice or fragmented experimentation.

The aim of this paper is to analyze the opportunities and risks of AI integration in education, with particular emphasis on teachers' competencies and institutional support. More specifically, the paper seeks to critically examine how AI can contribute to educational practice while identifying the conditions required for its responsible and sustainable implementation. The analysis considers the pedagogical potential of AI, the changing professional role of teachers, the organizational conditions required for successful implementation, and the principal risks associated with rapid technological adoption. The paper adopts a qualitative conceptual review approach based on academic literature, policy reports, and systematic reviews published mostly between 2020 and 2025. Sources were identified through major academic databases (Scopus, Web of Science, ERIC) and selected policy documents, based on their relevance to AI implementation in education, teacher competence, ethics, and digital transformation.

As its main contribution, the paper introduces a five-dimensional framework that integrates teacher competence, pedagogical purpose, institutional support, ethical governance, and continuous evaluation into a coherent model for sustainable implementation. The framework is structured around five interconnected dimensions: teacher competence, pedagogical purpose, institutional support, ethical governance, and continuous evaluation.

The remainder of the paper is structured as follows. The next section outlines the stages of digital transformation and introduces the conceptual framework. Subsequent sections examine the benefits and risks of AI in education, the role of teachers, and institutional readiness. The paper concludes with key implications and directions for future research.

2 METHODOLOGY

This study applies a qualitative conceptual review approach in which the authors synthesize the existing body of knowledge on the integration of AI in education. Rather than focusing primarily on individual authors' positions, the goal is to develop an original analytical framework and propose directions and guidelines for future research. The analysis is based on academic literature, policy reports, and systematic reviews published between 2020 and 2025. Sources were identified through major academic databases (Scopus, Web of Science, ERIC) and selected policy documents, based on their relevance to AI implementation in education, teacher competence, ethical considerations, and digital transformation processes. The analysis focuses on identifying recurring themes and conceptual patterns across the literature, which form the basis for the proposed five-dimensional framework for sustainable AI integration in education.

3 STAGES AND CONCEPTUAL FRAMEWORK OF DIGITAL TRANSFORMATION

Artificial intelligence is best understood as part of a broader process of digital transformation rather than as an isolated technological innovation. In educational discourse, the terms digitization, digitalization, and digital transformation are often used interchangeably, although they refer to distinct stages of institutional development. Clarifying these distinctions is essential for understanding the specific role and impact of AI in educational contexts (Chen et al., 2020).

Digitization represents the initial phase of change and refers to converting analogue materials into digital formats. In education, this includes electronic records, scanned archives, digital textbooks, and online repositories of learning resources. Such developments primarily improve access, storage, and the circulation of information, while the underlying logic of teaching and learning often remains unchanged. At this stage, technology supports existing practices rather than transforming them.

Digitalization goes further by using technology to improve established processes. Common examples include learning management systems, online grading platforms, communication tools, scheduling software, and digital reporting systems. At this stage, institutions may become more efficient and responsive, although

traditional pedagogical models frequently continue without substantial redesign. Process optimization becomes visible, but pedagogical change remains limited (OECD, 2024).

Digital transformation denotes a deeper and more comprehensive shift. It extends beyond tools and procedures to include changes in organizational culture, leadership practices, professional competencies, curriculum design, collaboration patterns, and decision-making structures. Hybrid learning models, data-informed student support, interdisciplinary teaching, and flexible learning pathways illustrate this more advanced stage. At this level, technology is embedded within broader institutional change rather than applied as an external add-on.

From this perspective, AI matters not simply because it is new, but because it can intensify wider processes of change. Yet institutions often confuse the acquisition of tools with transformation itself. Purchasing software is easier than redesigning professional learning, governance structures, incentives, or organizational culture. For this reason, many digital reforms generate visibility without depth. This gap between technological adoption and meaningful transformation highlights the need for more coherent conceptual frameworks (Chen et al., 2020).

To address this gap, the present paper proposes a framework for sustainable AI integration. The framework is designed to connect technological possibilities with pedagogical purpose, professional capacity, and institutional conditions.

Table 1. Conceptual Framework for Sustainable AI Integration in Education

Dimension	Core Focus	Guiding Question
Teacher Competence	Professional knowledge and judgement	Can teachers use, critique, and pedagogically guide AI?
Pedagogical Purpose	Alignment with learning goals	Does AI improve learning rather than merely accelerate tasks?
Institutional Support	Leadership, infrastructure, training	Are staff supported through coherent systems?
Ethical Governance	Privacy, fairness, transparency	Are risks actively managed and responsibilities clear?
Continuous Evaluation	Evidence-informed improvement	Is implementation regularly reviewed and refined?

No single dimension is sufficient on its own. Strong infrastructure without teacher competence remains fragile, while innovation without governance may generate new risks. Likewise, pedagogical ambition without evaluation often relies on assumptions rather than evidence. Sustainable transformation requires these dimensions to operate together. The proposed framework therefore emphasizes the interdependence of these dimensions as a condition for responsible and effective AI integration. Digital transformation is therefore as much a human and organizational process as a technical one.

4 BENEFITS OF AI IN EDUCATION

The benefits of AI in education are real, although they are sometimes overstated. Technology does not improve learning automatically. Positive outcomes emerge when tools are introduced within clear pedagogical purposes and guided by professional judgement. In this sense, the value of AI lies not in the technology itself, but in the conditions of its educational use. One clear advantage concern administrative efficiency. Teachers often devote considerable time to repetitive tasks such as formatting materials, drafting quizzes, organizing resources, or responding to routine communication. AI can reduce part of this workload and release time for mentoring, feedback, and direct engagement with students. This redistribution of effort is particularly significant, as it allows teachers to focus on higher-value pedagogical activities. Used wisely, automation may strengthen rather than weaken the human side of teaching (Celik et al., 2022).

Another significant contribution relates to personalization. Students differ in pace, confidence, language background, prior knowledge, and preferred ways of learning. AI-supported systems can recommend practice tasks, adapt levels of difficulty, or present explanations in alternative formats. While such systems cannot replace teacher judgement, they can make differentiated instruction more manageable. However, personalization remains effective only when aligned with clearly defined learning goals and pedagogical strategies.

Feedback is another promising area. Timely responses are strongly associated with learning progress, yet they are difficult to sustain in larger classes. AI can help generate preliminary comments, identify recurring errors, or support self-correction before final teacher review. This may improve responsiveness while preserving professional oversight. Importantly, AI-generated feedback should be understood as supportive rather than definitive, requiring validation and contextualization by the teacher.

AI may also strengthen accessibility and inclusion through translation tools, captioning, speech-to-text functions, and simplified text formats. For many learners, such features are not optional conveniences but meaningful conditions of participation. In this respect, AI contributes not only to efficiency but also to equity in educational access (Holmes et al., 2024; Fitzgerald & Evans, 2024).

At the institutional level, learning analytics may help identify disengagement risks, progression patterns, or resource needs. At the same time, data should inform judgement rather than replace it. Metrics can reveal patterns, but they cannot fully explain motivation, context, or learner experience. This highlights the importance of combining data-informed insights with professional interpretation. The real promise of AI lies less in replacing professional work than in creating more time and capacity for it (Fullan, 2013).

Table 2. Key Benefits of AI in Education

Benefit Area	Educational Value	Condition for Effective Use
Efficiency	Reduced routine workload	Teacher oversight
Personalization	Differentiated learning pathways	Pedagogical alignment
Feedback	Faster formative support	Human moderation
Accessibility	Inclusion of diverse learners	Universal design
Engagement	Interactive learning experiences	Meaningful task design
Analytics	Earlier intervention and planning	Ethical interpretation

5 TEACHERS AS KEY MEDIATORS OF AI INTEGRATION

Despite recurring claims that AI will automate major aspects of teaching, teachers remain the decisive actors in any meaningful educational use of technology. Teaching involves interpretation, motivation, ethical judgement, relational sensitivity, and responsiveness to learner needs. These are not peripheral tasks that can simply be delegated to automated systems. In this sense, the role of teachers is not reduced by AI, but redefined and, in many respects, reinforced (Hargreaves & Fullan, 2012; Celik et al., 2022).

AI can generate content, summarize texts, create examples, and support routine processes. What it cannot do is understand a hesitant student, rebuild confidence after failure, sense when confusion is hidden behind silence, or know when a carefully prepared lesson must change direction because the classroom requires something different. That professional responsiveness remains distinctly human. This distinction highlights the limits of automation in educational contexts (Selwyn, 2016).

For this reason, the rise of AI increases rather than diminishes the importance of teacher competence. Particularly relevant competencies include AI literacy, prompt competence, critical evaluation of outputs, data awareness, assessment redesign, and reflective pedagogy. These competencies extend traditional pedagogical knowledge by incorporating technological and ethical dimensions (Fullan, 2013; UNESCO, 2023; Holmes et al., 2024).

AI literacy involves understanding how systems function, what their limitations are, and where caution is required. Prompt competence refers to the ability to formulate clear and purposeful instructions when working with generative systems. Critical evaluation is essential because outputs may be inaccurate, biased, superficial, or fabricated. Data awareness includes sensitivity to privacy, ownership, and responsible data use. Assessment redesign has become increasingly important because traditional take-home tasks may no longer provide reliable evidence of independent student learning. Together, these competencies form a core component of teacher preparedness for AI-integrated educational environments (Williamson & Eynon, 2025; OECD, 2024).

Reflective pedagogy remains equally important. Teachers need to ask not only whether a tool can be used, but whether it should be used in a specific context, with particular learners, and for clearly defined learning goals. Such reflection is essential for aligning technological use with pedagogical intent.

Where teachers are excluded from innovation processes, implementation often becomes symbolic or resisted. Where they are trusted as co-designers of change, adoption becomes more credible, context-sensitive, and sustainable. This underscores the importance of involving teachers not only as users, but as active participants in the design and governance of AI integration (UNESCO, 2021).

Ultimately, AI may assist teaching, but it cannot replace the relational, interpretive, and ethical dimensions of educational work. Within the proposed framework, this central role of teachers is reflected in the dimension of teacher competence, which underpins all other aspects of sustainable AI integration.

6 INSTITUTIONAL SUPPORT AND ORGANIZATIONAL READINESS

Even highly capable teachers cannot sustain innovation without institutional support. Schools and universities therefore play a decisive role in determining whether AI adoption becomes meaningful practice or fragmented experimentation. In this context, institutional readiness becomes a critical condition for sustainable AI integration.

Organizational readiness begins with infrastructure: reliable connectivity, secure systems, appropriate devices, and access to trustworthy platforms. Yet infrastructure alone is insufficient. Many institutions possess technology that remains pedagogically underused because broader strategic and cultural conditions have not been addressed. This indicates that technological availability does not automatically translate into educational effectiveness (Selwyn, 2016).

Leadership is especially important during periods of transition. When leaders communicate clear priorities, invest in professional learning, and create space for experimentation, staff are more likely to engage constructively. When institutions rely on vague enthusiasm, symbolic modernization, or pressure-driven implementation, resistance is hardly surprising. Effective leadership therefore involves not only strategic direction, but also the cultivation of trust and professional agency.

Professional development is equally important. One-off workshops rarely produce lasting change. Staff need continuing opportunities for mentoring, peer exchange, collaborative experimentation, and reflective learning (Brookfield, 2017; UNESCO, 2023).

Governance must accompany innovation from the beginning. Privacy policies, procurement standards, academic integrity procedures, accessibility criteria, and evaluation mechanisms should not be treated as afterthoughts introduced only after problems emerge. Clear governance structures are essential for managing risks and ensuring responsible use of AI technologies (OECD, 2024; UNESCO, 2021).

Institutional readiness is therefore not a checklist completed once. It is an ongoing organizational capacity to learn, adapt, and respond responsibly. Within the proposed framework, this dimension highlights the importance of aligning infrastructure, leadership, professional development, and governance into a coherent support system for AI integration (Magzan, Jokić, & Karleuša, 2026b).

7 RISKS AND CHALLENGES OF AI IMPLEMENTATION

The risks associated with AI are rarely caused by technology alone. More often, they emerge when powerful tools are introduced without sufficient competence, reflection, or governance. In this sense, risks are not inherent to AI itself, but to the conditions under which it is implemented.

One major concern is reliability. AI systems can produce persuasive but inaccurate responses, fabricated references, or superficial explanations. Students may mistake fluency for truth, which makes critical literacy and teacher judgement more important than ever. This creates a new epistemic challenge, where the credibility of information must be actively evaluated rather than assumed (Chen et al., 2020; Williamson & Eynon, 2025).

A second challenge concerns assessment and academic integrity. If students can outsource parts of writing, coding, or problem-solving, traditional assignments may no longer reveal what learners actually understand. This should be interpreted less as a collapse of integrity than as a signal that assessment practices must evolve.

As a result, assessment increasingly needs to focus on process, reasoning, and authentic performance rather than final outputs alone.

Bias and fairness remain serious issues. Systems trained on uneven datasets may reproduce stereotypes or cultural distortions. In education, where fairness is a core principle, such risks cannot be minimized. Addressing these issues requires both technical awareness and institutional safeguards (Mishra & Koehler, 2006).

Privacy is another substantial concern. Many platforms collect prompts, behavioural data, or personal information. Institutions that adopt tools without clear legal, ethical, or contractual safeguards expose staff and students unnecessarily.

There is also a subtler pedagogical risk: dependency. If students routinely delegate thinking to automated systems, they may gradually weaken persistence, reasoning, and writing fluency. Efficiency gained too easily may come at the cost of capability slowly lost. This tension between efficiency and cognitive development represents a central pedagogical dilemma (Yazdani Motlagh et al., 2023; Zhao, 2012).

These tensions reveal a broader paradox. The same systems that promise personalization may intensify surveillance; tools that promise efficiency may reduce professional autonomy; systems designed to support learning may encourage passivity if used carelessly. Such paradoxes illustrate the need for balanced and critically informed implementation strategies (Dancsa et al., 2023).

For these reasons, the question is not whether AI carries risks—it clearly does—but whether institutions are prepared to govern those risks responsibly. Within the proposed framework, these challenges are primarily addressed through the dimensions of ethical governance, teacher competence, and continuous evaluation.

8 EXAMPLES OF AI TOOLS IN EDUCATION

The following examples illustrate common categories of AI-supported tools currently used in educational contexts. Rather than providing an exhaustive list, they demonstrate how different types of tools align with specific pedagogical functions.
These categories reflect the functional diversity of AI applications in education. However, their educational value depends less on specific platforms and more on how they are integrated into teaching and learning processes, in alignment with pedagogical goals, teacher competence, and institutional support (Magzan, Jokić, & Karleuša, 2026a).

Table 3. AI Tools in Education

Category	Examples	Main Purpose
Content Support	ChatGPT, Copilot	Drafting materials and idea generation
Writing Support	Grammarly	Language support and editing
Assessment	Quizizz, Kahoot	Formative assessment
Visual Design	Canva Magic Write	Presentation development
Accessibility	Translation / speech tools	Inclusion support

In line with the proposed framework, effective use requires alignment with pedagogical goals, teacher competence, and institutional support, rather than reliance on technological novelty alone.

9 CONCLUSION

Artificial intelligence should be understood neither as a simple solution nor as an inevitable threat. Its influence on education depends on the quality of implementation, the competence of teachers, and the responsibility of institutions. In this sense, the impact of AI is shaped less by technology itself than by the human and organizational conditions in which it is embedded. Where teachers are supported and governance is clear, AI can contribute to efficiency, inclusion, personalization, and more responsive learning environments. Where implementation is poorly managed, it may deepen inequality, weaken trust, and reduce educational quality. This dual potential highlights the importance of responsible and context-sensitive integration. This paper has

proposed a five-dimensional framework for sustainable AI integration based on teacher competence, pedagogical purpose, institutional support, ethical governance, and continuous evaluation. The framework provides a structured way of understanding how these dimensions interact and why none of them can be considered in isolation. Its central argument is straightforward: technology succeeds educationally only when human systems are ready for it. For policy makers, this implies investment not only in platforms but also in professional capacity, governance standards, and long-term support. For teacher education institutions, it means embedding AI literacy and critical pedagogical use into curricula. For school leaders, it means building cultures of responsible experimentation rather than compliance. Across all levels, sustainable implementation requires coordination between technological, pedagogical, and organizational strategies. Future research should empirically test the proposed framework across different educational sectors, national systems, and levels of schooling. Comparative studies would be especially valuable in showing how context shapes sustainable implementation. Such research would contribute to refining and validating the framework in diverse educational settings. Digital transformation is therefore as much a human and organizational process as a technical one. The future of education is unlikely to be defined by replacing teachers with machines, but by how wisely institutions combine technological capability with professional judgement and pedagogical care. Ultimately, the challenge is not to adopt AI, but to integrate it in ways that enhance, rather than diminish, the human foundations of education.

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AI Assistant for Managing Student Tasks with Integrated Learning Material Analysis

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Abstract. The development of information technologies, and especially the field of artificial intelligence, has enabled the creation of advanced systems that can help users in organization and decision-making. Today, AI assistants are widely used in various domains, and their ability to analyze data and generate recommendations makes them extremely useful tools in education as well. By integrating AI models into task management applications, it is possible to provide users with personalized recommendations, content analysis and learning support.

The subject of this work is the presentation of a developed web application that functions as an AI assistant for managing student tasks, with a special focus on analyzing the material and generating learning recommendations. The application allows users to view subjects, monitor the status of passed exams, and receive intelligent suggestions that can improve their learning process and time management. The application can be used as a model for the development of applications of similar purpose at other levels of education.

Key words and phrases: AI assistant, learning material analysis, time management.

1 INTRODUCTION

In modern society, individuals are required to engage in a multitude of tasks, making it imperative to effectively allocate and use time (Ghafar, 2023). It is recognized that effective time management has significant role for students in achieving academic results (Mohamed et al., 2018; Chase et al., 2013). The modern way of students' life means dealing with a large number of academic obligations, including attending lectures, preparing for exams, preparing seminar papers and continuously acquiring new knowledge. In such an environment, time management and efficient task management become a key factor for a successful course of study. However, a large number of students face difficulties in planning their activities, which often leads to stress, poor time management and insufficient academic results (Zagade et al, 2025).

The development of information technologies, and especially the field of artificial intelligence, has enabled the creation of advanced systems that can help users in organization and decision-making. Today, AI assistants are widely used in various domains, and their ability to analyze data and generate recommendations makes them extremely useful tools in education as well. By integrating AI models into task management applications, it is possible to provide users with personalized recommendations, content analysis and learning support.

The subject of this paper is the development of a web application that functions as an AI assistant for managing student tasks, with a special focus on analyzing the material and generating learning recommendations. The application allows users to review subjects, monitor the status of passed exams, and receive intelligent suggestions that can improve their learning process and time management.

The goal of this paper is to present the design and implementation of a system that combines the functionality of traditional applications for task management with the capabilities provided by artificial intelligence. Special emphasis was placed on the development of the backend and frontend part of the application, as well as on the integration of an AI model that enables the analysis of entered data and the generation of useful recommendations.

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The fact is that the Internet offers a wide range of applications to help students learn, organize their time and have academic achievements. What characterizes most tools is their focus on only one specific type of help, for example, the MyStudyLife application can be used to plan class schedules, assignments, and exam dates. The Wordtune application is an AI-powered writing assistant, Be Focused allows you to manage your study sessions through the Pomodoro Technique and so on. In contrast to these and similar tools, the application presented in this paper combines the vast majority of functionalities required for successfully organizing time and achieving success in studying.

The paper is organized in several parts. After the introductory part, the second chapter presents the technologies that are used for application development. The third chapter includes system definition, as well as requirements analysis. The fourth chapter describes the design and the system architecture, while the fifth chapter describes the implementation of the application in detail. At the end of the paper, concluding considerations and a proposal for future research are given.

2 USED TECHNOLOGIES

The system was implemented as a web application that includes frontend, backend, database and integration with artificial intelligence models. The choice of technologies was made based on their efficiency, availability and number of users in modern software development.

For the development of the application, Visual Studio Code was used as the basic development environment, which enables efficient writing and organization of code. XAMPP was used to run the database and the local server, which integrates the Apache server and the MySQL database. The application was tested using the Google Chrome web browser using the Developer Tools.

In the development of the application, the programming language JavaScript was used, which enables the implementation of functionality both on the frontend and on the backend part of the system. Its universality enables simpler integration of various application components and efficient data processing.

On the backend side, Node.js was used together with the Express framework, which allows defining API routes and processing requests. Also, additional libraries were used, such as jsonwebtoken for user authentication, multer for uploading files, pdf-parse and mammoth for document processing, as well as pdfkit for generating PDF reports. The Axios library was used for communication between the frontend and backend part of the application.

MySQL relational database management system was used for data storage. The database contains several tables that enable the organized storage of information about users, subjects, passed exams, exam plans and AI analyzes of materials.

Data is stored locally through the XAMPP environment, enabling simple database management and application testing during development.

Within the application, an AI module based on Large Language Models (LLM) has been implemented, which enable natural language processing and the generation of text responses. An OpenAI compatible API through the Groq platform was used to communicate with the AI model.

The model that was used belongs to the LLaMA 3 family, and it is used for the analysis of student obligations, load assessment, generation of a learning plan, as well as processing and summarizing text materials from PDF and DOCX documents.

The integration of this model enables the generation of intelligent recommendations, which transforms the application from a classic task management system into an advanced learning support tool.

3 SYSTEM AND REQUIREMENTS ANALYSIS

The application functions as a centralized system for managing student obligations. After successful authentication, the user gets access to his profile and the list of subjects organized by year and semester. The system allows the marking of passed subjects, as well as the review of basic information such as ECTS points, subject weight and additional obligations.

The user has the option of planning the exam by choosing the appropriate exam dates for each subject. Based on the entered data, the system uses an AI module to analyze the current load, taking into account the unposted

items, their weight and deadlines. The output of the analysis includes workload assessment, identification of critical subjects, and generation of learning recommendations.

In addition, the application allows loading of materials in PDF and DOCX format, after which content analysis is performed with the help of an AI model. The system generates a summary, key information, practice questions and a suggested study plan, further enhancing the exam preparation process.

In this way, the application serves not only as a tool for recording obligations, but as an intelligent assistant that actively helps the user in organizing and optimizing learning.

4 Functional requirements

Functional requirements define the basic capabilities that the system should provide to the user. The following functionalities were identified within the developed application:

- The system enables user registration and login via username and password, using token-based authentication.
- After registration, the user can view subjects filtered by year and semester, as well as view basic information about each subject.
- The user can mark subjects as passed, which updates the state in the database and reflects the progress of studies.
- The system enables the selection of exam dates for unpassed subjects, which allows the user to plan his obligations.
- The application enables the generation of an AI analysis that assesses the student's workload based on the failed subjects, their characteristics and the selected deadlines.
- The AI module generates learning recommendations, identifies critical subjects and suggests an activity plan.
- The system enables loading of materials in PDF and DOCX format, after which their analysis is performed using AI models.
- After analyzing the material, summaries, key information, practice questions and study plan suggestions are presented to the user.
- The application allows viewing the history of previous AI analyzes of materials, as well as their reopening and deletion.
- The system allows generating and downloading reports in PDF format.

These functional requirements form the basis of the system's operation and enable the user to effectively manage student obligations with the support of artificial intelligence.

5 Non-functional requirements

In addition to functional requirements, the system must satisfy certain non-functional requirements related to the quality, performance and security of the application.

One of the key requirements is system security, which is ensured through user authentication using tokens, as well as protection of access to API routes. In this way, only registered users have access to their data.

The system should provide satisfactory performance, i.e. fast loading of data and efficient processing of requests. Special attention is paid to the optimization of communication between the frontend and backend part of the application, as well as the proper handling of data from the database.

Also, the application should be easy to use, with a transparent and intuitive user interface. Clear organization of data and functionality allows the user to easily navigate within the system.

System reliability is also an important factor, which implies stable operation of the application without frequent errors or interruptions. The system should properly handle errors and provide appropriate messages to the user in case of problems.

Finally, the system should be scalable, that is, it should enable easy expansion of functionality in the future, such as additional AI analyzes or integration with other systems.

6 SYSTEM DESIGN AND ARCHITECTURE

The application is developed as a web system consisting of several interconnected components, including frontend, backend, database and AI service (Figure 1.a). This architecture enables a clear division of responsibilities between system components, easier maintenance and the possibility of expanding functionality in the future.

The system is organized according to the principle of client-server architecture, where the frontend application communicates with the backend server via a REST API. The backend part of the system processes user requests, communicates with the database and performs integration with the AI model.

Each system component has a clearly defined role and responsibility. The front-end part of the application was developed using the React library and represents the user interface through which the user interacts with the system. The backend part of the application is implemented using Node.js and the Express framework, and is responsible for processing requests, user authentication and communication with the database. The database was implemented using the MySQL system, where all data about users, subjects and analyzes are stored. The AI component of the system was implemented through an external service, which enables data processing and generation of recommendations. Communication between the frontend and backend part of the system takes place via the REST API, while the backend communicates with the AI service via HTTP requests.

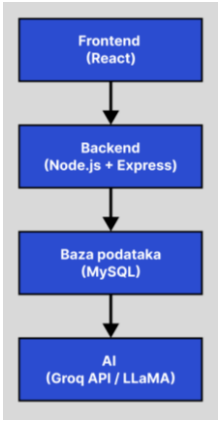


Figure 1.a System architecture

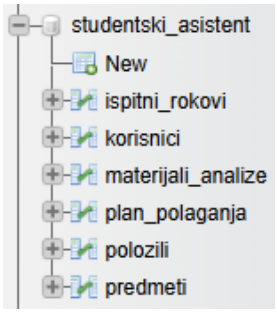


Figure 1.b Database structure

The database is organized as a relational system consisting of several tables interconnected by relations (Figure 1.b). Basic tables in the system include the *korisnici* table, which contains information about registered users, then the *predmeti* table, which contains data about subjects, as well as the *polozili* table, which records passed exams. In addition, the *ispitni_rokovi* table allows defining the available deadlines for taking exams, while the *plan_polaganja* table allows users to plan exams by selecting the appropriate deadlines. The *materijali_analize* table is used to store the AI analysis results of the loaded materials. This database structure enables efficient data management, as well as flexible connection of various system functionalities. Tables are connected by primary and foreign keys, which ensures data integrity.

Communication between system components is realized through clearly defined interfaces. The frontend application sends HTTP requests to the backend server using the REST API, where data is exchanged in JSON format. The backend server processes incoming requests, performs data validation and communicates with the database to perform the necessary operations. Also, the backend communicates with the AI service, to which it sends data for analysis and receives the generated results. This way of communication enables efficient flow of data and proper functioning of all system components.

7 SYSTEM IMPLEMENTATION

In this chapter, the implementation of the developed application is presented through a functional presentation of the user interface and the basic capabilities of the system. The focus is on the way how to use the application from the user's perspective, with the presentation of key parts of the system through the appropriate screens.

7.1. User login

User registration is the initial step in using the application. The system enables authentication through a username and password, which ensures data security and protection. After entering valid data, the user is

assigned an access token that enables further communication with the system. This mechanism allows only registered users to use the functionality of the application. The user registration form contains fields for entering a username and password. After a successful login, the user is redirected to the main page of the application. In case of incorrect data entry, the system displays an appropriate error message and prevents access to the application. In this way, the user receives clear information about the error and can try logging in again with the correct data. This ensures system security and prevents unauthorized access to the application.

7.2. Main page

After a successful login, the user is redirected to the main page of the application, which is the central place for managing student obligations. This page displays basic user information, including username, major and year of study. Also, all key functionalities of the system are available to the user through a unique interface.

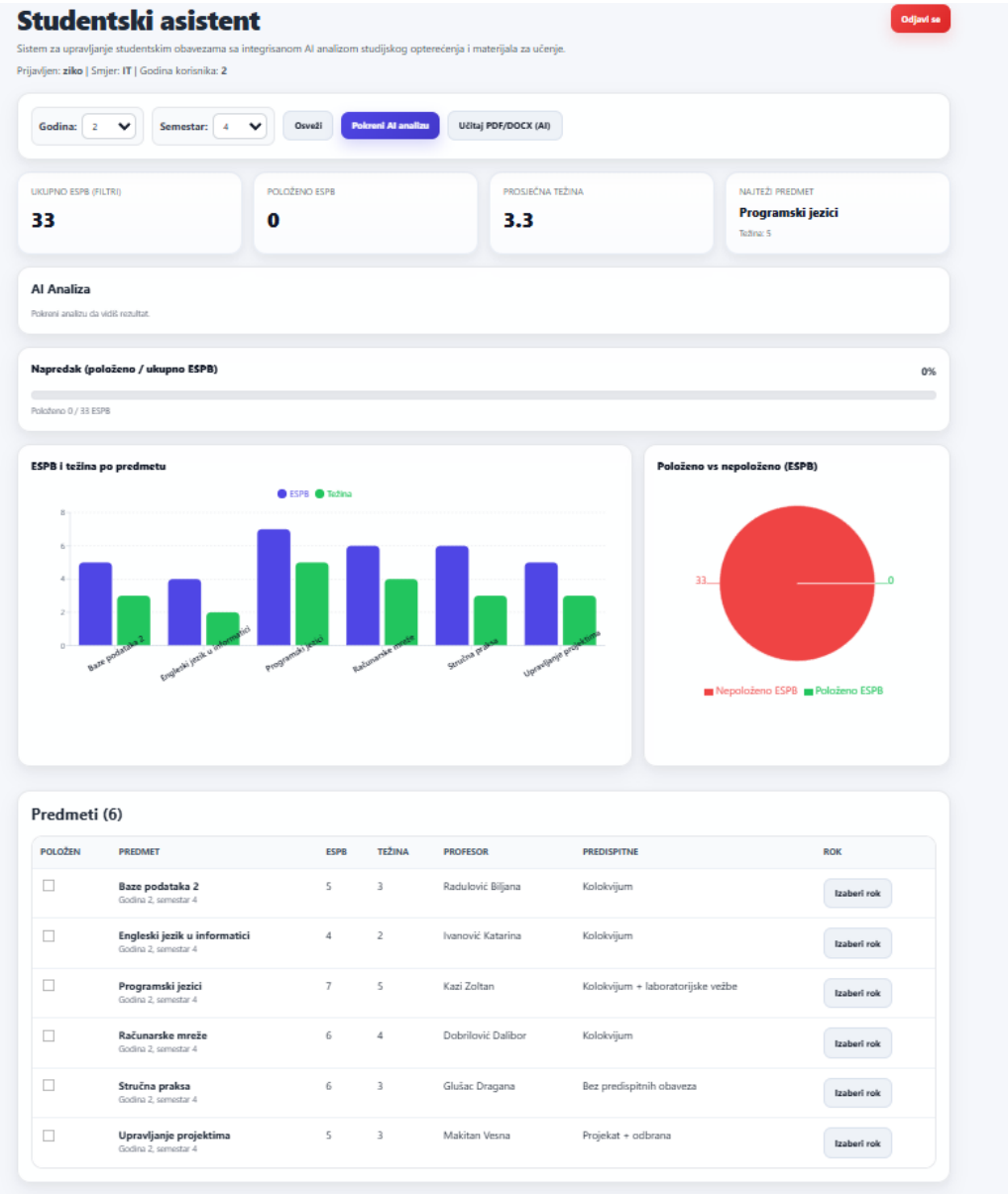


Figure 2. The main page of the application

The main page provides an overview of statistical data such as the total number of ECTS points, the number of passed points, the average weight of the subject, as well as the identification of the most difficult subject. This data provides the user with a quick insight into the current state and progress during studies. In addition,

options for filtering courses by year and semester are available on the page, as well as buttons to launch AI analysis and upload material for analysis. This organization enables the user to navigate easily and quickly use all system functionalities. The Figure 2 shows the main page of the application, which contains an overview of user data, statistics and available system functionality. Through this interface, the user can manage all aspects of their study obligations.

One of the basic functionalities of the application is an overview of subjects organized by year and semester (it can be seen at the beginning of the main page of the application). The system allows the user to easily filter subjects based on the selected year of study and semester, thus facilitating the review of relevant information. For each subject, basic data such as the name of the subject, number of ECTS points, weight of the subject, professor and pre-examination requirements are shown. This display allows the user a better insight into the structure of the study program and the requirements of each subject. Subject filtering allows the user to focus only on a specific part of the study, thereby reducing the amount of displayed data and increasing the transparency of the system. This functionality is especially useful when planning exams and analyzing workloads.

The application allows the user to easily manage subjects by marking the status of passed exams. Each subject in the table has the option of marking via a checkbox field, which allows the user to register that a specific subject has been passed (it can be seen at the end part of the main page of the application, tagged with *Predmeti*). By changing the course status, data in the database is automatically updated, which reflects the student's progress. If the subject is marked as passed, it becomes additionally visually emphasized, which allows the user better visibility and easier organization of remaining obligations. This functionality allows the user to have an accurate overview of passed and unpassed subjects at any time. In addition, the status change also affects other parts of the system, such as statistical displays and AI analysis, which only take into account unpassed subjects. In this way, the system dynamically adjusts the display of data and recommendations in accordance with the current situation.

In the same part, the application allows the user to plan exams by choosing the appropriate exam dates for each subject. This functionality is available for untaken subjects, which enables the user to organize future obligations and timely preparation for exams. The user can choose one of the offered exam dates for each subject, which are displayed based on the available data in the system. By choosing a deadline, it is recorded in the database, which creates a personal plan for taking the exam. Exam planning plays a significant role in system operation, as this data is also used in AI load analysis. Based on the selected deadlines and remaining subjects, the system generates recommendations and a study plan that helps the user organize his time.

7.3. Workload analysis

One of the key functionalities of the application is the AI load analysis, which allows the user to see the current level of studio load. This analysis is carried out on the basis of failed subjects, their weight, the number of ECTS points and the selected exam dates. The user initiates the analysis through the appropriate option in the interface, after which the system collects the relevant data and sends it to the AI model for processing. Based on the provided information, the system generates a workload estimate, identifies the most critical subjects and suggests concrete steps for learning. The result of the analysis includes a summary of the situation, the level of workload, a list of priority subjects, as well as a proposal for an activity plan and study schedule. This approach allows the user to make informed decisions and organize their time more efficiently. AI analysis represents a significant upgrade of classic systems for managing obligations, because it not only displays data, but actively helps the user in planning and optimizing the learning process.

The Figure 3 shows the result of the AI analysis, which includes workload assessment, identification of critical subjects and recommendations for learning organization. This data helps the user to better plan their activities and prepare more efficiently for exams. In addition, the system generates concrete proposals for steps that the user should take, as well as a rough study plan distributed by time intervals. Based on this information, the user can more easily set priorities and focus on the most demanding parts of the material.

The application enables the visualization of data through graphic displays, which provides the user with a clearer insight into the state of his study obligations. The visualization includes the display of data such as total ECTS points, subject weight distribution and the ratio between passed and failed exams. By using graphical components, data is presented in an intuitive way that facilitates understanding and analysis. Instead of looking at numerical values, the user can quickly see key information through graphs. This functionality plays a

significant role in decision-making, as it allows the user to recognize the workload and focus on the most demanding subjects. Data visualization is an important step between raw data display and AI analysis.

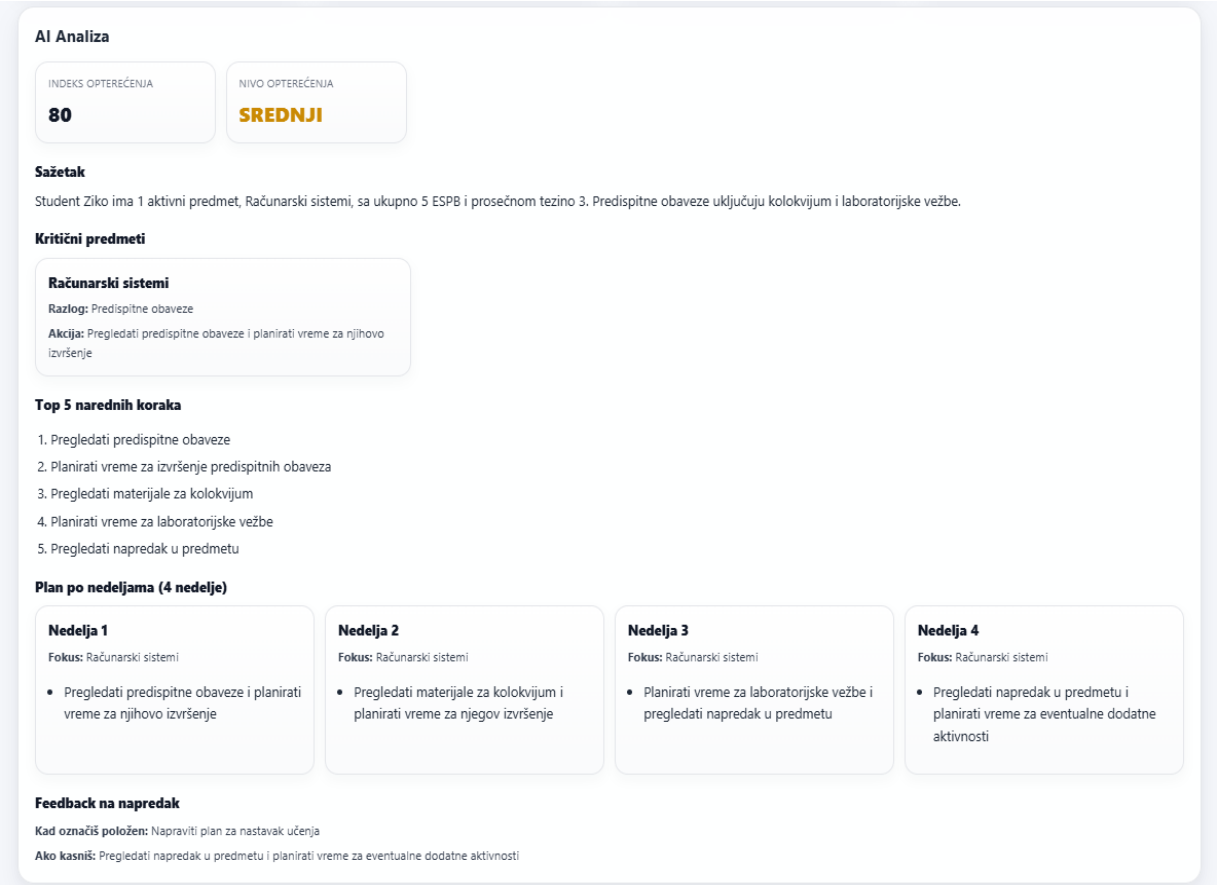


Figure 3. AI workload analysis

7.4. Study material analysis

The application allows the user to upload learning materials in PDF and DOCX formats, after which they are analyzed using an AI model. This functionality represents a significant support for students, as it enables the rapid processing of large amounts of textual content. The user can select the desired file from his device and start the analysis process through the corresponding option in the interface. After loading the file, the system extracts the text from the document and prepares the data for further processing. The resulting text is then sent to an AI model that performs content analysis and generates structured results, including a summary, key information and learning suggestions. This functionality allows the user to save time and focus on the most important parts of the material. The interface for uploading material for analysis contains a button for selecting a file from the user's computer. Clicking the "Choose File" button opens a dialog window that allows the user to find and select the desired PDF or DOCX document. This way of selecting a file is intuitive and easy to use, because it follows the standard functionalities of the operating system. After selecting the file, the user starts the analysis process by clicking on the material analysis button. The system then processes the uploaded document, performs text extraction and prepares it for further AI processing. After that, the data is sent to an AI model that generates a summary, key information and learning recommendations, making the process of preparing the material much easier for the user.

After successfully loading and processing the material, the system displays the result of the AI analysis in a structured and overview format. This result represents a key part of the application's functionality, as it enables the user to quickly view the most important information from the loaded document. The analysis result includes multiple segments, including key information, user-must-know sections, exam focus, and practice questions. These elements allow the user to focus on the most important parts of the material and organize the learning process more efficiently. Also, a glossary of basic terms is presented, which further facilitates the understanding of the material. This approach enables the transformation of complex and voluminous material into clearly

structured information, which significantly reduces the time required for learning and increases the efficiency of exam preparation.

Figure 4 shows the result of the AI analysis of the uploaded material, which includes key information, the most important parts of the material, focus for the exam, and practice questions. Also, the proposed study plan is presented, distributed by day, as well as a glossary of basic terms that facilitates understanding of the material. This structured display allows the user to quickly identify the most important parts of the material and organize the learning process more efficiently. After the analysis of the material, the user has the option of exporting the obtained analyzed material. The export functionality in PDF format allows the user to save the result of the analysis and use it as a reference during learning, which further improves the usability of the system.

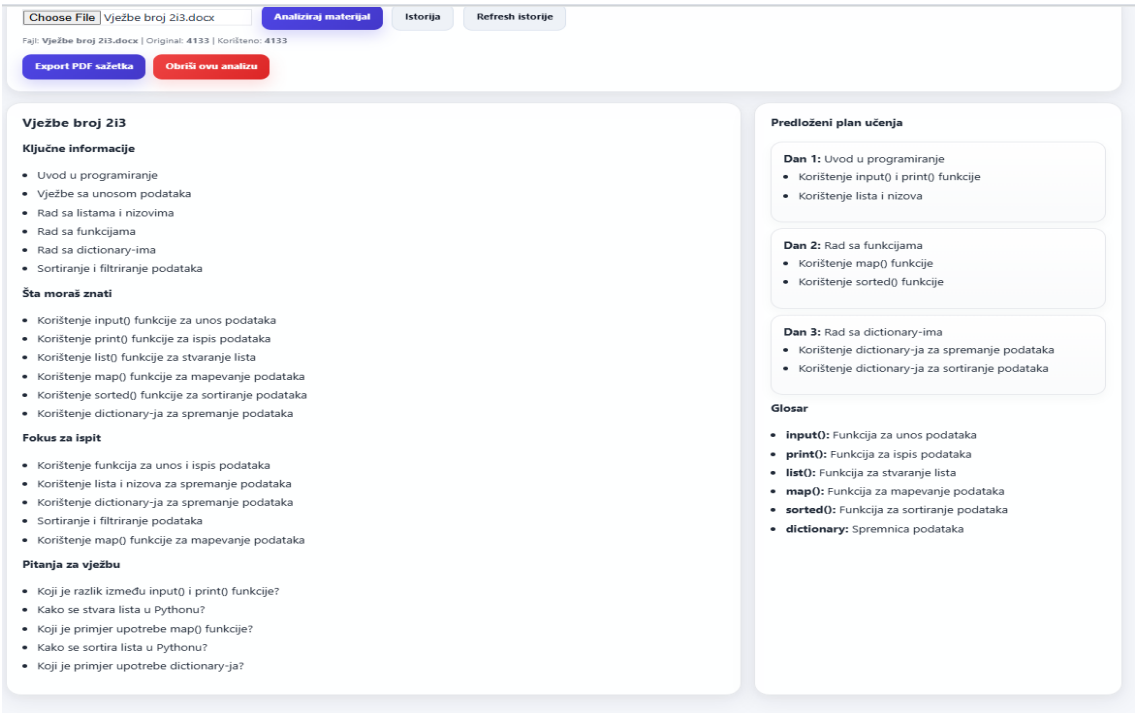


Figure 4. Results of study material analysis

The application allows the user to review the history of previously performed AI analyzes of materials. This functionality allows the user to access previously analyzed documents at any time without the need to reload and process the files. Within the history, the basic data about the analyzes are shown, including the file name, the date of creation, as well as additional information about the processing of the material. The user has the option of opening an individual analysis, reviewing it, and deleting it from the system. This functionality significantly contributes to the organization of work, as it allows the user to track his previous activities and use previously generated results as a learning aid. Also, the possibility of deleting analyzes enables maintaining visibility and managing data within the system.

The test results showed that the system successfully executes all basic functionalities. User authentication works reliably, with proper management of user sessions via JWT tokens. Functionalities related to working with subjects, including filtering and marking passed exams, work without errors and allow the user to easily manage data. AI analysis generates useful and relevant recommendations, which help organize learning. Loading and processing of materials was also tested and it was confirmed that the system successfully processes documents of different formats. Based on all of the above, it can be concluded that the system is stable and ready for use.

8 Conclusion

As part of this work, a web application was developed for the management of student obligations with an integrated analysis of the material using artificial intelligence. The aim of the work was to create a system that enables students to organize their studies more easily, review their obligations and receive recommendations based on data analysis. During the development of the application, modern web technologies were used, including Node.js and Express for the backend part of the system, React for the frontend, as well as the MySQL database for information storage. The special value of the system is reflected in the integration of the AI model,

which enables load analysis and generation of learning recommendations based on real user data. Implemented functionalities include user authentication, review and filtering of subjects, marking of passed exams, planning of exam deadlines, as well as loading and analysis of materials in PDF and DOCX formats. In this way, the user is enabled to manage all his student obligations in one place. The test results showed that the application works stably and that all key functionalities work reliably. The system enables easy use and provides the user with useful information that can contribute to better organization of time and more effective learning. The developed system represents a good basis for further development and improvement, especially in the field of application of artificial intelligence in education. By integrating additional functionalities and improving existing solutions, the application can be developed into an advanced tool to support students in their daily work. In the end, it can be concluded that the application of artificial intelligence in such systems has great potential and can significantly improve the way students plan and organize their duties.

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Methodological Challenges and Contemporary Approaches in Engineering and Technology Education

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Abstract. Contemporary education is characterized by rapid technological and societal changes that require the development of functional knowledge and key competencies. In this context, the subject of Engineering and Technology plays an important role in enabling students to understand technological processes and apply knowledge in real-life situations. However, its implementation is accompanied by various methodological challenges, including limited instructional time, heterogeneous student abilities, insufficient resources, and the need for continuous professional development of teachers.
This paper is based on a theoretical-analytical approach and aims to examine key methodological challenges and contemporary teaching approaches that can improve the quality of instruction and support the development of students' functional competencies. Particular emphasis is placed on project-based, problem-based, interdisciplinary, and digitally supported learning, as well as differentiation and experiential learning.
The main contribution of the paper lies in the systematization of methodological challenges and the proposal of a practical and adaptable lesson model that integrates theoretical and practical activities. The proposed approaches are applicable even in resource-constrained conditions, making them relevant for diverse educational contexts and supporting the development of competencies necessary for lifelong learning.

Key words and phrases: Engineering and Technology education; teaching methodology; project-based learning; functional learning; competencies; STEM education.

1 Introduction

Contemporary education is taking place in the context of rapid technological, social, and economic changes that significantly influence the goals, content, and methods of teaching. Within this context, the subject of Engineering and Technology assumes an increasingly important role as a learning environment in which students develop an understanding of technology, technological processes, and their impact on everyday life and work.

The curriculum of this subject is oriented toward the development of key competencies for lifelong learning, particularly digital, entrepreneurial, and technical-technological competencies. Engineering and Technology has a distinct educational value, as it integrates theoretical knowledge with practical activities and experiential learning, thereby fostering the development of functional knowledge and skills among students (Jokić, 2024).

Despite its considerable educational potential, teaching Engineering and Technology faces a number of methodological challenges, including limited instructional time, heterogeneity of students' prior knowledge and abilities, insufficient material and technical resources, and the need for continuous professional development of teachers. A particular challenge is achieving a balanced integration of theoretical content and practical activities, as well as critically examining teaching materials and their influence on students (Jokić et al., 2025; Jović & Jokić, 2026).

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In this context, improving teaching practice requires the application of contemporary methodological approaches, as well as the flexible and purposeful use of available resources (European Training Foundation, 2023). This paper adopts a theoretical-analytical approach and aims to examine key methodological challenges and contemporary teaching approaches that can contribute to enhancing the quality of teaching and fostering the development of students' functional competencies.

This paper is based on a theoretical-analytical approach and aims to examine key methodological challenges and contemporary teaching approaches that can improve the quality of instruction and support the development of students' functional competencies. The research is grounded in the analysis and synthesis of relevant scientific literature and contemporary educational policy documents.

The scientific and professional contribution of this paper is reflected in the systematization of key methodological challenges in teaching Engineering and Technology and in the development of practically applicable methodological guidelines that can be implemented in resource-constrained educational settings. The paper proposes an integrated framework that links theoretical foundations with concrete instructional practices, with the aim of improving the overall quality of teaching.

2 ENGINEERING AND TECHNOLOGY AS A SCHOOL SUBJECT – METHODOLOGICAL FRAMEWORK

2.1. Specific Characteristics of Teaching Technical and Technological Subjects

Teaching technical and technological subjects is characterized by a number of specific features that distinguish it from most general education subjects. It involves the integration of cognitive, psychomotor, and affective components of learning, as well as direct student engagement with materials, tools, and technological processes. This complexity requires careful instructional planning, clearly defined learning outcomes, and an appropriate selection of methodological approaches (Jokić, 2024).

Technical and technological education is oriented toward the development of technological literacy, defined as the ability of students to understand, use, and critically evaluate technology in everyday life (UNESCO, 2023). In this sense, the subject of Engineering and Technology goes beyond the mere acquisition of skills and has a clearly defined educational and formative function.

Contemporary curricula emphasize the alignment of learning outcomes with key competencies for lifelong learning, whereby technical and technological education contributes to the development of digital, entrepreneurial, and technical competencies (Jokić et al., 2024).

2.2. Learning by Doing and Experiential Learning as the Basis of the Methodological Approach

One of the fundamental methodological characteristics of teaching Engineering and Technology is learning by doing, which is grounded in the principles of experiential learning. Students acquire knowledge through active participation in planning, designing, testing, and evaluating technical solutions, thereby achieving a deeper understanding of the subject content. This approach enables the integration of theoretical knowledge with practical experience and supports the development of functional knowledge (Jokić, 2024).

Experiential learning contributes to the development of durable and applicable knowledge, as students connect theoretical concepts with concrete experience while simultaneously developing independence, initiative, and responsibility (OECD, 2023; Jokić et al., 2024).

2.3. The Relationship Between Theory and Practice in the Teaching Process

Effective teaching of Engineering and Technology is based on a balanced integration of theory and practice. Theoretical knowledge serves a functional role as a foundation for understanding technological processes and making decisions during practical work, while practical activities enable the verification and deeper understanding of theoretical concepts.

The principle of unity between theory and practice represents one of the fundamental premises of technical and technological education, although research indicates the presence of certain imbalances within curricula (Jokić et al., 2025).

The integration of theoretical and practical activities contributes to the development of higher-order cognitive processes, such as analysis, synthesis, and evaluation, with the teacher playing a key role in guiding students and fostering reflection (OECD, 2023).

2.4. Safety and Organization of Work in the Classroom/Workshop

Student safety represents one of the fundamental prerequisites for high-quality teaching in Engineering and Technology. Working with tools, materials, and devices requires clearly defined rules, continuous supervision, and consistent implementation of safety procedures, along with the gradual development of students' competencies for safe work in accordance with their age and abilities (Jokić, 2024).
In addition to safety, the organization of the learning environment and activities plays an important role in work efficiency, risk reduction, and the creation of a positive learning atmosphere.
The development of work habits and a safety culture should begin in primary education through clearly structured activities and appropriate organization of the learning environment (European Training Foundation, 2023).

3 CONTEMPORARY METHODOLOGICAL CHALLENGES IN TEACHING ENGINEERING AND TECHNOLOGY

3.1. Limited Instructional Time and Extensive Curriculum Content

One of the key methodological challenges in teaching Engineering and Technology is the imbalance between the allocated instructional time and the scope of curriculum content. Limited time often hinders the implementation of activities that require planning, practical work, and reflection, which are essential elements of high-quality technical and technological education.
Curriculum overload negatively affects the application of active teaching methods and often leads to the reduction or superficial implementation of practical activities, thereby diminishing the educational value of the subject and complicating the integration of theory and practice (OECD, 2023; Jokić et al., 2025).

3.2. Diverse Levels of Prior Knowledge and Student Abilities

Teaching Engineering and Technology takes place in heterogeneous classrooms where students differ in prior knowledge, interests, and abilities. This diversity represents a significant methodological challenge, particularly in practical work that requires an individualized approach.
Differentiated instruction involves adapting the complexity of tasks, pace of work, and level of support provided to students. However, its consistent implementation is often hindered by limited time and resources, which may result in decreased motivation and uneven student achievement (UNESCO, 2023; Jokić, 2024).

3.3. Material and Technical Conditions and Availability of Equipment

The quality of teaching in Engineering and Technology largely depends on material and technical conditions, including the availability of equipment, materials, and appropriate workspace.
Insufficient school equipment often limits the implementation of practical and project-based activities, forcing teachers to adapt content to existing conditions, which may reduce opportunities for learning through hands-on experience (European Training Foundation, 2023; Jokić, 2024).
The use of well-designed and multifunctional construction kits can enable more flexible organization of practical activities and significantly enhance the achievement of learning outcomes, particularly in resource-constrained educational environments.

3.4. Teacher Competencies and Professional Development

Teacher competencies are a key factor in ensuring the quality of teaching Engineering and Technology. These competencies include subject-specific knowledge, methodological and pedagogical skills, as well as digital competencies, along with a commitment to continuous professional development.
Although contemporary approaches require the application of active teaching methods and digital tools, opportunities for systematic professional development are often limited, which hinders the effective implementation of innovative methodological solutions in practice (OECD, 2023; Jokić et al., 2024).

3.5. Student Motivation and Perception of the Subject

Student motivation and their perception of the subject of Engineering and Technology significantly influence the quality of the teaching process. In some contexts, the subject is perceived as less important compared to other academic disciplines, which may negatively affect student engagement.
The relevance of content and its connection to real-life situations, as well as the representation of roles and professions, influence students' interests and aspirations. This highlights the importance of carefully designed instructional content and methodological approaches (UNESCO, 2023; Jović & Jokić, 2026).

Taking these challenges into account, there is a clear need for the application of contemporary methodological approaches that can contribute to overcoming these limitations and improving the overall quality of teaching.

4 CONTEMPORARY METHODOLOGICAL APPROACHES IN TEACHING

4.1. Project-Based Learning in Engineering and Technology Education

Project-based learning represents one of the most appropriate methodological approaches in teaching Engineering and Technology, as it enables students to engage over an extended period in complex and meaningful tasks that integrate knowledge, skills, and attitudes. Within project work, students go through phases of planning, implementation, testing, and evaluation, which corresponds to the nature of technical and technological processes.

This approach is fully aligned with the competency-based model of education, as it fosters the development of technical, digital, and entrepreneurial competencies, as well as problem-solving and collaboration skills (Jokić et al., 2024).

According to OECD (2023), project-based learning contributes to the development of functional competencies, particularly problem-solving, collaboration, and autonomy. In the subject of Engineering and Technology, projects may focus on designing technical models, improving everyday objects, or solving real-world technical problems, thereby increasing student motivation and the relevance of learning.

For example, a project task may involve designing and constructing a functional model of an eco-friendly house, where students plan material selection, build the model, and analyze the energy efficiency of their solution. In this context, the use of versatile construction kits can further facilitate project implementation and allow adaptation to different teaching conditions. In this way, students meaningfully connect theoretical knowledge with practical work and develop the ability to apply knowledge in real-life contexts. These findings are consistent with recent research indicating that STEM-integrated project-based learning enhances student engagement, problem-solving, and functional knowledge (Auliyani et al., 2025).

4.2. Problem-Based Learning and Learning Through Real-World Tasks

In addition to project-based learning, problem-based learning represents another significant approach. It is based on presenting authentic problems that do not have predefined solutions and that encourage students to investigate, analyze, and make decisions. This approach is particularly suitable for technical and technological subjects, as it reflects real-life contexts in which technology is applied.

UNESCO (2023) emphasizes that learning based on real-world tasks contributes to deeper understanding and the development of critical thinking. In Engineering and Technology education, such tasks may include analyzing technical systems, optimizing solutions, or evaluating the environmental impact of technology, thereby linking theoretical knowledge with practical application.

The application of problem-based learning supports the development of higher-order cognitive processes and enables students to actively construct knowledge, in line with contemporary didactic models (Jokić, 2024).

For example, students may be given the task of organizing a workshop workspace, where they analyze the arrangement of tools, safety conditions, and work efficiency, and propose optimal solutions. Such tasks promote functional thinking and the application of theoretical knowledge in practical contexts.

4.3. Differentiation and Individualization of Instruction

In addition to the aforementioned approaches, differentiation and individualization of instruction play a crucial role. Differences in students' prior knowledge, interests, and abilities require the application of differentiated and individualized methodological strategies.

In Engineering and Technology education, differentiation can be achieved by varying task complexity, material selection, pace of work, or the level of student autonomy. Contemporary pedagogical frameworks emphasize that differentiation contributes to educational inclusion and enables the progress of all students (OECD, 2023).

In practice, this approach requires additional methodological planning but allows teachers to address individual differences and improve the effectiveness of the teaching process. Flexible forms of learning organization, including modular and short instructional units, can further support adaptation to students' needs (Jokić et al., 2023a).

For example, within the same task, students may be offered activities of varying levels of complexity: a basic level involving the construction of a simple model based on given instructions, and an advanced level requiring

students to independently design and improve the model by adding functional elements. This approach enables all students to work on the same problem at a level appropriate to their abilities and pace of learning.

4.4. Interdisciplinary Approach in Teaching

Furthermore, an interdisciplinary approach enables the integration of Engineering and Technology content with other subjects, such as mathematics, physics, informatics, visual arts, or biology. This approach allows students to examine technical problems from multiple perspectives and develop a more comprehensive understanding of the world.

According to the European Commission (2022), interdisciplinary learning is a key component of modern STEM/STEAM education and contributes to the development of creativity and innovation. In Engineering and Technology education, interdisciplinary projects connect theoretical knowledge with practical work and enhance the relevance and meaningfulness of learning.

The integration of different domains of knowledge further contributes to the development of key competencies and the functional application of knowledge in real-world situations (Jokić et al., 2024).

For example, an interdisciplinary project may involve designing and constructing a bridge model, where students apply mathematical knowledge for dimension calculations, physics for understanding forces and loads, and technical knowledge for material selection and construction. Such an approach supports the integration of knowledge and the development of a holistic understanding of technical systems in real contexts.

Contemporary STEM approaches based on the engineering design process further enhance critical thinking and problem-solving through the integration of multiple disciplines (Syukri et al., 2026).

The proposed methodological approaches are particularly valuable because they can be implemented even in resource-constrained environments, without the need for complex technical infrastructure.

5 DIGITAL AND INNOVATIVE APPROACHES IN TEACHING PRACTICE

Contemporary methodological approaches are further enhanced through the application of digital technologies, which enable their more effective implementation in teaching practice.

5.1. The Use of Digital Tools in Technical Problem-Solving

Digital tools in Engineering and Technology education have the greatest educational value when used as a means for solving technical problems, enabling students to plan, test, and improve technical solutions, thereby strengthening the connection between theory and practice.

UNESCO (2023) emphasizes that digital technologies should be used to support active learning and critical thinking, through the exploration of technical problems, analysis of solutions, and documentation of work processes.

Digital tools should be integrated into problem-based and project-based learning to ensure their functional and pedagogically justified use (Jokić et al., 2024).

5.2. Digital Modeling, Simulations, and Technical Documentation

Digital modeling and simulations represent a significant innovative potential in Engineering and Technology education. By using 2D and 3D modeling tools, students can visualize technical solutions, test functionality, and identify errors before creating physical products.

Simulations contribute to the development of abstract thinking and systemic understanding, particularly when connected with practical tasks, while the creation of technical documentation fosters precision, planning, and responsibility (OECD, 2023; Jokić et al., 2024).

5.3. Development of Digital Competencies Through Teaching

Engineering and Technology education provides strong opportunities for the development of digital competencies through the solving of concrete technical problems, ensuring their applicability and long-term retention.

Digital competencies are developed in an interdisciplinary context and in connection with real-world problems through the use of digital tools in design and analysis (European Commission, 2022).

Microlearning can contribute to more efficient acquisition of digital content through short and focused instructional activities, although it requires careful methodological planning to avoid fragmentation of knowledge (Jokić et al., 2023a). Research also indicates that STEAM-based project learning significantly

contributes to the development of 21st-century skills, including collaboration, creativity, and critical thinking (Oanh & Dang, 2025).

5.4. Safe and Pedagogically Justified Use of Technology

Safety and pedagogical justification are key prerequisites for the effective use of digital technologies in teaching. Teachers are responsible for ensuring a safe digital environment and aligning technology use with clearly defined educational objectives.
It is essential to foster students' digital responsibility and promote the use of technology in ways that support learning and competency development (UNESCO, 2023).
The application of formative assessment supported by digital tools enables continuous monitoring of student progress and timely feedback, thereby enhancing motivation and learning outcomes (Jokić et al., 2023b).
In this regard, digital tools should be an integral part of the methodological framework of teaching, rather than an additional or supplementary activity.

6 TEACHING ENGINEERING AND TECHNOLOGY AND STUDENTS' CAREER GUIDANCE

In addition to improving the teaching process, contemporary approaches in Engineering and Technology education also play an important role in students' career guidance.

6.1. Experiential Learning as a Basis for Career Orientation

Experiential learning represents an important foundation for students' career orientation, as practical activities enable them to gain a more realistic understanding of technological processes, work requirements, and their own abilities. Through project-based and hands-on tasks, Engineering and Technology education allows students to "experience" different roles characteristic of technical professions, thereby fostering the development of technical, digital, and entrepreneurial competencies (Jokić et al., 2024).
Early career learning based on experience contributes to more informed educational and professional decision-making (OECD, 2023).

6.2. Development of Students' Interests, Self-Confidence, and Work Habits

Engineering and Technology education contributes to the development of students' interests, self-confidence, and positive work habits through successful engagement in practical tasks and the affirmation of diverse abilities. This approach is particularly important for students who may not excel in traditional academic subjects, as it enhances their sense of competence and motivation for learning (UNESCO, 2023).
At the same time, the way roles and professions are represented in teaching materials can influence students' career aspirations, highlighting the importance of their careful methodological design (Jović & Jokić, 2026).

6.3. Teaching as a Space for Exploring the World of Work and Professions

Engineering and Technology education can serve as a bridge between school and the world of work, enabling students to become familiar with contemporary professions and work processes through project tasks and the analysis of technical problems.
According to the European Training Foundation (2023), exposure to the world of work should begin in primary education through activities that raise awareness of opportunities without leading to early professional selection. Connecting teaching content with contemporary technological contexts contributes to a better understanding of the demands of modern professions (Jokić et al., 2024).

6.4. The Role of the Teacher in Career Learning

The teacher of Engineering and Technology plays a key role in students' career orientation as a planner, mentor, and mediator between education and the world of work. Through carefully designed tasks and reflective activities, teachers support students in recognizing their own interests and abilities, while connecting learning content with real-world professional contexts (OECD, 2023).
At the same time, teachers can contribute to breaking stereotypes and promoting equal opportunities, thereby emphasizing the educational and social dimension of teaching (Jović & Jokić, 2026).

7 DISCUSSION: METHODOLOGICAL POSSIBILITIES FOR IMPROVING TEACHING

Based on the previously discussed methodological frameworks, challenges, and approaches, several key directions for improving teaching practice can be identified.

7.1. Improving Teaching Under Existing Conditions

The improvement of Engineering and Technology teaching can be achieved even in resource-constrained conditions through the methodological restructuring of the teaching process. This includes clearer definition of learning outcomes, rationalization of content, and a focus on a smaller number of meaningful tasks, combined with both individual and collaborative work and the encouragement of student reflection (UNESCO, 2023; Jokić et al., 2024).

7.2. Balancing Theory, Practice, and Future Competencies

One of the key methodological challenges is achieving a balance between theoretical knowledge, practical activities, and the development of competencies. In this context, theory should serve a functional role in understanding and improving practical work.

In teaching practice, this implies concise and purposefully structured theoretical explanations, practical activities as the central component of instruction, and the development of soft skills through teamwork, thereby supporting functional knowledge and preparing students for contemporary challenges (Jokić et al., 2025; Jokić et al., 2024).

Although contemporary methodological approaches have significant potential, their effective implementation depends on teacher competencies, organizational conditions, and systemic support within the educational system.

7.3. Possibilities for Applying TVET Principles in Teaching Practice

Certain principles of Technical and Vocational Education and Training (TVET) can be applied in primary education through work-based learning, real-world tasks, and project-based approaches, adapted to students' developmental levels.

The application of these principles through the simulation of work processes, analysis of professions, and the development of work habits contributes to connecting education with the world of work and supports the development of functional competencies (European Training Foundation, 2023; Jokić et al., 2024).

7.4. Good Practice and Teacher Reflection

The quality of teaching can be improved through flexible methodological models, adaptation to local contexts, and continuous teacher reflection, as well as through the exchange of good practices and collaboration among teachers.

Reflection on teaching practice and a critical approach to instructional content, including the representation of roles and professions, contribute to creating a more inclusive and motivating learning environment (Jović & Jokić, 2026).

By integrating project-based, problem-based, and differentiated instruction, along with the functional use of digital tools, it is possible to develop a sustainable methodological model that aligns with contemporary educational demands and real classroom conditions.

7.5. A Methodological Model of a Lesson

As a practical contribution of this paper, a structured model of a lesson in Engineering and Technology education can be proposed, based on the integration of theoretical and practical activities and the development of functional competencies.

The proposed model includes the following phases:

(1) an introductory problem-based task to activate prior knowledge and motivation,

(2) brief theoretical guidance aimed at understanding the task,

(3) practical task implementation through individual or team work,

(4) testing and improvement of the technical solution,

(5) student reflection on the process and outcomes.

This lesson structure enables the integration of theory and practice, encourages active student participation, and contributes to the development of applicable knowledge and competencies in line with contemporary educational approaches.

The proposed model is flexible and can be adapted to different teaching topics and student age groups, ensuring its broad applicability in teaching practice.

8 CONCLUSION

Summary of Key Methodological Insights

The analysis of contemporary methodological challenges and teaching approaches indicates that Engineering and Technology education has significant potential for developing students' functional and practical competencies, but its realization largely depends on the methodological approach of the teacher. Active learning approaches, particularly project-based and problem-based learning, represent the most appropriate response to the specific nature of technical and technological content and the demands of contemporary education.

Key methodological insights emphasize the need for a balanced integration of theory and practice, the application of experiential learning, differentiation of instructional activities, and the functional use of digital tools, along with alignment with key competencies for lifelong learning (Jokić et al., 2024).

At the same time, identified challenges in achieving this balance confirm the need for careful methodological planning and adaptation of instructional content (Jokić et al., 2025).

The Importance of Contemporary Teaching Approaches for Educational Quality

Contemporary teaching approaches contribute to improving educational quality by enabling active student participation, fostering independence, and enhancing motivation. Project-based, problem-based, and interdisciplinary approaches, as well as the pedagogically justified use of digital technologies, create conditions for the development of knowledge relevant for further education and life in modern society.

These approaches are supported by recent meta-analyses indicating the significant impact of STEM project-based learning on students' creativity (Kwon & Lee, 2025).

The integration of digital and innovative approaches, including microlearning and formative assessment, contributes to the individualization of teaching and more effective monitoring of student progress (Jokić et al., 2023a; Jokić et al., 2023b).

Learning based on real-world problem-solving and connections to everyday life demonstrates greater educational effectiveness compared to reproductive learning models, thereby confirming the importance of Engineering and Technology education in contemporary schooling.

Recent studies consistently confirm that project-based, interdisciplinary, and STEM/STEAM approaches have a significant positive impact on the development of functional knowledge, creativity, and student competencies (Auliyani et al., 2025; Kwon & Lee, 2025; Oanh & Dang, 2025). The way content and professional roles are presented can further influence student motivation and aspirations, highlighting the importance of a critical approach to instructional materials (Jović & Jokić, 2026).

Recommendations for Teachers and Further Professional Development

Based on the findings of this study, the following recommendations can be made for improving teaching practice:

- plan instruction with clearly defined competency-based learning outcomes;
- increase the use of project-based and problem-based tasks;
- apply differentiation and individualization in teaching;
- use digital tools in the context of problem-solving;
- encourage student reflection on their own learning processes.

Teachers' professional development should focus on strengthening methodological and digital competencies, sharing good practices, and participating in professional learning communities.

In this way, Engineering and Technology education can contribute to the development of competent, independent, and motivated students prepared for contemporary society.

The particular value of this paper lies in the fact that the proposed methodological approaches do not require significant material investments, but are based on a thoughtful reorganization of the teaching process, enabling their broad and sustainable implementation in diverse educational contexts.

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Educational Robotics and Programming for Cognitive Development in Primary Education: A Longitudinal Case Study

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Abstract. In recent years, following the introduction of Informatics and Computing as a compulsory subject for grades 5–8 in the Republic of Serbia, robotics has gained significant traction among primary school students. Engaging with robotics kits enables students to apply their acquired knowledge effectively, foster creative problem-solving, enhance logical and computational thinking, and improve teamwork skills.

This paper examines the impact of educational robotics on students' cognitive development through a three-year longitudinal case study in primary education. The study explores the integration of robotics into curricular and extracurricular activities and its contribution to cognitive skill development. Data were collected through classroom observations, interviews, and analysis of student work.

Findings suggest improvements in algorithmic thinking (approximately 80%), autonomy (75–80%), and engagement (75%), indicating potential long-term cognitive benefits of robotics-based learning. Findings highlight the pedagogical value of educational robotics in fostering active, student-centered learning environments, emphasizing the importance of teacher guidance and structured task design.

Key words and phrases: Primary education, educational robotics, programming activities, STEM education, cognitive development

1 INTRODUCTION

Robotics education integrates designing, constructing, and programming robots. Robotics integrates mechanics, electronics, computer science, and automation, enabling students to learn through problem-solving, design, and programming activities. (Lapov et al., 2018), (Chaudhary et al., 2016). The application of robotics in education encourages active student participation and the development of cognitive and social competencies through work on functional robot models (Alimisis, 2013).

Although there is a large body of research on the application of robotics in education, in the Republic of Serbia, this field remains insufficiently explored in the context of primary education. The paper aims to analyze, through a case study, the impact of STEM-based learning activities involving robotics and programming on the development of students' motivation, cognitive abilities, and teamwork skills.To systematically examine the impact of educational robotics activities, the following research questions were defined:

- RQ1: How does participation in robotics activities affect student motivation?
- RQ2: To what extent do robotics activities contribute to the development of problem-solving skills?
- RQ3: How do robotics activities influence teamwork and collaboration among students?
- RQ4: What are the effects of robotics activities on students' cognitive development?

In this study, cognitive development is operationalized through indicators of computational thinking, problem-solving, and task efficiency.

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2 Theoretical Background / Literature Review

In robotics education, several key learning theories apply:

- Constructivism in learning and teaching, primarily based on the works of Ernst von Glasersfeld, Jean Piaget, John Dewey, Lev Vygotsky, and Paul Watzlawick. Constructivist learning is defined as a process of knowledge construction through active interaction with the environment (Fosnot & Perry, 2005). The fundamental assumption of this theory is the necessity of social interaction among students for learning to occur (Tarakli et al., 2025).
- Seymour Papert emphasizes the educational potential of computers in the development of experimental and reflective learning (Slotnick, 2017).
- The Self-Determination Theory, according to Richard M. Ryan and Edward L. Deci, explains motivation through the needs for autonomy, competence, and relatedness, which are encouraged through practical activities (Ryan & Deci, 2018). The practical application of robotics in teaching, as well as working on real-world projects, provides satisfaction and motivates students to further progress in this field.
- David A. Kolb's Experiential Learning Theory: According to Kolb (Kolb, 1984, p. 38), "Learning is the process whereby knowledge is created through the transformation of experience. Knowledge results from the combination of grasping and transforming experience".

2.1 The Impact of Robotics Education on Students' Cognitive Development

The development of educational robotics and its integration into school subjects in many countries has encouraged a re-examination of its significance and impact on students, particularly in relation to their cognitive development. Piaget defines intelligence as a set of complex cognitive abilities such as problem-solving, analysis, judgment, and reasoning, which serve the function of effective adaptation (Zotović-Kostić, 2023).

Although researchers in some countries attempt to determine the impact of robotics on students' cognitive development, the methods and approaches for measuring these changes are not globally standardized, and research results therefore often vary.

A 2020 study in Canada, conducted with 31 children aged 6–8, showed that learning robotics improves computational skills, including visuospatial memory and logical reasoning. Eye-tracking data indicated better focus and faster information processing (Liu et al., 2023). Results of a 2023 systematic review based on 22 studies show that robotics activities contribute to the development of sequencing, debugging skills, and more complex concepts such as conditionals and loops, particularly in younger learners (Ching & Hsu, 2023).

The aforementioned theoretical approaches form the basis for analyzing educational robotics as an active, student-centered learning approach. In this paper, these theories are used as an interpretative framework for understanding observed student behaviors and learning outcomes.

3 Educational Robotics in Serbian Primary Schools

School subjects for upper grades of primary schools in the Republic of Serbia, from which robotics competitions are implemented, are Informatics and Computer Science, Technology and Engineering. Regardless of its relevance, robotics, according to the Rulebook on the Curriculum and Learning Plan*, is not represented as a separate teaching topic in either of the two mentioned subjects.

3.1 Learning environment

In the primary school "Nata Jeličić" in Šabac, the computer science classroom is equipped with LEGO EV3 and SPIKE Prime kits, Tello drones, mBot robots, micro:bit devices, a 3D printer, and supporting equipment. In addition, over the past four years, students together with their mentors have participated in and achieved significant results in various competitions in programming and the application of the aforementioned equipment.

3.2 Procedure

Depending on the competition they are preparing for (and the number of students per team), the sections are organized on weekdays or on Saturdays. For the FIRST LEGO League, projects followed the official seasonal themes, while for other competitions, students worked on open-ended projects developed through group discussions, research, and practice of previous competition tasks.

3.3 Pedagogical Goals and Learning Outcomes of the Robotics Section

- Development of critical thinking, problem-solving skills, and creativity.
- Interdisciplinary approach – connecting mathematics, physics, informatics, and technology.
- Development of students' digital and programming competencies.

3.4 Teaching Models and Approaches

- Project-Based Learning (PBL). Its focus is on students, while the teacher is primarily perceived as a coordinator of the teaching and learning process (Županec, Lazarević, & Olić-Ninković, 2024).
- Problem-Based Learning (PBL). Searching for solutions to real-world problems requires students to actively construct knowledge through authentic activities similar to those carried out by professionals in various fields. (Ristanović, Radović & Marković, 2025).
- Inquiry-based learning and experiments.
- Integration of robotics into existing subjects and elective programs.

4 Research Methodology and Case Study Design

In this study, a qualitative approach was applied through a case study, with the aim of conducting a detailed analysis of the implementation of educational robotics in a real school environment. This approach was chosen because it enables a deeper understanding of complex educational processes over an extended period of time.

4.1 Sample of participants

The case study was conducted at the primary school "Nata Jeličić" in Šabac during the 2022/23, 2023/24, and 2024/25 school years. Each school year, approximately 20 students from grades 5 to 8 attended one of five programming and robotics sections. Specifically, these included preparation for the FIRST LEGO League (*FLL*) competition, programming and control of micro:bit devices, "Knowledge for the Future", control and programming of Tello drones and mBot Series 1 robots, as well as competitions in Python programming. Of the listed competitions, only FLL is not included in the official Competition Calendar*, which means that registration fees and other related costs must be covered by sponsors.

The sample can be characterized as a convenience sample, as participation in the activities was not mandatory, and students took part within extracurricular robotics and programming sections. The groups were heterogeneous in terms of age, gender, and prior knowledge. The main limitation of the study is the relatively small and non-random sample.

4.2 Data collection methods

Data collection was conducted continuously over three school years, which enabled longitudinal monitoring of students' development. Data were collected through: observation of students' activities during workshops, analysis of students' projects and competition results, informal interviews and conversations with students, and teachers' reflective notes. Given the qualitative nature of the study, results represent interpretive indicators rather than statistically generalized findings.

4.3 Data analysis procedure

Qualitative data collected over a period of three school years were analyzed using thematic analysis. The analysis was conducted in three steps: initial data analysis, categorization, and interpretation of results. In the initial phase, data from classroom observations, teacher reflective notes, informal student interviews, and

project documentation were reviewed. The data were divided into smaller, meaningful units, such as student statements, behaviors, and recorded activities. In the second step, these units were assigned codes describing recurring patterns in student behavior and learning. The codes were then grouped into broader categories representing the main areas of impact of robotics instruction, namely computational thinking, teamwork, and motivation for progress and learning. In the final phase, the relationships between these categories were analyzed in order to identify how they evolved over time. The frequency and intensity of these patterns were estimated based on their recurrence over the three school years.

To ensure greater reliability, the data were cross-validated using multiple sources, including classroom observations, student reflections, and competition results. This approach enabled triangulation and confirmation of the findings from different perspectives. The results presented in the Results section are based on the frequencies of coded observations collected over a three-year period. These frequencies were then converted into percentages for easier comparison and interpretation.

5 Results and Discussion

5.1 Developed skills

By analyzing the collected data (observation of students' activities, analysis of projects, and teachers' reflective notes), recurring patterns in student development were identified. Through thematic analysis, improvements in algorithmic thinking were observed in approximately 80–85% of students, based on the frequency of coded observations, which was reflected in a better understanding of loops, conditional statements, and task sequencing. Teamwork skills improved in the majority of students, particularly among those who had no prior experience in collaborative activities, which is consistent with the social aspect of constructivism (Tarakli et al., 2025). Independence in work increased in 75–80% of students, manifested through more frequent self-initiated detection and correction of errors in code and robot design, in line with Papert's approach (Slotnick, 2017).

The results are based on a convenience sample of approximately 20 students per school year (grades 5–8), observed over a three-year period using coded qualitative data and frequency analysis. A summary of the results is presented in the table below for clearer overview and interpretation.

Table 1. Summary of Results Based on Research Questions (RQ1–RQ4)

Research Question	Main finding	Percentag/indication
RQ1 (motivation)	Increased motivation and engagement	~75% of students
RQ2 (problem-solving)	Improved algorithmic thinking	~80–85% of students
RQ3 (teamwork)	Better collaboration in mixed groups	The majority of students
RQ4 (cognitive development)	Improved autonomy and task efficiency	~75–80% of students

5.2 Competition results

The student teams vary across grade levels. When certain students from a team complete the eighth grade, younger students take their place, so the teams are always mixed in terms of grade level and, in many cases, gender as well. In LEGO-based teams, the proportion of girls is higher than in other disciplines.

Analysis of the results shows that more than 60% of the teams achieved qualification to a higher competition level (regional or national), while approximately 40% of the teams won one of the top three places at various competition levels. These results indicate a stable level of team performance despite changes in team composition across school years.
The table below presents the achieved results of the students.

Table 2. Competition Results

School year	Activity / Competition	Number of students	Competition level	Result
2022/23	FLL (Lego robotics)	9	National	7th place out of 16
2022/23	Tello drone	4	Regional	3rd place

School year	Activity / Competition	Number of students	Competition level	Result
2022/23	mBot Series 1	4	Regional	No placement
2023/24	FLL (Lego robotics)	8	National	4th place out of 18
2023/24	Tello drone	4	Regional	No placement
2023/24	mBot robot	4	Regional / National	3rd place (regional), 2nd place (national)
2023/24	Python programming	3	Municipal / Regional	Passed
2023/24	Python programming	1	National	3rd place
2023/24	Micro:bit Student work showcase	2	National	Participation
2024/25	Micro:bit Student work showcase	2	National	Participation, special award
2024/25	mBot robot	4	Regional / National	2nd place (regional), 2nd place (national)
2024/25	Tello drone	4	Regional	Did not qualify for the national level
2024/25	FLL (Lego robotics)	8	National	Not held / exhibition event

Observed improvements

Based on the longitudinal monitoring of student activities, several key improvements were identified:

- Longitudinal tracking over three school years showed high retention – no student dropped out of the club after joining, although variations in engagement levels were observed among participants. Increased motivation (according to Self-Determination Theory) (Ryan & Deci, 2018) was reflected in consistent participation and higher engagement in approximately 75% of students, confirmed by more frequent self-initiated idea proposals during workshops.
- Increased engagement during activities was observed in approximately 75–80% of students, which is consistent with (Slotnick, 2017).
- Improved teamwork skills, in line with (Fosnot & Perry, 2005) and (Tarakli et al., 2025). Since the teams are mixed by grade level and gender, participation in team activities led to improved communication skills and easier interaction among students within the school.
- Faster task completion compared to the beginning of the program was observed in approximately 90% of students, which is consistent with (Kolb 1984).

As part of the qualitative data collection, students' reflections were analyzed to gain deeper insight into their learning experiences and perceived progress. Student D.S. reported increased motivation during the second FLL season, stating: "In the second FLL season, I had higher motivation to work due to my previous experience. I wanted our team to perform better, so I put in more effort." This statement aligns with the observed increase in engagement over time. Student L.V. reflected on skill development in drone control, noting: "In the first season, I had better control of the drone. I aim to further improve my skills during practice in order to perform better." This indicates a continuous orientation toward skill improvement and mastery learning. Student D.K. reflected on his learning progress and motivation, stating: "I can see progress in my work, which motivates me to put in even more effort. In the second season, we achieved better results with the micro:bit than in the first. I consider this a significant success for both members of the team." This statement supports the observed increase in student motivation and sustained engagement over time, as well as the development of performance-oriented and collaborative skills.

The obtained results directly address the defined research questions. Regarding RQ1, increased student motivation is evidenced by high retention rates and sustained engagement across all three years. In relation to RQ2, improvements in problem-solving skills are reflected in the development of algorithmic thinking and more efficient task completion. Concerning RQ3, enhanced teamwork is demonstrated through improved communication and collaboration within heterogeneous student groups. Finally, with respect to RQ4, the observed gains in computational thinking, autonomy, and task efficiency indicate a positive impact of robotics activities on students' cognitive development.
The obtained results of the longitudinal case study suggest that robotics education, based on constructivist principles (Piaget, Vygotsky) and experiential learning theory (Kolb), enables students to actively construct knowledge through hands-on work, experimentation, and project-based activities.

In contrast to most short-term studies (Liu et al., 2023; Ching & Hsu, 2023), this research covers a period of three school years, which provides insight into long-term effects (e.g., student retention and cumulative skill development).

Although the findings indicate positive effects of robotics education on students' cognitive development, some limitations should be considered. The study is based on a relatively small, non-random sample from a single school, which may limit the generalizability of the results. Additionally, the qualitative nature of the research relies on interpretative analysis, which may introduce subjectivity. Nevertheless, the results are consistent with previous studies (Liu et al., 2023), (Ching & Hsu, 2023), confirming that educational robotics can support the development of computational thinking and problem-solving skills. These findings highlight the importance of systematically integrating robotics into primary education, not only as an extracurricular activity but as a structured component of the curriculum.

6 Conclusion

Analysis of the existing curricula in primary education indicates a lack of a clear national document defining methodology, standards, and unified pedagogical approaches for teaching robotics. Improving robotics education requires teacher professional development, integration of robotics into existing school subjects, and stronger institutional support for STEM fields.

The main contribution of this study lies in the presentation of a longitudinal case study on the implementation of educational robotics in a primary school in Serbia, with a particular focus on the development of students' competencies. The obtained results indicate that the systemic implementation of robotics education can represent a significant step toward the modernization of primary education in the Republic of Serbia. The findings of this study suggest that sustained engagement in educational robotics activities leads to measurable improvements in students' computational thinking, problem-solving abilities, and motivation, particularly when implemented over a longer period of time. Future research should focus on expanding the sample size, incorporating quantitative measurement instruments, and comparing different instructional models in order to further validate and generalize these findings.

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The difficulty of using XR systems - some experiences

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Abstract. This article presents a methodological framework for evaluating the difficulty of using eXtended Reality (XR) systems by combining subjective and objective assessment methods. The framework integrates a set of 2D and 3D test scenarios designed to systematically measure users' motor, visual, auditory, and cognitive abilities during interaction with XR environments. For each scenario, specific performance metrics and optional distractors are defined to capture task complexity under controlled conditions. The methodology further incorporates standardized user-experience questionnaires (SUS, NASA-TLX, VRSQ, IPQ), enabling the collection of subjective perceptions alongside behavioral and performance-based indicators. The resulting approach provides a comprehensive basis for assessing user workload, interaction difficulty, and overall usability in XR systems. It also reflects the current absence of unified procedures for objective evaluation in this domain. The proposed framework can support future research, comparative studies, and optimization of interaction techniques in both immersive and non-immersive XR applications.

Key words and phrases: eXtended Reality (XR), User eXperience (UX), usability evaluation, objective metrics, subjective metrics, virtual environments.

1 INTRODUCTION

Extended Reality (XR) is an application platform that combines virtual reality (VR), augmented reality (AR), and mixed reality (MR) technologies (Hudák & Sobota, 2021). Although it is not encountered every day, XR is gradually becoming a key part of the gaming industry, as well as simulation, training, and educational systems. XR is not immune to rapid technological development, as it continues to bring an increasingly wide range of innovative solutions and opens up new possibilities for interaction and experience. Its technologies are increasingly in demand, and it would be a mistake not to use their potential.

However, the current implementation of XR also brings certain challenges and problems (Flavián, Ibáñez-Sánchez & Orús, 2019), including:

- availability of appropriate hardware and software equipment,
- creation of high-quality and sufficient digital content,
- ensuring user collaboration in a virtual environment, including sharing virtual content,
- the complexity of using XR and related technologies, which affects the user experience and the overall user experience.

XR and related technologies have been used in our university teaching practice for approximately 15 years (and in research for about 30 years). Currently, these technologies are employed at the authors' workplace (Laboratory LIRKIS - Laboratory of Intelligent inteRfaces of Communication and Information Systems) primarily in practical classes across selected courses, such as User Interfaces and User Experience, Computer

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Game Development, Computer Graphics, Virtual Reality Systems, and Modeling and Simulation or limited in the course University of the Third Age (senior students). They are also extensively used in bachelor's, master's, and doctoral theses. As the laboratory equipment covers the entire virtualization pipeline, students are exposed to these technologies on a relatively broad scale and perceive this experience very positively. In practice, they primarily work with XR headset-based systems, as well as with a virtual CAVE system developed through our own research and development activities. This system represents a unique asset compared to many other universities that do not have access to such immersive CAVE environments.

Within this pedagogical context, we also focus on analyzing the impact of the use of these technologies in the educational process, with particular emphasis on virtual learning environments. These environments are examined throughout their entire lifecycle, from the design phase to user testing. Our research addresses not only the complexity of digital educational content and the costs associated with its development, but also the effects of XR technology usage on the target groups, namely students and teachers, within the teaching process.

One of our key research activities involves examining the complexity of deploying currently available XR technologies. While these technologies have the potential to enhance the efficiency and effectiveness of teaching, particularly in supporting the understanding of complex concepts, they may also impose cognitive and physical demands associated with working in immersive virtual environments. This assessment is conducted using both objective and subjective evaluation methods, with a strong focus on user experience. We anticipate that this approach will enable students and teachers to acquire interaction and communication skills in XR environments more rapidly and effectively, as well as to develop competencies in creating and managing digital content. The expected benefits include not only reduced costs of educational content development and improved accessibility for target groups, but also a deeper understanding of the complexity and suitability of XR technologies within pedagogical practice.

2 User Interfaces and User Experience

According to (ISO 9241-210: HCI), user experience (UX) is the sum of the user's perceptions and reactions that arise as a result of using or anticipated using a particular product, system or service. This includes emotions, beliefs, preferences, perceptions and physical or psychological reactions that occur before, during and after the interaction (i.e., it encompasses the entire time course of the experience). Providing the best possible user experience should be the primary goal of any interactive medium. In the case of software products, this aspect is particularly important in XR systems, where the primary goal is to ensure the most authentic and immersive form of user interaction with a computer-generated virtual environment (VE).

When evaluating UX-focused systems, it is recommended to combine subjective and objective methods, which together provide a comprehensive view of the user experience. This approach is based on established UX testing methodologies (Tcha-Tokey, Loup-Escande, Christmann, & Richir, 2016):

- Subjective (attitudinal) methods (García, Cano, & Moreira, 2024) – are based on individual assessments of test participants, which are most often obtained through questionnaires, interviews or other qualitative techniques.
- Objective methods – based on quantitative measurement, using devices and sensors to monitor physiological or behavioral reactions of users during interaction with the system.

In addition to the aforementioned pedagogical area, these methodologies are also used in the evaluation of XR systems created in the home laboratory of the LIRKIS authors, such as:

- the L-NeRVEn system for neurorehabilitation in collaborative XR for stroke patients (Korečko, Nehila, & Sobota, 2023), (Korečko, Sobota, Nehila, & Chmura, 2024) or
- educational VR environments with a scenario defined by a process graph (Korečko, Sobota, Mattová, & Kašela, 2022).

The device mediating the virtual environment to the user is most often an XR headset, usually from the Meta (Oculus) Quest product family.

Questionnaires and interviews are primarily used as subjective methods, capturing the views of individual participants in the relevant experiments. In order to ensure the greatest possible degree of compatibility with other similar measurements and also the degree of reliability of the results, four significantly expanded questionnaires are used, focusing on various aspects of UX. The first two questionnaires have a wide range of

uses and can also be used for non-immersive XR. They are the System Usability Scale (SUS) (Brooke, 1996), (Brooke, 2013) for assessing the usability of the system and the NASA Task Load Index (NASA-TLX) (Hart, 2006), where the user expresses how burdensome the performance of tasks in the system was. The SUS questionnaire is also commonly used in the context of VE and XR, for example to compare different types of XR headsets (Webster & Dues, 2017), methods of interaction with VE (Voigt-Antons, Kojic, Ali, & Möller, 2020) or to evaluate architectural simulations (Globa, Yildirim, Lyu, & Gocer, 2023). Examples of the use of the questionnaire in the field of VE and XR are the assessment of the mental load of surgeons during laparoscopic operations (Zheng, Jiang, Tien, Meneghetti, Panton, & Atkins, 2012) or the evaluation of VR training focused on medical first aid (Knudsen, et al., 2023). Recently, extensions of NASA-TLX focused on VE and XR have appeared, for example (Harris, Wilson, & Vine, 2020), (Vidal-Balea, Fraga-Lamas, & Fernández-Caramés, 2024), which add additional questions to the original ones.

The remaining two questionnaires only make sense to use in immersive XR (in this case, XR headsets). These are the Virtual Reality Sickness Questionnaire (VRSQ) (Kim, Park, Choi, & Choe, 2018), focused on the negative aspects of the XR experience, and the Igroup Presence Questionnaire (IPQ) (Schubert, Friedmann, & Regenbrecht, 2001), capturing the feeling of presence in a VE.

The primary source for objective UX evaluation is, for example, measurements of the success rate and duration of solving individual tasks (Spangenberger, Freytag, & Geiger, 2024) and (Lawson & Mayer, 2024) or video recordings recorded during the relevant testing from the first and third person perspectives. They are also implemented in the LIRKIS laboratory. The recording from the first-person perspective is usually provided by capturing the image output of the XR headset, and from the third person perspective it is captured by a separate camera placed on a tripod. Video recordings serve to evaluate the user's activity in the VE from the experimenter's perspective, including anomalies in this activity, and also as a secondary form of determining the duration of completing individual tasks.

Regarding objective methods, there are no generally accepted procedures for the field of XR (although it is possible to rely on ISO 9241-210: HCI and ISO 9241-11). In the following, we will try to present the procedures, metrics and scenarios typically used in the implementation of these methods in the authors' home laboratory.

3 Difficulty of Control and Manipulation in VE

As already mentioned, subjective and objective methods are usually used for UX measurement. The standardization of subjective methods (usually questionnaires) is relatively well developed. The same situation does not apply to objective methods and, moreover, they are usually influenced by the capabilities (both technical and programmatic) of the workplace where the measurement is performed. It is especially important to define metrics that will help us accurately monitor and evaluate the relevant experiments. The importance of accurate monitoring and measurement is emphasized, for example, by Seffah, Donyaee, Kline, & Padda (2006), where the most important items are the effectiveness and efficiency of measurement.

- Efficiency is a measure of the duration required for a user to complete a task with the least effort.
    - Time - is one of the most commonly used metrics. In many works, it is defined as the duration of a task. That is, the interval between the start of a task and its completion. The shorter the task execution time, the easier the task or the more efficient the participant. This metric is the basis for measuring efficiency and productivity.
    - Number of attempts - among the usability evaluation metrics is the number of attempts, which tells us how vigorously the user is learning and improving in performing tasks.
- Effectiveness is a measure of the user's success in performing a task.
    - Correct order - may not always be a tightly defined metric but is usually closely related to the success rate of the task. In some tasks, it is essential to follow the correct order of steps in order for the task to be successfully completed.
    - Number of errors or failed attempts - is a metric that tells us how many errors the user made before completing the task. Few errors usually indicate user precision or task simplicity.

In addition to these items (metrics), in the XR area we also use:

- virtual space dimension (2D, 3D),
- the measure of the simulated virtual physical quantity (e.g. volume, color, brightness, sound, etc.),

- the number of interactions with virtual objects,
- measured limbs or other body parts (e.g. head, fingers, eyes, ears, etc.),
- accommodates right- and left-handed people,
- types or multimodality of I/O devices (e.g. keyboard, mouse, gamepad, XR headset controllers, mobile phone sensors, monitor, XR headset screens, etc.)
- the number of usable/used I/O devices in the context of their multimodality, including their combinations and alternatives.

Furthermore, these metrics are combined with the aforementioned subjective questionnaire methods.

4 Test Scenarios and their Parameters

Several test scenarios were implemented to measure the difficulty of controlling XR systems developed within the laboratory. The following tables (Table 1, Table 2) will list the parameters of 22 scenarios, which were subsequently used mainly for testing the difficulty of teaching VEs. For the L-NeRVEn system, specific scenarios for the given area were later used. These scenarios mostly consisted of 3D scenarios (16) (for L-NeRVEn only 3D), the rest of the scenarios were 2D (6). Each scenario was given a unique identifier (S01-S22) and the text:

1) Clap (Instead of hands, take cymbals and make a sound with them),
2) Find a red ball among balls of a different color (Different geometric shapes, search by size, not by color),
3) 3D maze (Maze in catacombs with a torch (reduced visibility), maze from hedge, stone),
4) Hit the ball into the basketball hoop (Hit a paper ball into the trash can),
5) Sort objects from smallest to largest (Different fruits according to real size),
6) Build a tower of blocks, stack blocks on top of each other (Add texture to blocks (if a tower is built, a connected texture of the tower is created),
7) Open a box and put objects in the VE into it (Open a chest and put toys into it),
8) Interact with different geometric shapes in the correct order (textured objects),
9) Test movement in VE (Turn right, take a step, turn left, take a step, turn 180° and take a step),
10) Test fine motor skills (Unlock the door and open it, first unlock, then open),
11) Determine the location of the sound (There will be several speakers (people, animals) in the VE, determine which one is playing music by the sound),
12) Pour water from one glass to another (Chemical ampoules, pour green acid),
13) Walk between the given objects without touching them (Walk between cacti),
14) Identify the object and its outline (Several objects will be thrown, their outlines will be drawn on the ground, you need to move them to their place. The objects will be furniture),
15) Reaction to sound (The user should react to one predetermined sound in an VE with multiple distracting sounds),
16) Tidy up objects (Place small objects of healthy food on a large plate, all unhealthy ones out of sight),
17) Maze 2D (Find your way through the maze),
18) Pair objects (Forest path surrounded by nature),
19) Hit the circles with the cursor (Shoot at targets, ducks that will appear and disappear after a while),
20) Reaction time (If the light turns on, you must press the button),
21) Follow the line with the cursor (Instead of the line, there will be a river),
22) Catch falling objects with the cursor (Fruit and bombs, food and garbage, balloons and sharp objects).

Subsequently, Table 1 contains the number of VE dimensions, measurement metrics and the number of necessary input controllers. Table 2 mainly contains the elements that are tested by the scenario (limbs, legs, fine motor skills, orientation, reaction, sound perception, etc.).

The scenarios were designed so that the metrics were as diverse as possible. All 3D scenarios have the option of containing a random number of basic distractors, a maximum of 5. These distractors include: screen blackout, moving object, time pressure, fog or random sounds. 2D scenarios can contain a maximum of 2 distractors, which include: moving object, random sounds, blackout + time pressure. Some scenarios contain special distractors that are specific to the given scenario. Each scenario has a set time limit, the length of which depends on the given

scenario (can be changed, but not during the run).

Table 8 Dimensions, metrics, and driver count table

Scenario	Dimension	Number of Metrics (excluding time and task completion)	Metrics (excluding time and task completion)	Number of controllers
S01	3D	0	existence only	2
S02	3D	1	number of hesitations	1
S03	3D	1	number of hesitations	1
S04	3D	1	number of attempts	1
S05	3D	1	correct order	1
S06	3D	1	correct order	1
S07	3D	1	correct order	1
S08	3D	1	correct order	1
S09	3D	1	correct order	1
S10	3D	1	correct order	2
S11	3D	1	number of bad attempts	1
S12	3D	1	amount of water in the spilled glass	2
S13	3D	2	number of interactions with the object, number of hesitations	1
S14	3D	3	number of correctly placed, correctly rotated and repaired objects	1
S15	3D	3	reaction to the correct sound, time from the sound to the reaction to it, number of bad attempts	1
S16	3D	3	correct field of view, number of attempts, number of bad objects in the field of view	1
S17	2D	0	existence only	1
S18	2D	2	number of correct pairs, number of errors during the connection	1
S19	2D	2	number of rings hit, number of missed ones	2
S20	2D	2	reaction time, number of clicks during the red light	2
S21	2D	2	number of attempts, number of cursor stops	2
S22	2D	3	number of fruits, bombs and uncaught fruits caught	1 / 2

This article does not provide a detailed description of the cognitive characteristics of the users tested, nor a detailed description of the testing process, nor an overall evaluation of the testing, including statistical processing of the results. The purpose of the article was to present the procedure for testing UX in XR systems developed in the authors' home laboratory. The testing also showed that the order of the scenarios does not, in principle, affect the results. The respondents were verbally instructed before the start of the testing.

Table 9 Table of tested elements

Scenario	What is tested	Part of the human body used/social cognitive abilities (except vision)
S01	hand coordination	upper limbs, wrist
S02	color sensitivity	upper limbs, fingers
S03	orientation, movement planning skills	lower limbs, orientation skills, decision-making skills, quick decision-making
S04	movement accuracy	coordination upper limbs, fingers, consistency of task performance, accuracy
S05	visual perception, logical arrangement	upper limbs, fingers
S06	manipulation accuracy	upper limbs, fingers
S07	manipulation accuracy	upper limbs, fingers
S08	memory testing	upper limbs, fingers
S09	spatial orientation	lower limbs, orientation skills
S10	fine motor testing	upper limbs, fingers, accuracy

S11	auditory perception, orientation by sound	fingers, sound skills
S12	testing fine motor skills	upper limbs, fingers, wrist, stability and balance, accuracy
S13	spatial perception, movement accuracy, consistency of task performance	lower limbs, orientation skills, stability, accuracy, quick decision-making
S14	shape recognition skills, manipulation	upper limbs, lower limbs, fingers
S15	auditory perception, attention	fingers, sound skills, reaction speed, attention and concentration
S16	spatial orientation, visual field	upper limbs, lower limbs, fingers, visual attention
S17	orientation, movement planning skills	upper limbs, fingers, orientation skills, quick decision-making
S18	manipulation accuracy	fingers
S19	reaction speed, movement accuracy	fingers, reaction speed, adaptation to change, accuracy, quick decision-making
S20	reaction time testing, fine motor skills	fingers, reaction speed, attention and concentration
S21	hand-eye coordination, precision of movement	fingers, accuracy
S22	reaction speed, hand-eye coordination, selective attention	fingers, accuracy, quick decision-making

As mentioned earlier, at the end of each scenario and the entire testing, a subjective UX evaluation was also performed by the respondents in the form of the aforementioned questionnaires. Respondents answered the questions generally using a 5-point Likert scale, from 1 (completely disagree) to 5 (completely agree).



Figure 12 Participant during testing the difficulty of using the developed XR systems, including his view of the virtual environment.

5 Conclusion

This paper outlined a practical methodology for evaluating interaction difficulty in XR systems, combining established subjective questionnaires with a set of objectives, task-specific performance metrics. The approach was validated across 22 scenarios covering motor, perceptual, and cognitive demands, with configurable distractors that enable controlled variation of task complexity. While subjective measures provide insight into perceived workload and discomfort, the objective metrics capture concrete behavioral indicators such as accuracy, task order, error frequency, and reaction timing.

The work highlights the current absence of unified procedures for objective XR evaluation and demonstrates how a consistent set of scenarios and metrics can support repeatable testing within a laboratory environment. Although this study did not include statistical analysis or a detailed characterization of participant groups, the

framework is structured to accommodate both in future work. Expanding the methodology toward cognitive measurements, automated logging, and larger-scale comparative studies represents a natural direction for further development.

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The Use of Cloud Services for Scientific Research Purposes

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Abstract. Cloud services are used for a variety of purposes nowadays. They are used for computing activities, data storage and analysis, networking, database management, access to development tools, online available applications, etc. Some of the advantages of cloud services are: scalability, flexibility, reducing Information Technology (IT) infrastructure costs, availability, security and the support for new technologies. The researchers often need IT resources and ready-made software tools in their research that they can directly use for various proof-of-concept scenarios. This paper presents cloud services and cloud provider programs that researchers can leverage to achieve their scientific research goals in various fields.
Key words and phrases: Cloud, cloud services, IT resources, scientific research.

1 INTRODUCTION

Cloud is a model of using IT resources over the Internet. These are resources that are not located locally in companies or organizations, but rather external resources that are provided through the infrastructure of cloud service providers. This involves a complex infrastructure that is part of the data centers of cloud providers that are responsible for providing uninterrupted service to the end users. Data centers are large and sophisticated facilities that house servers and the entire cloud infrastructure. In addition to servers, data centers also contain networking devices, storage devices, power systems, temperature control systems, security systems, etc. A key concept in the cloud is the virtualization. It enables the creation of virtual resources based on physical resources in the cloud or the main infrastructure in the data centers. These virtual resources can then be used by multiple users. Although they are created based on physical resources, they still function as separate IT resources. This allows better utilization and sharing of data center infrastructure.

Cloud service providers offer ready-made services that can be used by the end users. There are three basic categories of cloud services: Infrastructure as a service (IaaS), Platform as a Service (PaaS) and Software as a Service (SaaS) (Kavis, 2014), (Younis et al., 2024). IaaS services enable the availability of basic IT infrastructure such as: virtual machines, networking devices, storage disks, etc. This type of service is most often used by users, companies, or organizations that do not want to invest in expensive physical infrastructure and decide to somehow rent infrastructure from a remote cloud service provider. PaaS model enables the development and execution of applications without developers to worry about the servers, databases, or operating systems. This allows rapid development and testing of applications on different platforms. SaaS services allow the use of ready-made software applications over the Internet. Sometimes companies need quick access to applications and access from anywhere. Using applications that need to be installed can be a cumbersome process. This may include purchasing applications, expensive licenses, installing them on each individual device, etc. This can take a lot of time and may not achieve the desired goal in the end. That is the reason why many companies decide to use cloud services, that can be used from anywhere and at any time.

According the recommendations of the National Institute of Standards and Technology, there are 5 essential characteristics of cloud computing model: on-demand self-service, broad network access, resource pooling, rapid elasticity and measured service (Mell & Grance, 2011). The users themselves order the services they want to use without any human interaction with the service provider. The services can be accessed from

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anywhere using a variety of devices and platforms. The resources of the cloud service provider a pooled in order to serve multiple users. The basis of this is the multi-tenant model, where the users only pay for the usage of the allocated resources. The resources can be elastically provisioned when needed, and released when no longer needed. Additionally, these resources can be scaled. There are two ways of scaling: vertical and horizontal. Vertical scaling allows increasing (scale-up) or decreasing (scale-down) the performance of resources depending of the utilization. Horizontal scaling allows addition or reduction of resources of same type (e.g., virtual machines) to handle the ongoing usage according to the workload. Cloud services also have metering capability for different types of abstraction levels (e.g., processing, storage, bandwidth, etc.). Their usage can be controlled, monitored and reported. This provides transparency for the consumer of the services and also for the cloud service providers. It is especially important for users to track their spending and plan the budget for using the cloud services.

The use of cloud technologies is really popular nowadays. Many companies and organizations use these technologies to meet their goals. Some of them use cloud-based IT infrastructure, some use ready-made cloud services, while others use various services to develop and host their applications (Kiryakova et al., 2015), (Gevko et al., 2021).

The researchers in their research, and proof of concepts, often need IT infrastructure in order to be able to practically carry out the experiments. Sometimes experiments require better IT resources with more power, memory, and storage space. The physical IT infrastructure they possess often does not meet the demands of complex research. The scaling of physical infrastructure components required for certain stress tests or use cases in experiments is a rather difficult operation. Additionally, the researchers sometimes need to run the experiments on different devices or platforms. They are often limited in this because they must own those devices and platforms in order to be able to do the experiments and obtain appropriate results. The cloud services according to their models and characteristics, can play a major role in the scientific research. Given the potential they have and the offered opportunities, they can significantly help the researchers. This is the reason why in this paper we consider the use of cloud services for scientific research purposes.

This paper is structures as follows. Section 2 presents the related work for the use of cloud services in the research. In Section 3, we give an overview of cloud providers and the most used cloud services from different cloud providers. Section 4 presents the use of cloud services for scientific research purposes. Section 5 is a conclusion of our work.

2 Related Work

(Shakeabubakor et al., 2015) in their paper present the use of cloud services and applications in order to improve the productivity of university researchers. They identified and noted some of cloud services that can be useful for the researchers and also depict the impact of the usage of cloud services on research activities. An interview was conducted with the researchers. The main conclusion of the interview was that the lack of knowledge about the cloud had an effect on the attitude towards the trust and the usage of cloud services. In (Iatsyshyn et al., 2019) the authors emphasized the importance of the use of cloud services for the preparation of the future PhD students and improve their digital competence. According to the paper, it is recommended for PhD students to use cloud-based platforms and services that would help them with scientific and scientific-organizational activities which would have a positive impact of organization and implementation of scientific research. The authors in (Navale & Bourne, 2018) present a perspective of the use of cloud computing applications for biomedical science. They highlighted the opportunities offered by cloud services, and in particular the services related to processing of big data that is important in biomedical research. Examples of individual cloud tools, workflows, platforms, healthcare cloud services and general-purpose cloud-based tools are also shown in the paper. The usage of cloud computing in e-science and the research challenges and opportunities are described in (Yang et al., 2014). The authors in this paper provide an insight of the need for cloud resources and services in the research communities. They also considered the cloud-based High-Performance Computing (HPC) in e-science. In (Nosenko et al., 2018) the authors present the importance of usage of high-tech cloud-based tools for collaboration among research institutions and universities. They also proposed a method for improving the research environment of higher educational institutions. A survey of the European Open Science Cloud (EOSC) services for expanding the capacity and capabilities of multidisciplinary scientific applications is shown in (Calatrava et al., 2023). The EOSC initiative provides an open, trusted, virtual and federated computing environment that can be used for hosting of scientific applications and also to store, share and reuse research data. The authors in their paper describe 10 thematic services of EOSC synergy that are grouped by scientific

disciplines such as Earth observation, Biomedicine, Astrophysics, and Environmental domain. The services provided by EOSC could be very important for the researchers.

3 Cloud Service Providers and Cloud Services

Over the years, a lot of companies have migrated their applications to the cloud, which has significantly increased the revenues of cloud service providers (Zdravev et al., 2021). The revenues from cloud services increased to $330 billion last year (Richter, 2025). The development of generative AI and new trends in the cloud have contributed to revenue growth. According to the global cloud market share of cloud service providers, Amazon Web Services (AWS) is still on the top with 29% (Richter, 2025). Microsoft Azure is on the second place with 20% and Google Cloud Platform (GCP) is on the third place with 13%.

The access to services is through cloud portals that are provided by the cloud service providers. In their portals, service providers offer a catalog of cloud services consisting of categories in which the specific services are located (Figure 1). The categories serve to make it easier to find services and to identify services that have a similar purpose. This is especially important for cloud providers that offer a large number of services and with the categorization we can easily find the service in the service catalog.

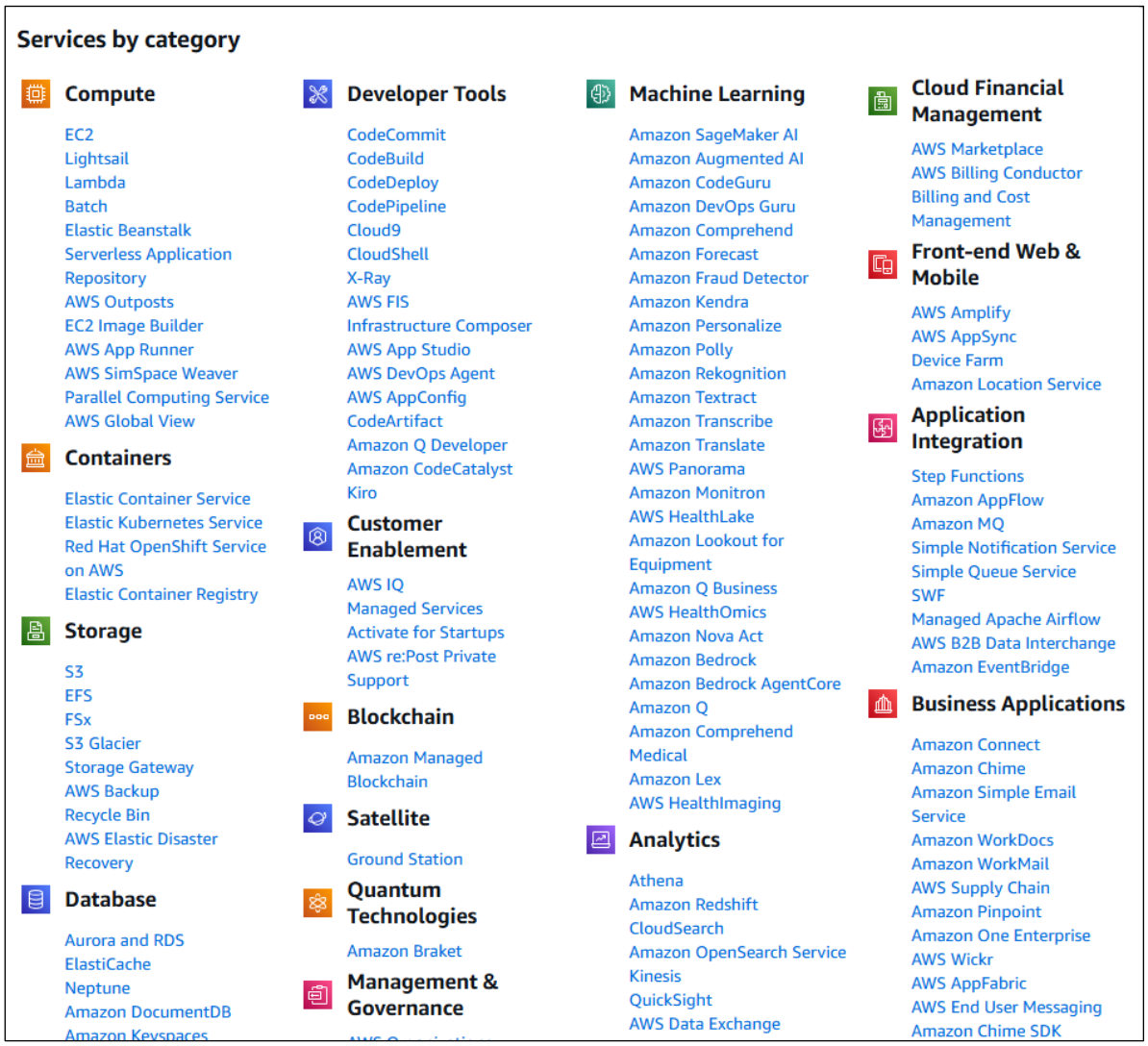


Figure 1. Categories of services in AWS

Table 1 shows services from different cloud service providers divided into 6 different categories: Compute, Storage, Databases, AI & Machine Learning, Internet of Things (IoT) and Analytics. Although there are other categories, some of the more recent ones are presented here.

Table 1. Cloud services from multiple cloud service providers in different categories

Category	Amazon Web Services	Microsoft Azure	Google Cloud Platform
Compute	EC2, Lambda, Lightsail	Virtual Machines, App Services, Virtual Machine Scale Sets	Compute Engine, Kubernetes Engine, VMware Engine
Storage	S3, EFS, FSx	Disks, Storage accounts, Data Lake Storage	Cloud Storage, Filestore, Managed Lustre
Databases	Aurora and RDS, DynamoDB, Neptune	Azure Database for MySQL/PostgreSQL flexible servers, Azure SQL Database, Azure Cosmos DB	Database Center, Cloud SQL, Firestore
AI & Machine Learning	Amazon SageMaker AI, Amazon Bedrock, Amazon Rekognition	Azure Machine Learning, AI Search, Bot Services	Vertex AI, Document AI, AI Applications
Internet of Things (IoT)	IoT Core, IoT Analytics, IoT Greengrass	IoT Central Applications, IoT Hub, Device Update for IoT Hubs	Combination of various GCP services is used such as Pub/Sub, Dataflow
Analytics	Athena, QuickSight, EMR	Analysis Services, Data factories, Data Lake Analytics	BigQuery, Pub/Sub, Dataflow

4 Cloud Services for Scientific Research Purposes

Nowadays, the researchers often encounter the need for certain IT infrastructure, tools or services that can be used in their research. This especially applies to the practical part, the proof-of-concept part, the results analysis part, etc. Although we can also use physical IT infrastructure for this purpose, it is not always sufficient. This primarily depends on the complexity of the experiments or the practical tasks that are part of the research. If we have a complex practical part that requires good infrastructure and dedicated services, in that case we can use cloud resources.

Another thing that cloud services enable is that we do not have to buy expensive equipment that will be used for a short period of time. With cloud services, we can use the infrastructure we need, and then when we no longer need it, we can delete the allocated resources. With the removal of the resources, the payment we have for them ceases. In this case, we only pay for what we have used (pay-as-you-go model) for a certain period of time.

Another thing that is also important for researchers is the rapid acquisition of the appropriate IT infrastructure or services needed to conduct the research. The procurement of physical IT infrastructure can sometimes be a complicated process, from compliance with procedures and laws when it comes to state institutions, to the time required for procurement and delivery, to the people who need to be hired for installation, etc. On the other hand, with the use of cloud services, the necessary resources are obtained upon request by the user and delivered immediately. This is especially important if the researchers have experiments that need to be conducted quickly. The cloud services and corresponding resources can be used immediately for research.

Sometimes the access to the appropriate infrastructure and services needs to be from different locations and on different devices. This is especially evident in research involving multiple researchers from different countries or locations. The physical infrastructure may have certain limitations in terms of access to it. Cloud services, by setting access rules, offer the possibility of accessing resources and services from anywhere and from any device. This can also be very significant for the researchers.

Additionally, with cloud services, the researchers can allocate as many resources as they need, instead of the usage of expensive infrastructure that need to be provided in advance. The feature of cloud services that is also important for researchers is the scaling. Sometimes when conducting experiments, we cloud start with infrastructure that is not performing at its best. In some cases, we have experiments where we need to examine how certain stress test passes when the number of users of certain application increases sharply. This also leads to a demand for resources (e.g., virtual machines) with better performance that can handle the user workload. The cloud services provide auto-scaling functionality that can immediately address the above situation.

The researchers often have a limited budget for purchasing equipment for their research. If they use cloud services, they need to have a control over costs. Typically, cloud service providers provide functionality for tracking accumulated costs through their cloud portals. The costs can be displayed by specific categories or by specific resources. Additionally, there is a possibility for tracking and analyzing costs in terms of a timeframe, for example daily accumulated costs, monthly, yearly or custom defined time period. Service providers also provide charts for the costs and consumption of resources, which also facilitates the process of analysis and cost trends.

Often, cloud service providers offer services for specific fields of research that have emerged as relevant over the years (Table 1). This is especially interesting for researchers who conduct research in these areas and need tools that are offered as cloud services. Sometimes some of the researchers look for tools or applications that can be installed on their computers and pay expensive licenses for that, without knowing that there are tools which cloud providers offer as a services. In this way, they can save money and use the services according to the pay-as-you-go model if it is a matter of short-term research and gain access to tools that have a specialized purpose in the research.

Cloud providers also provide access to services for academic purposes through special platforms intended for educational institutions (Velinov et al., 2024). Most often, through these platforms, the students and the researchers receive a free budget for using the services for a certain period of time. This budget they receive is not much, but it can help with some smaller research work in context of using appropriate cloud resources and services. This may include creating appropriate virtual machines for research purposes, using database management services, gaining access to SaaS solutions, etc. When using these platforms, we should only pay attention to the budget, because after it is used up, the access to the resources is not allowed. In context of this, we need to do timely data migration and other important things regarding the research work.

Cloud service providers also promote campaigns and programs for researchers to obtain free credits for using cloud services. For example, AWS offers the AWS Cloud Credit for research program (AWS Cloud Credit for Research, 2026). The following individuals can apply for this program: full-time faculty members at an accredited research institution, full-time research staff at an accredited research institution and graduate, post-graduate, or PhD students that are enrolled at an accredited research institution. Microsoft offers the Azure Cloud Computing Services for Education program that can be used by the students and researchers for free cloud credits and access to free cloud services (Inspire innovation in education with Microsoft Azure, 2026). Google Cloud promotes the Google Cloud for research program (Google Cloud for research, 2026). It offers a full stack, collaborative and AI-optimized platform that can be used for state-of-the-art research. Eligible to apply for this program are: faculty, PhD students and postdoctoral researchers from accredited higher education institutions and nonprofit research institutions in approved countries.

5 CONCLUSION

Cloud services are really widely used nowadays. They offer many advantages and full potential for future development and usage in different fields. Many researchers today require IT infrastructure and services that can be used in their research. In context of this, they can take advantage of the opportunities and benefits offered by cloud services. Nowadays, there are many academic programs for cloud technologies that can be used by students and researchers. Additionally, there are also campaigns and initiatives for obtaining free credits for using cloud services. This paper presents the opportunities for using cloud technologies for scientific research purposes.

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AI-Fuzzy Logic in Urban Micromobility Virtual Driving Simulations

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Abstract. The paper "AI-Fuzzy Logic in Urban Micromobility Virtual Driving Simulations" explores the application of fuzzy logic in assessing situational awareness of young micromobility drivers through virtual driving simulations in urban environments. Building on Endsley's model of situational awareness, the system incorporates input parameters such as reaction time, decision accuracy, and error frequency, which are processed by a fuzzy controller and translated into linguistic variables. These are then classified into low, medium, or high awareness levels, forming the basis for personalized training recommendations that support progressive skill development in a safe and controlled setting. The virtual simulations replicate real-world challenges ranging from simple pedestrian crossings to complex intersections with multiple participants, distractions, and reduced visibility, thereby enabling realistic evaluation of drivers' cognitive capacities. Findings indicate that fuzzy logic surpasses the rigid boundaries of traditional assessment methods, offering a more flexible and precise understanding of performance. Beyond its educational role, the system has potential to contribute to smart city development by identifying critical traffic points and informing safer infrastructure design.

Key words and phrases: Artificial Intelligence (AI), Situational Awareness (SA), Urban Micromobility, Fuzzy Logic, Virtual Driving Simulations.

1 INTRODUCTION

The rapid expansion of micromobility, particularly the use of electric bicycles and scooters, has introduced new challenges in urban traffic safety. Young riders, who represent the majority of users, often face complex traffic environments where situational awareness is crucial for making timely and accurate decisions. Traditional assessment methods, which rely on rigid thresholds and deterministic models, are limited in their ability to capture the variability and uncertainty inherent in human behavior.

Artificial Intelligence (AI), and specifically fuzzy logic, offers a more flexible and realistic approach to evaluating situational awareness. By interpreting drivers' reactions through linguistic variables, fuzzy logic overcomes the constraints of conventional methods. Virtual driving simulations of intersections provide an ideal environment for testing these models, as they replicate the complexity of real traffic conditions while eliminating physical risk.

Integration of AI and fuzzy logic can enhance the assessment of micromobility drivers' situational awareness. It highlights the potential of these methods to generate personalized training scenarios, improve safety outcomes, and contribute to the development of adaptive educational tools for urban mobility.

Urban micromobility, particularly the use of electric scooters and bicycles, is increasingly adopted for short urban trips and has become an integral part of the travel habits of younger generations. While these vehicles offer sustainable and flexible mobility options, their rapid expansion has also introduced new safety challenges in densely populated urban environments. According to the European Commission. (2025), at least 11 fatalities related to e-scooter use have been recorded in Europe since 2018. Data from Road Traffic Safety Agency of the Republic of Serbia. (2024) further highlight the risks: between September 2023 and the end of 2024, 144

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accidents involving light electric vehicles were reported, resulting in one fatality and 131 injuries, including 27 children. A recent case in Bosnia and Herzegovina (February 2026) tragically illustrated the dangers, where young riders wearing headphones failed to hear a tram driver's warning and lost their lives (European Western Balkans, 2026).

These statistics emphasize the urgent need for intelligent systems capable of anticipating risk scenarios and enhancing situational awareness among micromobility users. Artificial intelligence offers powerful tools for modeling driver behavior, predicting potential hazards, and delivering adaptive training tailored to individual needs. By integrating fuzzy inference methods, rule-based reasoning, and adaptive algorithms, AI frameworks can transform behavioral indicators such as reaction time, decision accuracy, and error frequency into actionable insights.

The framework presented in this paper aims to anticipate risk scenarios in urban micromobility by synthesizing expert knowledge through IF–THEN rules, simulating realistic traffic conditions, and generating situational awareness scores that guide personalized training.

This paper is organized into four interrelated chapters. The Introduction points out that the integration of artificial intelligence and fuzzy logic can improve the situational awareness assessment of micromobility drivers. This is followed by a section on related works, which provides a comprehensive review of the literature on the theoretical foundations of AI-driven frameworks for anticipation risk scenarios in micromobility. The core of the study is presented in the chapter "Situational Wareness And Fuzzy Logic In Urban Micromobility", which outlines the conceptual shift towards personalized training systems. This chapter contains two subchapters. A subchapter that describes a virtual simulation of driving through a city environment, based on fuzzy logic. and a sub-chapter focusing on the training scenario of the progressive development of micromobility driver skills: from basic observation and reaction exercises, through more complex scenarios with multiple objects, up to advanced simulations that simultaneously combine multiple risks. Finally, the Conclusion synthesizes the findings that the system not only assesses the current level of situational awareness, but also provides personalized recommendations that help micromobility drivers progressively develop their skills and traffic safety.

2 Related Work

Research on micromobility safety has intensified in recent years due to the rapid growth of electric scooters and bicycles in urban environments. Several studies emphasize the importance of situational awareness and predictive modeling in reducing accident risks. For example, the European Transport Safety Council (2022) highlighted the rising number of accidents involving e-scooters and recommended the integration of intelligent monitoring systems to improve rider safety. Similarly, the International Transport Forum (2024) provided country-specific profiles, including Serbia, which underline the challenges of regulating light electric vehicles and the need for adaptive safety measures.

Situational awareness has long been recognized as a critical factor in traffic safety. Endsley (1995) defined situational awareness as the perception of environmental elements, comprehension of their meaning, and projection of their future status. This framework has been widely applied in aviation, military, and increasingly in transportation research. Studies such as Salmon et al. (2018) have adapted situational awareness models to road traffic contexts, demonstrating that reduced awareness is strongly correlated with higher accident risk. More recent work by Stanton et al. (2017) emphasized the role of situational awareness in human factors engineering, highlighting its relevance for micromobility users who often operate in unpredictable urban environments.

Artificial intelligence approaches have been widely explored in traffic safety research. Fuzzy logic controllers have proven effective in modeling uncertainty and subjective assessments of driver behavior, offering structured methods for quantifying competencies (Chen et al., 2021). Previous works have applied fuzzy inference systems to evaluate reaction times, decision accuracy, and error frequency, demonstrating their potential in creating adaptive training environments.

Reinforcement learning has become an important tool in Intelligent Transportation Systems (ITS) due to its adaptability and self-learning capabilities. Recent studies highlight its applications in traffic signal control and autonomous driving, while also noting challenges in path planning, driving behavior, and multi-agent coordination. (Yu, et al. 2021).

Micromobility systems such as e-scooters offer benefits for reducing congestion and supporting sustainability, but safety remains a major concern. Recent reviews emphasize the role of sensing technologies, simulations, and infrastructure design in improving safety, while also identifying gaps in standardized frameworks, demographic diversity, and integration of emerging technologies like AI and augmented reality (Kim, et al., 2025). Furthermore, recent research addresses V2V and V2I communication, as well as the safety of vulnerable road users such as pedestrians, cyclists, and electric scooter riders. Recent work reviews state-of-the-art V2X and AV technologies and proposes a deep learning-based motion control architecture to improve VRU identification, tracking, and communication (Yusuf et al. 2024).

In summary, existing literature confirms the relevance of AI-driven frameworks for anticipating risk scenarios in micromobility. However, most prior studies focus either on general traffic safety or on isolated aspects of driver behavior. The framework proposed in this paper builds upon these foundations by integrating fuzzy inference, expert knowledge synthesis, and personalized educational interventions, specifically tailored to the unique challenges of urban micromobility and situational awareness.

3 Situational Awareness And Fuzzy Logic In Urban Micromobility

In academic discourse, situational awareness is often conceptualized through Endsley's three-level model, which distinguishes between perception, comprehension, and projection of environmental elements (Endsley, 1995). This framework is particularly relevant in traffic psychology, where young micromobility drivers—such as e-bike and e-scooter users—must process multiple stimuli under conditions of uncertainty and distraction. Their limited experience and vulnerability in complex urban settings make them an important target group for research and training interventions.

Traditional evaluation methods, which rely on deterministic thresholds, often fail to capture the variability and uncertainty inherent in human decision-making. Fuzzy logic provides a methodological advancement by introducing linguistic variables (low, medium, high awareness) that better reflect the gradational nature of cognitive performance (Zadeh, 1965). Within intersection-based simulations, fuzzy controllers process input parameters such as reaction time, decision accuracy, and error frequency, translating them into adaptive measures of situational awareness.

This approach resonates with human factors research, which emphasizes the importance of flexible evaluation tools that account for variability in cognitive load and attentional resources. Rasmussen (1997) highlighted the challenges of risk management in dynamic systems, stressing the need for models that can adapt to changing conditions and human variability. By embedding fuzzy logic into intersection-based driving simulations, researchers can replicate real-world challenges—pedestrian crossings, multi-object interactions, distractions, and reduced visibility—while maintaining experimental rigor.

Thus, fuzzy logic not only operationalizes theoretical constructs of situational awareness but also bridges them with applied training strategies. The resulting evaluations provide nuanced insights into young drivers' cognitive capacities and generate evidence-based recommendations for targeted skill development, contributing to safer urban mobility practices.

Fuzzy Logic in Urban Micromobility Virtual Driving Simulations

The virtual simulation of driving through the city environment, based on fuzzy logic, is not only a tool for training young micromobility drivers, but also a valuable research framework. It enables the collection of data on driver behavior in different conditions, which gives researchers insight into patterns of perception, decision-making and resistance to distractions. Such data can serve as a basis for academic studies in the fields of psychology, cognitive sciences and traffic engineering.The aim of the research was to conduct a virtual driving simulation experiment in an urban environment for electric bicycle and scooter drivers navigating a series of intersections of increasing complexity (from one to five intersections).

Figure 1. illustrates the fuzzy-logic-based decision system used in urban micromobility virtual driving simulations.

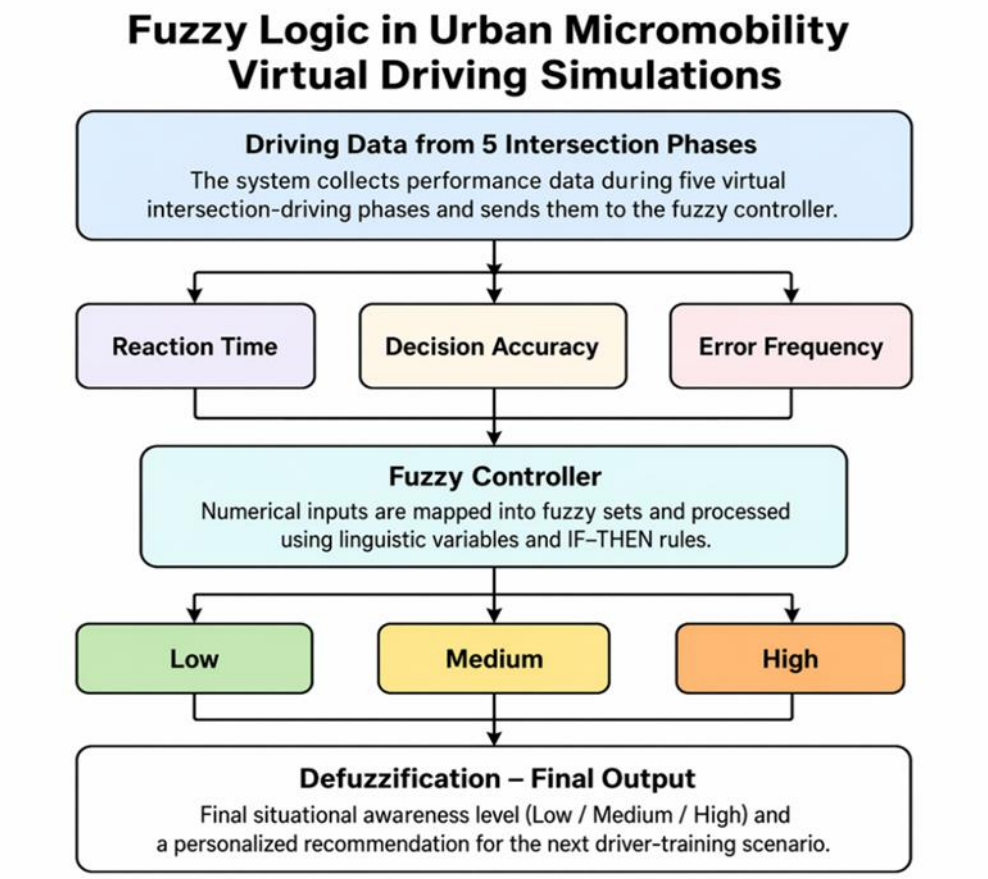


Figure 1. System of Fuzzy Logic in Urban Micromobility Virtual Driving Simulations

The process begins with the collection of driving-performance data obtained during five intersection-driving phases in the virtual environment. Three main input variables are considered: reaction time, decision accuracy, and error frequency. These numerical indicators are forwarded to the fuzzy controller, where they are mapped into fuzzy sets and processed using linguistic variables and IF–THEN inference rules.

The fuzzy controller evaluates the participant's driving performance and classifies the resulting situational awareness into one of three levels: Low, Medium, or High. In the final stage, through defuzzification, the system produces a crisp output representing the participant's final situational awareness level. This output is then used to generate a personalized recommendation for the next driver-training scenario, enabling adaptive and performance-oriented training within the urban micromobility simulation environment.

At the beginning of the virtual simulation, micromobility drivers are faced with a simple challenge, such as a pedestrian crossing, which tests their ability to perceive and react quickly. As the driving progresses, situations become more complex - combinations of pedestrians and vehicles appear, and then a larger number of participants appear simultaneously, which increases cognitive load and requires real-time decision-making.

In the later stages of the virtual simulation, distracting factors are introduced, such as the use of a phone or headphones, which test the driver's resistance to distractions. Finally, the driving takes place in conditions of reduced visibility, which assesses the ability to react in challenging perceptual circumstances. In this way, the simulation covers a wide range of real-life challenges that young drivers encounter in urban traffic.

All driver responses - response speed, decision accuracy and error rate - are collected and processed using fuzzy logic. Instead of rigid boundaries, a system of linguistic variables is applied, which allows for flexible and realistic assessment of behavior. This approach is particularly important because it recognizes that human behavior is not binary, but exists on a continuum between different levels of attention and ability.The result of

the simulation is an evaluation of situational awareness, accompanied by personalized training recommendations that help young riders develop safer traffic habits. If a low level of awareness is identified, training focuses on basic perception exercises and reducing distractions. At the medium level, emphasis is placed on more complex intersections and distraction resistance, while at the high level of awareness, the rider is prepared for advanced scenarios and unexpected events.

The experiment of virtual driving simulation with five intersections makes it possible to assess, in a safe environment, how young micromobility riders respond to different challenges, while fuzzy logic provides precise and flexible interpretation of their abilities, see Figure 2.

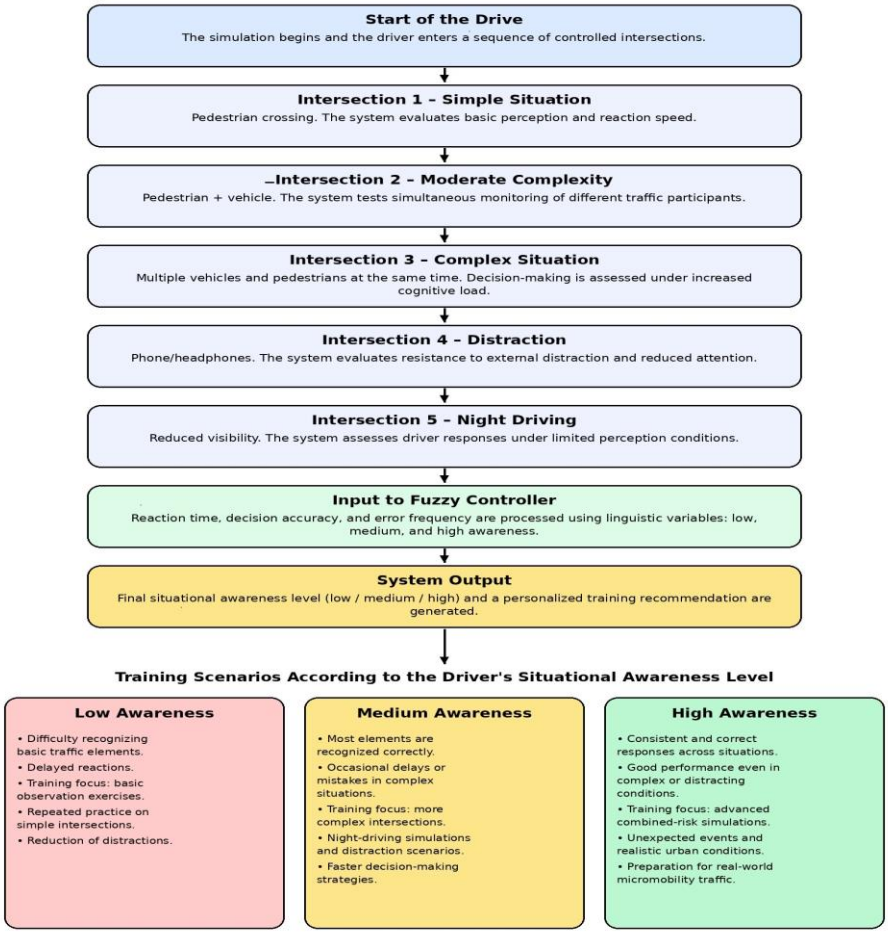


Figure 2. System of the virtual driving simulation for assessing situational awareness in urban micromobility

Figure 2. illustrates a sequence of intersections with increasing complexity, ranging from simple pedestrian crossings to night driving under reduced visibility. Driver reactions—such as response time, decision accuracy, and error frequency—are processed through a fuzzy controller that classifies situational awareness into low, medium, or high levels. Based on the output, the system generates personalized training recommendations, enabling progressive skill development and safer behavior in urban traffic.

This system has broader applications, as it can be used not only for educating young riders but also for shaping urban safety policies, developing smart traffic systems, and designing infrastructure adapted to micromobility. In this way, virtual simulations and fuzzy logic become tools that connect technology, education, and safety, contributing to risk reduction and the creation of safer urban environments.

Training Scenarios According to the Drivers' Situational Awareness Level in Virtual Driving Simulations

The previously presented virtual driving simulation experiment allows to examine in a controlled environment how drivers react to different traffic challenges - from simple situations with pedestrians, through complex intersections with multiple participants, all the way to driving under distractions or in conditions of reduced visibility. Based on the assessment results, the system not only classifies the driver into categories of low, medium or high situational awareness, but also generates training recommendations that are adapted to his current level of competence. This approach enables the progressive development of skills: from basic observation and reaction exercises, through more complex scenarios with multiple objects, all the way to advanced simulations that combine multiple risks simultaneously.

In this way, training scenarios become a dynamic tool for improving safety in urban micromobility, because the driver receives clear guidelines that prepare him for real traffic conditions.

In this way, the system not only assesses the current level of situational awareness, but also provides personalized recommendations that help micromobility drivers to progressively develop their skills and traffic safety.

Table 1 shows training scenarios according to the level of situational awareness of urban micromobility drivers:

Table 1. Training scenarios according to the level of situational awareness of urban micromobility drivers

DRIVER'S LEVEL OF SITUATIONAL AWARENESS	DESCRIPTION OF DRIVER BEHAVIOR	PERSONALIZED TRAINING RECOMMENDATIONS
Low Situational Awareness	Difficulty recognizing basic traffic elements, reacts late, often makes mistakes in simple situations.	Focus on basic observation exercises (pedestrians, vehicles, traffic lights), repetition of simple intersections in the simulation, elimination of distractions.
Medium Situational Awareness	Successful recognition of most elements, but occasional delays in reaction or errors in more complex situations.	Exercises in more complex intersections with multiple objects, simulations of night driving and driving under distractions, developing strategies for faster decision-making.
High Situational Awareness	Consistently recognizing and responding appropriately to a variety of situations, including complex and disruptive conditions.	Advanced simulations with combined risks, scenarios with unexpected events, preparation for real conditions in urban traffic.

Personalized training recommendations not only help individuals, but can be aggregated into statistical models that show the general level of situational awareness of the young driver population. Such models can serve as an indicator of the community's readiness for a wider application of micromobility and as a basis for educational campaigns.

In this way, virtual driving simulations and fuzzy logic go beyond the limits of individual training and become a research tool that connects education, technology and urban planning. Their application contributes to the development of smart cities in which traffic safety, efficiency and sustainability are seen as interconnected goals.

4 CONCLUSION

The presented virtual driving simulation experiment shows that the application of fuzzy logic in assessing the situational awareness of micromobility drivers represents a significant contribution to the improvement of safety in urban traffic. The simulation of driving through different intersections allows the driver's ability to perceive, understand and predict events to be tested in a controlled environment, without physical risk. This provides a realistic but safe way of assessing their skills.

By using a fuzzy controller, the data on the driver's reactions are translated into linguistic variables that enable a flexible interpretation of the behavior. This approach overcomes the rigid boundaries of traditional methods and provides a nuanced picture of the level of situational awareness - from low, to medium, to high. Based on this, personalized training recommendations are generated, which progressively develop the driver's competencies.

The application of fuzzy logic in this context shows how theoretical models can be transferred into practical experiments that simulate real driving conditions. This opens the possibility for the development of new methodologies for assessing situational awareness, which are more flexible than traditional tests and better reflect the complexity of urban traffic.

From the point of view of smart cities, such experiments can contribute to the creation of a safer infrastructure. Analysis of typical mistakes of young drivers can point to critical points in city traffic - intersections with high risk, streets with reduced visibility or zones with frequent distractions. Based on this, the city authorities can plan interventions such as improved signaling, smart traffic lights or specialized paths for micromobility. The virtual simulation of driving through the city environment, based on fuzzy logic, is not only a tool for training young micromobility drivers, but also a valuable research framework. It enables the collection of data on driver behavior in different conditions, which gives researchers insight into patterns of perception, decision-making and resistance to distractions. Such data can serve as a basis for academic studies in the fields of psychology, cognitive sciences and traffic engineering.

In the future development of the system, the emphasis will be on increasing the realism of the simulation and its adaptability. The integration of augmented and virtual reality technologies can further bring drivers closer to real traffic conditions, while the combination of fuzzy logic with machine learning enables the system to adapt to individual behavior patterns. The inclusion of biometric data on attention, stress and fatigue can contribute to a more precise assessment of situational awareness, and the connection with data from smart cities opens up the possibility of testing drivers in semi-real conditions. In this way, the system develops into a comprehensive tool for education and risk prevention, which connects theoretical models with practical training and real data, thus contributing to safer urban micromobility in the long term.

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Digital Competences of Preschool Children

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Abstract. Digital competencies are an important segment of modern preschool education. In preschool, the emphasis is not on technical knowledge, but on the development of logical thinking, creativity, cooperation and problem-solving skills through the meaningful use of digital technologies. Educators and parents play a significant role in this process, guiding children towards safe and responsible use of technology. The paper presents the application of the Bee-Bot educational robot, as a tool for the development of digital competencies, algorithmic thinking, spatial orientation and collaborative learning.
Through project activities, children connect different areas of learning, explore, plan, and solve problems. The importance of developmentally appropriate and moderate use of digital technologies is particularly emphasized, while preserving free play, movement, and direct social interaction, as the basis for the holistic development of the child.

Key words and phrases: digital competencies, preschool education, Bee-Bot, digital technologies, project-based learning**.**

1 INTRODUCTION

In modern society, which is largely shaped by the development of digital technologies, digital competencies are becoming one of the key skills for the successful functioning of an individual. Although they are often associated with school age, children already gain their first experiences with digital devices and content during the preschool period. Today, children grow up in media-rich households and are in contact with digital devices from an early age on (Gemo et al., 2018; Palaiologou, 2016; in Elbaum et al, 2024). At this age, the emphasis is not on technical knowledge, but on the children's narrative competence (Shengjergji et al, 2026), social-emotional learning (Fang et al, 2026), motor creativity and computational thinking (Karaca et al, 2026), development of logical thinking, curiosity and problem-solving skills.

Preschool institutions and educators have a significant role in creating a supportive environment in which digital technologies are used in a developmentally appropriate way (Shengjergji et al, 2026). Through carefully planned activities, children are enabled to experience technology as a tool for learning and collaboration, and not just as a source of entertainment. It is particularly important that digital competences are developed in accordance with the age characteristics of children with ongoing support and guidance from educators.

In this paper, the experiences in the preschool institution "Detinjstvo" Žabalj are presented, as an illustration of the application of certain type of digital technologies, the Bee-Bot educational robot, at this level of education. It is important to note that the guidelines for the use of digital technologies in our country are recognized through the Fundamentals of the Preschool Education Program (Ministry of Education, Science and Technological Development – MESTD, Republic of Serbia, 2018) and are not mandatory. Their implementation largely depends on the equipment of preschool institutions, as well as on the individual engagement of educators in the use of digital technologies in working with children.

2 DIGITAL COMPETENCES

Digital competences refer to knowledge, skills and attitudes about digital technology: their knowledge, effective use and positive, but critical attitudes towards the importance and impact of digital technologies. (Arsenijević et al, 2011)

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At the level of educational policy of the Republic of Serbia, when it comes to preschool education, the use of digital technologies is defined by the Fundamentals of the Preschool Education Program (Stojković, 2019). Its Program "Years of Takeoff" (MESTD, 2018) lists eight key competences for lifelong learning in preschool education:

- Communication in the mother tongue;
- Communication in a second language;
- Mathematical, scientific and technological competences;
- Digital competence;
- Learning to learn;
- Social and civic competences;
- Initiative and entrepreneurship;
- Cultural awareness and expression.

According to (Kaloferova, 2020), digital competence consists of five key areas:

- Information and media literacy;
- Communication and collaboration;
- Digital content;
- Security and problem solving;
- Interaction with technology.

The formation, construction and development of digital competences of preschool children are influenced to varying degrees by parents and the family environment, kindergarten and interaction with peers in kindergarten, as well as their personal and direct experience in using digital technology. (Stevanović et al, 2023)

Digital competences are developed through the meaningful use of digital technologies for accessing information, playing and researching, documenting various activities, and developing a culture of using digital technologies. (Arsenijević et al, 2011)

As mentioned in the introduction, the use of digital technologies in preschool institutions in our country is largely influenced by the equipment of these institutions. According to (Šaponjić et al, 2020), more than 50% of respondents believe that their institution is not adequately equipped with digital technologies, and that the existing equipment is not used for the purpose of developing the digital competencies of children and educators. The use of digital technologies is also influenced by the personal engagement of educators in preschool institutions. According to (Belenzada et al, 2021; Šaponjić et al, 2021, in Stevanović et al, 2023), about 40% of respondents never use digital tools and technologies to support children's play and exploration, together with children to access information and learning sources, as well as document activities and processes in the educational group and kindergarten, with the aim of developing various types of early literacy.

The development of digital competences also includes acquiring the basics of digital safety. In preschool, this aspect is achieved through guided use of technology, selection of appropriate content and the presence of adults. Children are gradually introduced to the rules of safe use, such as privacy protection and limited screen time, which is the basis for responsible behavior in the digital environment. The quality of the application of digital technologies largely depends on the competences of the educator. The educator has the role of a mediator who plans, directs and reflects on the educational process. This includes the ability to critically select digital tools, adapt activities to the age of children and connect digital content with learning objectives. (MESTD, Guide for developing a topic/project with children, 2022)

The family is the primary context for early development. Interactions with caregivers—particularly adults—provide critical support for children’s early cognitive, language, and socio-emotional development (Niklas & Schneider, 2017; Tucker-Drob & Harden, 2012; in Li et al. 2026). Therefore, the influence of parents on the development of digital competences in children is of utmost importance, because it is in the family environment that a child gains his first experiences with technology. This influence can be encouraging, but also limiting, depending on the way parents approach digital devices and content. Parents are primarily role models. Children learn by observation, so if parents use technology meaningfully, the child will also develop “healthy digital habits”. It is important for parents to influence the choice of age-appropriate applications, games, and devices, as quality educational content can significantly stimulate children's development. It is

important to emphasize that parents, with their attitudes and support, influence a child's self-confidence in using technology.

3 Case Study: Implementation of Bee-Bot in Preschool Institution "Detinjstvo"

In modern preschool education, which increasingly relies on the development of 21st century competencies, digital technologies occupy a special place as a means of learning through play, exploration, and active participation of the child (MESTD, Teacher for the Digital Age, 2019). Children can use digital tools such as: smart boards, interactive carpets, tablets, smartphones, bee-bot educational robots (Figure 1.), games for learning programming and computational thinking, applications for creating animations, applications for drawing, coloring and creative creation, interactive picture books with the help of QR codes and others (Stevanović et al, 2023). In this context, the application of a simple and developmentally appropriate tool, such as the bee-bot educational robot (British educational supplier, TTS Group, 2004. https://www.tts-group.co.uk/), is presented, which allows children to enter the world of digital literacy and the basics of programming in a natural and interesting way.



Figure 1. Bee-bot educational robot

Bee-bot, as an educational robot adapted to the youngest, provides the opportunity for children to adopt the basic principles of logical and algorithmic thinking through direct experience, movement and manipulation. Its ease of use, based on visual commands and clear feedback, makes it suitable for interaction in everyday educational activities. By introducing the robot into work with children, the emphasis shifts from the passive use of digital content to active learning, where the child becomes a researcher, creator and problem solver. Through designed activities, children develop not only digital competencies, but also cooperation, communication, creativity and independence.

Research context and sample

Fundamentals of the Preschool Education Program, The Program "Years of Takeoff" (MESTD, 2018), suggests that the education of children is not determined by pre-planned activities, but rather that the children's interest is followed and topics for projects are initiated accordingly. This is how the story of the project "Together – Let's Learn About the Life of Bees" came about. This story was initiated by a boy named Dositej, who brought a picture of himself next to a beehive, that his father had bought, to kindergarten. Dositej said that his father knew nothing about bees and the children suggested that they learn about the life of bees and help his father. Every project begins in a similar way, in which steps/activities are planned based on the children's suggestions in cooperation with the educators. Also, everything is documented within the "project story": the proposal for each step of the project, the method of implementation, the problems that arise and the solutions that are found, the results that are achieved, the progress and the knowledge that children adopt. According to the same program "Years of Takeoff" (MESTD, 2018), "planned learning situations" are also implemented within the projects – activities that are prepared and implemented by educators, with the aim of educating children and teaching them about something new and answering questions that arise during the

project. In this way, children were introduced to the bee-bot. The project "Together – Let's Learn About the Life of Bees" was implemented in the period April-May 2026, with a group of 24 children aged 4-6 years.

Research implementation

The first step in the project "Together – Let's Learn About the Life of Bees", which was based on the children's suggestions and agreements, was to go to the library and learn about the life of bees, followed by making a beehive, and one of the next steps led to a "planned learning situation" which was an introduction to bee-bots (which was "helped" by the educators who placed the bee-bots in a visible place that day).

The process of use begins with children getting to know the robot – children observe its appearance, discover the buttons and what happens when they press a certain command. They discovered that the bee robots have red eyes while charging, and green eyes when fully charged. They also "saved" the robot by turning tables and placing a mat on them for the robot to move on, so that it would not fall. They learned how the robot works, how to plan a path, how to continue from a "conquered" field, how to erase the given path and start a new one, in case of an error or in case of a new start. In this way, through play and experimentation, they gain their first experiences with the concept of management and control.

The basis on which the bee-bot moves is a transparent base in the form of a grid with 5x8 fields, of which the 5 outermost starting fields for the 5 bee-bots. In the context of the project "Together – Let's Learn About the Life of Bees", educators have prepared a base that is placed under the main base for the bee-bot to move, which contains drawings, such as: cloud, flower, bee, hive, honey..., concepts related to the theme of the project. These drawings are placed exactly in certain fields of the grid of the main base. The task of the bee-bot is to get from the starting position (one of five) to a given/imagined concept/field on the grid (as decided by the child). When the child is in the first position, determines which field he/she wants the bee-bot to reach, he/she suggests, plans and programs the route. Meanwhile, the other children wait, learn to be patient, and help their friend to find their way. The next child also chooses the field they want their bee-bot to reach, taking care not to “collide” with a bee-bot that has previously started or reached its destination. When they start the bee, they carefully observe whether it will reach the goal, which arouses curiosity and excitement in them. If a mistake is made, the children go back to the beginning, analyze what went wrong, and try again, thereby developing perseverance and problem-solving skills. Every child in the group participates in this game, while the game itself lasts no more than half an hour as part of the daily activities of the children in kindergarten or at the children’s request (this means that during the project implementation, the game with the bee-bots was not necessarily every day).

During the Bee-Bot activities, educators kept notes on how children approach problem solving, plan their path, collaborate with peers, and respond to mistakes. Each child’s step and suggestion were recorded, group agreements are monitored, and shared solutions are found, which is recorded in the project story. Children’s statements, suggestions, strategies used by children during programming, as well as changes in their way of thinking during the activity are recorded. The following are particularly monitored:

- the child's ability to predict the movement of the Bee-Bot;
- the way the child counts fields and plans steps;
- noticing and correcting mistakes;
- persistence after an unsuccessful attempt;
- cooperation and negotiation with other children;
- use of spatial concepts (forward, backward, left, right);
- independence in giving commands.

For example, educators noted that children initially entered commands through trial and error, while later they increasingly planned the route together, counted the fields on the grid, and only then gave commands. It was also noted that after unsuccessful attempts, children analyzed where the error occurred and proposed new solutions, demonstrating the development of logical thinking, perseverance, and cooperation.

During the programming of the Bee-Bot, the children's persistence was evident. For example, during the task of getting the bee from the hive to the flower, the children first entered the wrong number of steps, so the bee reached a rain cloud. Dositej then said: "She went to the wrong place." Lazar suggested: "Let's erase and count again." The children counted the fields on the grid together, re-entered the commands, and successfully brought the bee to the goal.

In the second situation, Bee-Bot turned in the wrong direction. Dunja noted, “We didn’t tell it to turn here.” After a discussion, the children decided they needed to add a turn command and tried again. The second attempt was successful.

Research results

During the implementation of project activities, educators use these devices to help children connect different areas of learning in an integrated way. Through the project approach, they document children’s progress and knowledge, while children explore, ask questions, and seek solutions, with digital tools playing a supporting role in this process. For example, as part of the project "Together – Let's Learn About the Life of Bees", children used Bee-Bot to plan the robot's movement on a created surface – a meadow. The task was for the robot to reach a specific goal (flower, bee, hive) from a starting point. The children planned the route together, counted the steps, entered commands, and checked the accuracy of the solution. If an error occurred, they analyzed the process and tried again, thereby developing perseverance and problem-solving skills.

The educators' observations showed that over time, the children increasingly independently planned routes, predicted the Bee-Bot's movements, corrected mistakes, and collaborated in problem-solving. At the end of the project, the entire group of 24 children mastered the use of the Bee-Bot and acquired the skills and knowledge that were foreseen in the project activities.

Games with Bee-bot are diverse and can be adapted to different areas of learning. In language games, children guide the bee to pictures and name concepts, compose stories and connect pictures in the order of events. In mathematical activities, they use substrates with numbers, shapes or tasks, and through play they acquire mathematical content. Spatial orientation games are often organized, where children acquire concepts such as: left, right, forward and backward. Cooperation games are especially important, in which children in small groups come up with a solution together, agree and share roles. Through these activities, children not only learn how to use a digital device, but also develop broader competencies – logical thinking, communication, independence and creativity. Bee-bot allows them to learn through their own experience, mistakes and successes, which makes this way of working natural.

Such activities contribute to the development of logical thinking, spatial orientation, cooperation and communication. In addition, the use of digital technologies in project work encourages cooperation among children, as it requires agreement, exchange of ideas and joint decision-making. In this way, in addition to digital, social and communication competencies are also developed. In addition to the developmental benefits, it is important to point out the importance of establishing a balance between the use of digital technologies and other forms of activity. Children need free play, movement, spending time in nature and direct social interaction. (MESTD, Strategies for joint program development in accordance with the specificities of individual ages of children; Guide to the arrangement of spaces in kindergartens, 2022) Digital technologies should be a complement, not a substitute, for experiences that are crucial for the overall development of a child.

Modern research indicates that moderate, meaningful, and guided use of digital technologies can have a positive impact on children's development (Bers, 2018; Popat & Starkey, 2019; Wing, 2006, 2008; in Karaca et al, 2026), while uncontrolled and excessive use can lead to various developmental risks (Brauchli et al., 2024; Webb et al., 2024; Madigan et al., 2019; Walsh et al., 2020; Zhao et al., 2022; in Li et al, 2026). Therefore, it is necessary to ensure a balance and a context in which technology has a clear pedagogical function.

4 Conclusion

Digital competencies in preschool age represent an important segment of modern educational work, but they do not relate to the early acquisition of technical knowledge, but to the development of the foundations of thinking, an investigative approach and a responsible attitude towards technology. Through carefully designed activities, as well as the application of developmentally appropriate tools, children are enabled to use digital technologies as a means of learning, collaboration and creative expression. The role of educators and parents is crucial in this process, because through their actions they guide the child towards healthy and safe digital habits. In this way, digital competencies become part of the child's broader development and the basis for successful and responsible participation in modern society. The paper illustrates the above through a presentation of the use of digital

technologies in preschool education of children, specifically, the Bee-bot educational robot, in the preschool institution "Detinjstvo" Žabalj.

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AI in Serbian Education Without a Compliance Framework: A Regulatory Gap Analysis

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Abstract. Serbia's AI in education strategy has achieved genuine regional recognition: a UNESCO-endorsed K-12 AI curriculum, a comprehensive 2025-2030 development strategy, and the GPAI presidency for 2025-2027. Yet this ambition exists alongside a measurable compliance gap. The EU AI Act, in force since August 2024, classifies several common educational AI applications, including automated grading, adaptive learning, and examination monitoring, as high-risk systems subject to specific legal obligations. A forthcoming Serbian national AI law, explicitly modeled on the EU Act, will extend these obligations domestically. This paper applies document analysis to map the compliance requirements applicable to AI deployments in Serbian education against the provisions of the 2025-2030 strategy. The analysis finds that every compliance requirement, including risk classification, technical documentation, human oversight, conformity assessment, student notification, log retention, incident reporting, and Fundamental Rights Impact Assessment, is absent from the strategy. The paper identifies the deployer-to-provider transition under Article 25 as a particular risk for domestic EdTech companies, and proposes a compliance self-assessment tool as a practical instrument for closing the identified gap. Implications for Serbia's EU accession trajectory and GPAI governance commitments are discussed.

Key words and phrases: EU AI Act, AI compliance, education, Serbia, regulatory gap, high-risk AI, EdTech.

1 Introduction

The deployment of artificial intelligence in education is accelerating globally, and Serbia is no exception. Serbian schools are actively using AI tools for grading, lesson planning, adaptive learning, and student monitoring. The country's 2025-2030 AI Development Strategy explicitly promotes AI integration across all levels of education and positions Serbia as a regional leader in AI governance.

This leadership claim rests on genuine achievements. Serbia is one of eleven countries worldwide with a government-endorsed K-12 AI curriculum recognized by UNESCO (UNESCO, 2022). It holds the GPAI presidency for 2025-2027 and has adopted voluntary ethical guidelines for responsible AI development (Republic of Serbia, 2023). However, the EU AI Act, Regulation (EU) 2024/1689, in force since August 2, 2024, introduces binding compliance obligations for AI systems deployed in education that are classified as high-risk. A Serbian national AI law modeled on this framework is in preparation (Zunic Maric & Beric, 2025; Gecic Law, 2025). When it enters into force, every school and EdTech company deploying AI in a high-risk use case will face concrete legal obligations.

This paper asks a direct question: does Serbia's AI education strategy prepare institutions for these obligations? The answer, documented through systematic gap analysis, is no. The paper identifies the specific gaps, explains why they matter from an engineering management perspective, where regulatory non-compliance is a measurable organizational risk, not merely a legal abstraction, and proposes a practical instrument for addressing them. The contribution is positioned at the intersection of technology governance, educational policy, and compliance engineering, reflecting the dual technical and managerial lens that the subject demands.

2 Background

2.1. The EU AI Act and Education

The EU AI Act establishes a risk-based framework for AI governance organized around four tiers: unacceptable risk (prohibited), high-risk (subject to mandatory compliance obligations), limited risk (transparency obligations only), and minimal risk (no specific obligations). Annex III, Section 3 classifies as high-risk any AI system used to determine access to educational institutions, evaluate student performance, or monitor student behavior during examinations (European Union, 2024). These classifications are use-dependent, not tool-dependent: the same AI system can occupy different risk tiers depending on its specific application context.

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For deployers of high-risk AI systems, the Act imposes eight categories of obligation: risk classification, technical documentation (Article 11), human oversight mechanisms (Article 26), conformity assessment (Annex VI), student notification (Article 26(11)), log retention (Article 12), serious incident reporting (Article 73), and Fundamental Rights Impact Assessment (Article 27). Article 4 additionally requires deployers to ensure AI literacy of staff dealing with AI systems in a regulatory context, a distinct obligation from general public AI literacy. Article 5(1)(f) prohibits AI systems that infer emotions in educational settings, with limited exceptions. General-purpose AI models used in education are subject to additional transparency obligations under Article 53.

The Act's extraterritorial scope under Article 2 means that these obligations apply to any provider or deployer whose AI systems are placed on the EU market or whose outputs affect persons located in the EU, regardless of where the provider or deployer is established. For Serbian companies whose AI products are used in EU member states, compliance obligations under the EU Act are already active. Saarela, Gunasekara, and Karimov (2025) provide a comprehensive analysis of the Act's implications for educational AI, confirming that the high-risk classification of automated assessment tools is unambiguous under the current text.

2.2 . Serbia's AI Governance Context

Serbia's 2025-2030 AI Development Strategy (Vlada Republike Srbije, 2025) is the primary policy document governing AI in education. It builds on the 2020-2025 strategy (Vlada Republike Srbije, 2019) and explicitly references alignment with EU regulatory frameworks. The strategy addresses AI curriculum development, teacher training, public AI literacy, and institutional governance through the Council for Artificial Intelligence and the Institute for Artificial Intelligence of Serbia.

The strategy does not address compliance obligations. This is not an oversight unique to Serbia: a cross-national review by Karimov and Saarela (2025) found that most government AI strategies prioritize deployment and literacy over regulatory readiness. However, Serbia's position as a country actively deploying AI in schools, preparing national AI legislation, and holding an international AI governance presidency makes this gap particularly consequential. Dragomir (2025) notes that EU frameworks are increasingly shaping AI governance in candidate and partner countries, creating regulatory convergence pressure that Serbia's strategy does not yet reflect. The European Commission\'s ethical guidelines for educators on AI use (European Commission, 2022) represent the practical operationalization of this convergence pressure at the institutional level, yet Serbian educational policy documents contain no reference to them. Zunic Maric and Beric (2025) and Injac Attorneys (2025) confirm that no binding AI-specific legislation is currently in force in Serbia, while NUNS (2025) documents active EdTech market activity in the absence of any compliance framework.

3 METHODOLOGY

This study employs document analysis as its primary method. The analytical framework proceeds in three steps. First, the compliance obligations applicable to high-risk AI deployments in education are extracted from the EU AI Act text (European Union, 2024), with particular attention to Annex III Section 3, Articles 4, 5, 11, 25, 26, 27, 53, 72, and 73. Second, the provisions of Serbia's 2025-2030 AI Development Strategy are reviewed for any corresponding compliance provisions. Third, each EU Act obligation is mapped against the strategy to identify presence, partial presence, or absence.

The analysis is grounded in the engineering management tradition of compliance gap analysis, treating regulatory requirements as a structured set of organizational obligations and assessing the degree to which existing policy instruments address them. This approach is analogous to the conformity gap analysis used in ISO certification processes, adapted to a regulatory rather than standards context. The scope is limited to document analysis; primary data collection through surveys or interviews with educators or policymakers represents a necessary direction for future research, particularly for empirical validation of the compliance tool proposed in Section V.E.

4 RESULTS: GAP ANALYSIS

4.1 What Serbia's Strategy Covers

The 2025-2030 strategy is substantive. It addresses AI curriculum development across primary, secondary, and higher education (Measure 3.2), building on the existing K-12 curriculum recognized by UNESCO (UNESCO, 2022) as one of the most comprehensive government-endorsed AI curricula globally. Teacher training and digital competency programs are explicitly included (Measure 3.2), as are public AI literacy initiatives (Measure 3.3), non-formal and lifelong learning pathways (Measure 3.4), voluntary ethical guidelines (Republic of Serbia, 2023), and institutional governance infrastructure through the Council for Artificial Intelligence.

These provisions go beyond what many comparable countries have achieved. The strategy's explicit reference to EU regulatory developments and its alignment with UNESCO frameworks demonstrate genuine policy awareness. The challenge is not ambition; it is the gap between strategic intent and the operational compliance requirements that binding legislation will introduce.

4.2 What Serbia's Strategy Does Not Cover

The gap analysis reveals that the strategy contains no provisions for any of the compliance requirements that the forthcoming AI law will impose. Table 1 presents the complete findings.

Table 1. Gap analysis: EU AI Act requirements vs. Serbia's AI education strategy provisions.

EU AI Act Requirement	Legal Basis	Strategy Provision	Status
AI literacy (regulatory context)	Art. 4	General literacy only	Partial
Risk classification	Annex III	None	Absent
Technical documentation	Art. 11	None	Absent
Human oversight	Art. 26	None	Absent
Conformity assessment	Annex VI	None	Absent
Student notification	Art. 26(11)	None	Absent
Log retention	Art. 12	None	Absent
Incident reporting	Art. 73	None	Absent
FRIA	Art. 27	None	Absent
Emotion recognition prohibition	Art. 5(1)(f)	None	Absent

The only partially addressed requirement is AI literacy. Article 4 of the AI Act defines a deployer-specific obligation: providers and deployers must ensure sufficient AI literacy of staff dealing with the operation and use of AI systems on their behalf, considering their respective rights and obligations in the context of this Regulation (European Union, 2024, Art. 4). General public literacy about AI as a technology is materially different from deployer literacy about regulatory obligations, risk classification, and oversight duties. The strategy addresses the former but not the latter.

4.3 The Invisible Deployment Problem

The most consequential finding is that AI tools are already deployed in Serbian schools without any systematic mapping of what is in use, how it is used, or which risk classification applies. Current deployments include large language models for grading and test creation, Moodle AI plugins and adaptive learning platforms, AI-powered content generation tools for teaching materials, and AI-based assessment and grading assistance. Private sector actors, including domestic EdTech companies, are actively marketing AI solutions to Serbian schools without any defined compliance framework (NUNS, 2025).

Risk classification is use-dependent, not tool-dependent. The same AI system can occupy different risk categories depending on application. A large language model used by a teacher for lesson planning brainstorming is minimal risk, with no specific obligations beyond AI literacy. The same system used to grade essays where the grade affects student marks is high-risk under Annex III, Section 3(b), requiring human oversight, documentation, and conformity assessment. AI used to determine whether a student passes or fails is high-risk under Annex III, Section 3(a). AI proctoring during examinations is high-risk under Annex III, Section 3(d). AI used to detect student emotions during class is prohibited under Article 5(1)(f), regardless of risk tier.

This use-dependent classification means that compliance cannot be addressed at the tool level; it must be addressed at the deployment level, which requires knowing how each tool is being used in each school. Schools and teachers are, in practice, deployers of AI systems in the sense defined by Article 3(4) of the EU AI Act, entities using AI systems under their authority in a professional context, without awareness of this regulatory status or the obligations it entails. Without a systematic mapping of deployments, compliance assessment is structurally impossible.

5 DISCUSSION

5.1 Regulatory Debt

The gap documented in Section IV constitutes what this paper terms regulatory debt, a concept borrowed from software engineering, where short-term decisions create compounding future costs. Every school that has deployed a high-risk AI system without the required documentation, oversight mechanisms, and conformity assessment is accumulating obligations that will need to be addressed retroactively once the national AI law enters into force. The cost of retroactive compliance is substantially higher than prospective compliance: technical documentation must be reconstructed, oversight procedures must be designed and implemented under time pressure, and any non-conforming system must be suspended or modified before continued use is legally permissible.

Serbia's experience with GDPR implementation provides a relevant domestic precedent. Serbia adopted the Law on Personal Data Protection (Zakon o zastiti podataka o licnosti, Sl. glasnik RS, br. 87/2018) aligned with GDPR in 2018, but practical implementation lagged significantly behind the legislative framework. Organizations that had not prepared in advance faced substantially higher costs for retroactive compliance. The pattern is directly applicable: a law is enacted in alignment with EU requirements, implementation capacity is assumed rather than built, and the compliance burden falls disproportionately on institutions that treated the legal deadline as the starting point rather than the endpoint of their preparation.

The enforcement timeline compounds this risk. The EU AI Act's provisions on high-risk AI systems became applicable on August 2, 2026. Serbian companies whose products are used in EU member states are already within scope under Article

2. The forthcoming national law will extend equivalent obligations domestically. Institutions that treat compliance as a future concern are, in practice, already non-compliant with obligations that are either active or imminent. From an engineering management perspective, this is a risk management failure: the probability of enforcement is increasing, the cost of remediation is rising, and the window for low-cost prospective compliance is closing.

5.2 Serbia's Unique Position

Serbia occupies a position that is both advantageous and exposed. Three factors distinguish its situation from that of other countries navigating the same regulatory transition.

First, as an EU accession candidate, Serbia has an obligation under the Stabilisation and Association Agreement to align its legislation with EU law before accession, not after. The forthcoming AI law is part of this process, meaning that the regulatory trajectory is not a matter of political choice but of international legal commitment. Regulatory readiness in education is therefore not optional; it is a precondition for the accession path that Serbia has committed to.

Second, as one of only eleven countries recognized by UNESCO for government-endorsed K-12 AI curricula, Serbia has more at stake than countries starting from zero. Countries that have not yet deployed AI in education have no regulatory debt to manage. Countries that have deployed AI extensively but without a compliance framework face a proportionally larger gap to close. Serbia's early adoption advantage, the achievement that earned it UNESCO recognition, is simultaneously the source of its compliance exposure.

Third, as the holder of the GPAI presidency for 2025-2027, Serbia's international credibility on AI governance depends on demonstrating domestic implementation that matches its diplomatic commitments. The Belgrade Ministerial Declaration commits signatories to responsible AI development; a domestic deployment landscape without compliance oversight would undermine the credibility of that commitment. These three factors converge to create a window of opportunity: the AI law has not yet been enacted, compliance requirements can still be integrated into the education strategy at low cost, and the reputational and legal incentives for doing so are stronger for Serbia than for most comparable countries.

5.3 The Supply Chain Question

A question beyond the scope of this paper but identified as critical for future research concerns the compliance supply chain of AI systems in education. When a school uses a large language model for grading, compliance responsibility is distributed across the deployment chain: the school as deployer, and the model provider as the upstream party whose obligations under Article 53, including technical documentation, copyright policy, and a published summary of training content, apply regardless of where the provider is established, provided the model is placed on the EU market. The interaction between these provider obligations and the deployer obligations of educational institutions creates a compliance chain that neither Serbia's strategy nor the forthcoming AI law has yet addressed.

The analytical framework applied in this paper, mapping intended use to Annex III classification, then testing for the presence or absence of each deployer obligation, is domain-agnostic. The same gap analysis structure applies to any sector where AI systems are deployed in high-risk use cases, including employment and workers management (Annex III, Section 4), creditworthiness assessment (Section 5), and critical infrastructure (Section 2). Adapting the compliance self-assessment approach to these domains is a natural extension of this work.

5.4 The Deployer-to-Provider Transition

Article 25 of the AI Act establishes the conditions under which a deployer becomes a provider. A deployer assumes full provider obligations under Article 16 in three scenarios: when it places a high-risk AI system on the market under its own name or trademark; when it makes a substantial modification to a high-risk AI system; or when it modifies the intended purpose of a system in a way that renders it high-risk (European Union, 2024, Art. 25).

In the Serbian EdTech context, this provision has immediate practical relevance. A company that fine-tunes a general-purpose language model for automated essay scoring or adaptive learning path generation, and deploys that system under its own brand to schools, is no longer a deployer of a third-party product. It is a provider of a high-risk AI system subject to the full provider compliance regime: conformity assessment, technical documentation (Article 11), EU database registration (Article 71), post-market monitoring (Article 72), and serious incident reporting (Article 73). Neither the 2025-2030 strategy nor the draft national AI law currently addresses this transition mechanism, leaving a class of domestic AI developers in a state of structural non-compliance that is likely to intensify as the EdTech market matures and customization of foundation models becomes standard practice.

5.5 Proposed Solution: Compliance Self-Assessment Tool

The gap analysis reveals a need for a practical, accessible instrument that educational institutions can use to assess their compliance readiness, not a legal textbook, but a structured self-assessment tool that translates regulatory requirements into operational questions. This paper proposes an AI Education Compliance Checker designed around the following logic: a school or teacher registers AI tools currently in use, specifying for each tool its name, provider, and intended purpose; the tool maps each use case to the Annex III classification framework through a structured question sequence; and a gap report is generated identifying which obligations apply to each deployment and which are not yet addressed, with specific recommended actions for each identified gap.

The tool functions as a self-assessment instrument analogous to the internal conformity assessment procedure described in Annex VI of the Act, which applies to most educational AI systems. It is not a certification; certification requires accredited conformity assessment bodies such as ATS in Serbia and notified bodies in the EU. Rather, it is a readiness assessment that prepares institutions for the compliance requirements that the forthcoming national law will introduce. The classification logic is use-dependent by design, reflecting the Act's own framework: the same tool can generate different compliance profiles depending on how it is deployed.

A prototype has been developed as a React-based web application and is demonstrated at this conference. The prototype implements the use-dependent classification logic described in Section IV.C, generating per-system risk classifications and corresponding obligation checklists. The planned development path moves from the conference prototype to a minimum viable product suitable for real-world piloting in Serbian schools, with the goal of validating the tool's utility before the national AI law enters into force.

6 Conclusion

Serbia's AI education strategy is serious and regionally significant. The UNESCO-recognized K-12 curriculum, the 2025-2030 strategy, and the GPAI presidency are not decorative achievements. They reflect institutional investment and policy continuity over several years. That foundation matters, because what this paper documents is not a failure of intent but a structural gap between strategic ambition and regulatory readiness.

The gap is measurable and specific. Every compliance requirement applicable to high-risk AI systems in education is absent from the current strategy. The forthcoming national AI law will make these requirements binding, and Serbia's GDPR implementation experience is a useful reference point: the organizations that treated compliance as a post-enactment problem paid significantly more than those that prepared in advance. The deployer-to-provider transition under Article 25 adds a layer of risk that is not yet on the radar of domestic EdTech developers, many of whom are already customizing foundation models for educational use without recognizing that this customization changes their legal status. And Serbia's position as an accession candidate, a UNESCO-recognized curriculum leader, and the current GPAI presidency holder means the reputational cost of inaction is higher here than in countries with no comparable international commitments.

Three recommendations follow from this analysis. First, integrate compliance readiness provisions into the AI education strategy before the national law enters into force; the window for proactive alignment is narrowing. Second, mandate AI tool mapping in schools; without knowing which tools are deployed and for which purposes, risk classification is structurally impossible. Third, pilot the compliance self-assessment tool proposed in this paper in a representative sample of Serbian schools to generate the empirical data this study cannot provide. Document analysis can identify the gap; only field research can measure its actual scope and the practical barriers to closing it. That empirical work is the necessary next step, and it is one that the engineering management research community is well positioned to lead.

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How AI is transforming the teaching process in higher education

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Abstract. The rapid integration of Artificial Intelligence (AI) is fundamentally reshaping the landscape of higher education, moving beyond simple automation toward a paradigm shift in pedagogy. This paper explores the multi-faceted impact of AI on the teaching process, focusing on the transition from standardized instruction to personalized learning, the automation of administrative tasks, the evolving role of the educator from a primary information source to a cognitive mentor, the application of generative AI by students, and the critical ethical challenges regarding academic integrity. To ground these theoretical shifts in practice, the study employs a qualitative methodological approach through in-depth surveys with university professionals from North Macedonia, Romania, and Bosnia and Herzegovina. The findings reveal a shared regional crisis in traditional assessment methodologies, a growing concern over the "shortcut epidemic" eroding students' critical thinking, and a divergent philosophical understanding of AI as either a supplementary tool or a fundamental paradigm shift. Ultimately, the study provides a critical baseline for policymakers and educators to navigate the AI-driven transformation of the university classroom and safeguard the core values of higher education.

Key words and phrases: Artificial Intelligence, Higher Education, Personalized Learning, Pedagogical Transformation, North Macedonia, Romania, Bosnia and Herzegovina.

1 INTRODUCTION

Artificial intelligence is a technological revolution that will profoundly transform society in all its dimensions. The European Commission (2018) describes AI as "systems that exhibit intelligent behavior by analyzing their environment and taking action—with a degree of autonomy—to achieve specific goals." UNESCO (2021) defines AI as "technological systems capable of processing information through a process resembling intelligent behavior, and generally including functions of reasoning, learning, perception, anticipation, planning, or control." With the widespread adoption of generative AI starting in November 2022, it has become accessible to everyone. But it is also a source of anxiety and uncertainty for many stakeholders. By its very nature, it is a source of biases that are difficult for citizens to identify but can have significant consequences, particularly regarding the veracity of claims.

In the context of higher education, AI is used by online learning platforms that personalize learning paths according to students' individual needs, while virtual assistants facilitate access to information. Beyond functioning merely as an advanced tool, AI fundamentally challenges established teaching practices, redefines the roles of both teacher and student, and questions the very nature of knowledge acquisition and validation within academic institutions. Recent data indicates that almost all European youth (97%) are daily internet users (Eurostat, 2025, as cited in European Schoolnet, 2025), with a significant majority engaging with AI-driven platforms. Beyond daily social interactions, students are increasingly relying on artificial intelligence

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applications to facilitate their academic activities and support their educational development (Waller et al., 2025, as cited in European Schoolnet, 2025).
This dynamic is particularly well understood through the Actor-Network Theory (ANT) of Akrich, Callon, and Latour (2006). In this framework, AI behaves as a "non-human actor" that actively participates in the processes of translating interactions within the educational network. By taking part in the interactions of the educational system, AI redefines the traditional roles of the teacher. The teacher increasingly assumes the role of supervisor and facilitator of learning.

However, critiques of the teacher-facilitator view remind us that education is not simply about transmitting technical knowledge. Philip Jackson, in *Life in Classrooms* (1990), argues that the teacher plays a central role in the construction of knowledge and values. This interaction is enriched by human exchanges, questioning, and in-depth reflection that forge critical thinking. The teacher-student relationship is not simply a vehicle for learning; it also represents a model of behavior, values, and thought. By providing personal perspectives and in-depth knowledge, teachers often inspire students, an aspect that AI cannot emulate.
Consequently, this reconfiguration is not without controversy. In this respect, the question of assessment becomes central. Indeed, AI offers new possibilities for content production, which poses a challenge in terms of assessment, particularly for evaluating the skills actually acquired and individual understanding. Institutions are therefore obliged to rethink their assessment practices to guarantee the validity of learning.
Addressing these profound shifts requires a strategic and localized response. As noted in recent regional policy frameworks: " *Artificial intelligence represents a powerful tool with the potential to radically transform education for the better. However, its successful integration requires a thoughtful, ethical, and pedagogically grounded approach. This Guide is a step in that direction, offering practical guidelines and a critical overview for all those who wish to harness the power of AI to create better, more effective, and more inclusive education for everyone*." (Ministry of Digital Transformation, 2025). AI is redefining the role of the teacher as the sole source of knowledge, which is influencing power dynamics. These changes are evident in practices and can alter the expectations of various stakeholders. Ultimately, the integration of AI raises critical ethical concerns, such as equitable access and the protection of students' personal data, illustrating the profound difficulty of seamlessly integrating these systems into higher education.
The remainder of this paper is structured as follows: Section 2 analyzes the national policy frameworks and infrastructural readiness regarding AI integration across the region. Section 3 examines the role of AI in higher education and institutional implementation. Section 4 details the qualitative methodology and presents the research findings gathered from academic professionals in North Macedonia, Romania, and Bosnia and Herzegovina. Finally, the paper concludes with a critical summary and recommendations for safeguarding the core values of higher education in an AI-driven environment.

2 National Approaches and AI Integration Across European Educational Systems

The integration of artificial intelligence into regional educational systems is not a uniform process; it is heavily influenced by varying levels of digital infrastructure, institutional readiness, and national policy frameworks. Analyzing the comparative landscape across Eastern and Southeastern Europe reveals a complex intersection of strategic ambition and practical infrastructural limitations.

2.1. *National Strategies and Policy Frameworks*

Across the region, governments are taking initial steps to regulate and promote the use of AI in education. In Romania the Ministry of Education announced in March 2025, that it “decided to implement a pilot project for the use of artificial intelligence in educational units, in order to optimize (…) the educational process in general”, after a meeting with the management of Microsoft Romania. The adoption of artificial intelligence (AI) in the education system is included in the *National Strategy in the field of AI 2024-2027*. The Ministry of Education “must remain lucid and circumspect in its relationship with technological products offered by software companies”. “The priority of this institution must be the harmonious development and safety of students and teachers. Thus, it must ensure that any tools or technologies used in the classroom can be supervised and controlled directly by operators in the country, without depending on a commercial entity whose interests could be contrary to national ones.

For comparison, Estonia—often viewed as a model for digital education—plans the introduction of AI in structured stages. Before utilizing AI applications, Estonian students and teachers undergo rigorous training courses to develop the capacity to critically analyze and responsibly utilize artificial intelligence.
This strategic recognition is gradually echoing across the Balkans, aligning with broader EU conditions. In Croatia, the *National Strategy for the Development of Artificial Intelligence* has positioned AI as a primary driver of development up to 2030. In Serbia, a strategy for AI development (2020–2025) was defined to align with the European AI initiative, leading to the establishment of the Research and Development Institute for Artificial Intelligence in Novi Sad, alongside applications in industry and education. Similarly, the Parliament of the Federation of Bosnia and Herzegovina emphasized AI development in its 2021–2027 strategy, highlighting the need to mobilize existing resources (Ajanović et al., 2023). In North Macedonia, integration is currently guided by the 2025 "Guide for artificial intelligence intended for teachers, professional associates, and students" published by the Ministry of Digital Transformation, which represents a crucial first step in standardizing the ethical use of AI in classrooms.

2.2. *The Digital Divide and Infrastructural Readiness*

Despite these strategic ambitions, the region faces a severe digital skills gap and infrastructural deficits. The organization managing the international digital skills certification standard (ICDL) has publicly warned that Romania possesses some of the lowest levels of digital skills in the European Union. In 2025 European Commission report noted that 31.8% of Romanians have basic or above basic overall digital skills, far below the EU average of 60.4%. In Bosnia and Herzegovina 36.25%, in Serbia 42,02% in North Macedonia 28.50% (Eurostat, 2026).
When it comes to educators, the practical adoption of AI remains highly uneven. According to the OECD's most recent International Teaching and Learning Survey (TALIS 2024), teacher engagement with AI varies significantly across the region. While 46% of Romanian teachers and 42% of teachers in North Macedonia report having used AI in their work (both performing above the OECD average of 36%), only 29% of teachers in Serbia report doing so. Furthermore, the survey highlights that among Romanian educators who do not use AI, 58% cite a lack of skills and 39% cite a lack of infrastructure as primary barriers.
This infrastructural barrier is evident across the region. In Bosnia and Herzegovina, the implementation of AI remains fragmented, primarily driven by international projects. Crucially, a significant connectivity gap persists; approximately 14,000 students across 500 schools in BiH lack adequate internet access, prompting recent initiatives by UNICEF and other stakeholders to push for stronger digital investments (UNICEF, 2023). These digital inequalities are directly reflected in standardized academic performance and are compounded by varying levels of national investment. For comparison, in 2023 GDP in education spending in Romania (3.3%), contrasting sharply with the highest shares in Belgium 6.3 % and Sweden 7.2%.In the Western Balkans, investment levels also vary but remain generally below the EU average (4.7%); In 2023 Serbia allocates approximately 3.4% of its GDP to education, Bosnia and Herzegovina allocates 3.2 % of its GDP to education while North Macedonia invests around 3.2% in 2024 (Eurostat, 2023, World bank group, European Commission, 2025) Consequently, in the 2022 PISA assessments, Romania scored below the OECD average (in mathematics, reading and science 428 points, compared to an average of 472 points in mathematics OECD countries; compared to an average of 476 points in reading in OECD countries, compared to an average of 485 points in science in OECD countries). Similarly, regional peers lag significantly behind, with Serbia averaging around 440 points. Although Bosnia and Herzegovina allocate a higher share of GDP to education compared to Romania, these results indicate a lower efficiency of the education system and lower productivity of educational investments in terms of learning outcomes (scoring 406 in mathematics, 403 in reading, and 398 in science in PISA 2018). North Macedonia also scores significantly below the OECD average (389 in mathematics, 359 reading and 380 in science) (OECD, 2023) While Serbia performs relatively better within the region—scoring 440 in mathematics, 440 in reading, and 447 in science—it still remains below the overall OECD average (OECD, 2023). If the introduction of AI is not accompanied by foundational digital education, adapted assessments, and robust certification, it risks severely exacerbating these existing disparities.
Recent empirical research in North Macedonia involving 130 primary school students and 100 educators across five schools highlights a profound perceptual divide regarding AI integration. The findings indicate that while approximately 50% of students actively utilize tools like ChatGPT as an easy shortcut for homework and essay writing, they fundamentally lack a formal understanding of the technology's underlying mechanisms.

Conversely, educators display deep skepticism and anxiety, viewing student AI adoption as a threat to independent critical thinking and classroom control. Ultimately, the study underscores that this negative pedagogical stance is primarily driven by a lack of institutional resources and training, concluding that systemic educator professional development is urgent to foster an ethical and balanced digital transformation. (Mitevska-Poceva, 2023).

This institutional unpreparedness is a broader European issue. The Vodafone Foundation study, *"Artificial Intelligence in European Schools,"* conducted among 7,000 students across seven countries, identified an emerging "AI skills gap." While 74% of surveyed students believe AI will play a significant role in their professional careers, less than half feel adequately prepared by their schools. The study's main findings highlight:

- there are severe inequalities in access to connectivity and AI tools for students from low-income families;
- at the European level, there is a systemic lack of AI skills, content, and guidance for educators;
- while students are optimistic about innovative AI learning approaches, 27% feel completely left out when it comes to using AI at school.

Furthermore, while 74% of all surveyed students believe artificial intelligence will play a significant role in their professional careers, less than half feel adequately prepared by their schools. Addressing this deficit, Joakim Reiter, Director of External Affairs at Vodafone Group, stated: *"Our research suggests that a new 'AI skills gap' is emerging, which could further widen digital skills inequalities, particularly for children from lower-income families. For Europe to fully reap the potential of AI, the education sector and policymakers need to ensure that this new technology is part of the curriculum for all children, regardless of their background."*

This sentiment is strongly echoed at the local level. In Romania, the level of familiarity with AI is highly correlated with socioeconomic status; 65% of children from affluent families report being quite or very familiar with AI. As Angela Galeța, Director of the Vodafone Romania Foundation, noted: *"While Romanian students recognize that artificial intelligence plays a vital role in their academic success, the lack of digital skills and teacher training means that this technology is neglected in many schools. However, using AI without a critical understanding of how it works and without respecting ethical principles can amplify the risks."* To counter this, local initiatives such as the *School of the Future* program (part of the European *Skills Upload Jr.* initiative) are actively launching new lesson plans focused on the responsible and conscious use of AI, directly supplementing the standard curriculum.

2.3. *Institutional Implementation and Industry Alignment*

At the higher education level, the response to these challenges is highly polarized. In contrast to fragmented implementations, some institutions are treating AI as a strategic priority. At the West University of Timișoara (UVT), technology is considered a core focus. UVT aims to be a driver of digital transformation through an approach that seeks to:

- integrate digital skills and AI culture into all fields of study;
- train students in critical thinking and the ethical use of emerging technologies;
- train teachers in digital pedagogy and AI-assisted education; and
- develop interdisciplinary research dedicated to the impact of AI on education and society.

Supported by a Flex Foundation grant, UVT is equipping virtual reality (VR) labs in its Faculty of Economics and Business Administration and the Faculty of Computer Science. In this space, participants can test their level of financial literacy through simulated transactions on financial markets and explore essential entrepreneurial skills through modules dedicated to risk-taking, creativity, performance, and market analysis. The VR lab also offers students the opportunity to explore otherwise inaccessible worlds, such as the International Space Station and flight simulators, transforming learning into an immersive experience.

Conversely, in universities across Bosnia and Herzegovina, digital transformation is progressing unevenly, hindered by a lack of unified institutional strategies (Hrnjić et al., 2025). To adequately respond to these

dynamic changes, bridging the gap between universities and the economy is paramount. This requires addressing several structural imperatives:

- the need to rethink the national industry and launch comprehensive programs for reindustrialization;
- the need to restructure higher engineering education in accordance with the new requirements of the knowledge-based society;
- the need to strengthen the links between universities and the economic environment, increasing academic contribution to innovative products;
- the development of efficient ways to finance engineering students by focusing their diploma, dissertation, and doctoral projects on concrete problems formulated by economic agents.

As Ajanović et al. (2023) suggest, modernizing technical education does not merely mean increasing technological disciplines, but introducing "human factors engineering" to ensure graduates are adaptable to future workplace conditions. These diverse institutional approaches—ranging from pro-active strategic investment in Romania to fragmented initiatives in Bosnia and Herzegovina—illustrate the broader regional struggle to synchronize higher education with the rapid pace of AI evolution.

This institutional challenge is further corroborated by primary survey data from Macedonian higher education institutions, which reveals that while familiarity with generative AI and text tools exceeds 94%, actual practical adoption remains in a developmental stage, with only 54% of the academic community utilizing them occasionally (Parnardzieva Stanoevska et al., 2024). Crucially, the empirical evidence underscores a powerful consensus among Macedonian students, assistants, and professors, who explicitly state that automated systems can never replicate the essential nature of human connection and academic mentorship. Furthermore, the study highlights a profound pedagogical risk, noting that heavy reliance on these tools threatens to turn students into passive consumers rather than active learners, given that very few respondents recognized AI as a driver for enhancing critical thinking or complex problem-solving skills (Parnardzieva Stanoevska et al., 2024).

2.4. *Psychological and Cognitive Implications for Students*

Beyond logistics and skills, the rapid adoption of AI raises profound cognitive and psychological concerns. Research shows that adolescence and early adulthood represent a critical, extended period for brain development. Age alone is not a definitive indicator of psychological maturity, meaning students may react in vastly different ways to AI interactions depending on their temperament, neurodiversity, mental health, and socioeconomic background. Crucially, biases—stemming from unrepresentative training data, a lack of diversity in product testing, and adult-designed programming—can deeply impact younger users. Adolescents are generally less likely than adults to question the accuracy and underlying persuasive intent of information provided by an automated bot.

The impact of these tools on pure cognitive processing is highly concerning. A recent study by the Massachusetts Institute of Technology (MIT) analyzed 54 participants divided into groups writing essays independently, with the help of search engines, or with the assistance of AI. The conclusion demonstrated that AI users "consistently performed worse at the neural, linguistic, and behavioral levels." As the authors of the study concluded, longitudinal studies are urgently required to understand the long-term impact of Large Language Models (LLMs) on the human brain before they can be universally accepted as a net positive for human cognitive development.

Furthermore, the psychological implications of AI integration extend deeply into emotional well-being. A recent report by the Stanford Brainstorm Lab for Mental Health Innovation and Common Sense Media revealed that while artificial intelligence chatbots—including OpenAI's ChatGPT, Anthropic's Claude, Google's Gemini, and Meta's Meta AI—are marketed primarily for academic tasks, three out of four teens actually utilize them for companionship, emotional support, and conversations about mental health. Adolescents often have difficulty distinguishing between the simulated empathy of a chatbot and genuine human understanding. As a result, young people are susceptible to forming high levels of trust in AI-generated personas that present themselves as friends or mentors.

The Stanford report highlights a severe danger in this dynamic: these systems create a false sense of security and frequently fail to recognize when they must firmly direct a struggling user to seek help from a trusted

human adult. While these technologies can provide a baseline of social support for young people who might otherwise struggle to form connections, they carry a profound risk of creating unhealthy dependencies. Preliminary research indicates that strong attachments to AI entities can blur the boundaries of human interaction, potentially interfering with the development of necessary social skills and the ability to form and maintain healthy relationships in the real world.

3 AI IN HIGHER EDUCATION

The impact of AI on higher education appears to be a complex process of negotiation and adaptation, involving all stakeholders in the network and fundamentally redefining the very nature of teaching. In this context, higher education institutions (HEIs) have a major role to play. As they host millions of students—the future workforce—HEIs are uniquely positioned to experiment with and analyze emerging uses of AI, particularly because they encompass all the disciplines capable of exploring these ongoing socio-technical changes. However, AI adoption is currently developing within these institutions in a highly heterogeneous manner, predominantly driven at the individual level rather than systematically. This observation holds true across the pedagogy of both educators and students, as well as in institutional administration.

The lack of unified frameworks for the use of AI within institutions constitutes a significant obstacle to its successful adoption, especially for academic staff. Furthermore, infrastructural deficits and the absence of sovereign, institution-specific AI models prevent most universities from encouraging the widespread use of external AI platforms, given the significant risks to data privacy. This diversified, unregulated use inevitably leads to an increased risk of deepening inequalities not only within individual institutions but also between different universities across the region.

With the rapid integration of artificial intelligence in higher education, profound new questions are emerging regarding the place and role of this non-human entity. AI can no longer be reduced to a simple technological tool; it is actively becoming a fully-fledged actor, endowed with interactional capabilities that alter the fundamental dynamics of the educational system. Students frequently "humanize" this new actor, a phenomenon starkly illustrated by a conversation overheard between two students in a university library. The first student stated, *"I decided to be nice to ChatGPT so it would give me the right answers. It knows my life story; it asked me how my law studies were going."* The second student exclaimed, *"Oh really? What you're saying is scary, but you know you're talking to a robot..."* This paradigm, particularly the complete trust students often place in generative AI outputs, poses a fascinating and critical challenge for educators. Consequently, the central systemic question raised by AI concerns the evolving role of the teacher in authentically assessing and certifying the skills acquired by the student.

Addressing this challenge requires a careful reevaluation of the educator's identity. Viewing the teacher merely as a "facilitator" can make educational systems highly vulnerable to technological malfunctions. Kenneth Gergen, in *The Saturated Self* (1991), discusses the danger of technology dependency across various aspects of human life, including education. If teachers are relegated to the role of mere facilitators for AI systems, they risk losing essential pedagogical skills, and students may become dangerously dependent on machines for their cognitive processing. In the event of technological failure, limitations, or algorithmic bias, the educational system could find itself without the qualified human intervention required to ensure continuity of genuine learning.

Pedagogical autonomy for teachers is therefore necessary to guarantee consistent and sustained education, regardless of technical shifts. Reducing the educator to a mere facilitator is a simplistic approach that ignores the richness of the teacher-student relationship and the multi-dimensional nature of teaching. AI should be positioned as an ally, not a replacement. Teachers must retain their core roles as experts, mentors, and sources of inspiration, while leveraging AI as an auxiliary tool to enrich their pedagogical delivery. True modernization of education relies on a harmonious coexistence between human instructional skills and technical capabilities, constantly emphasizing the centrality of human interaction in the educational process.

To institutionalize this coexistence, university curricula must be proactively updated. Higher education does not exist solely to produce narrow hyper-specialists; rather, it provides foundational training and technological adaptability, allowing graduates to specialize dynamically throughout their careers via postgraduate courses or corporate training. Therefore, modernizing higher education requires structurally adapting students to fluid future workplace conditions. Following the example of leading institutions, universities must establish specialized master's programs focused on AI, alongside interdisciplinary curricula offering AI topics as minors to support its ethical application across other academic fields. By regularly updating these curricula to reflect current developments and offering continuous non-formal education for lifelong learning, higher education can safeguard its relevance and fully equip students for an AI-driven society.

4 METHODOLOGY

The research was conducted in March and April 2026. Data was collected through a qualitative online survey featuring in-depth, open-ended questions. This methodological approach was specifically chosen over quantitative multiple-choice testing, as it allowed the academic professionals to provide rich, reflective, and unconstrained narratives regarding their personal pedagogical experiences and challenges with AI integration. To ensure a comprehensive and systematic exploration of how Artificial Intelligence is reshaping the higher education landscape, the qualitative questionnaire was specifically designed around six core thematic domains. This structured approach allowed the research to capture a holistic view of the AI integration process, ranging from philosophical perceptions and individual pedagogical practices to broader institutional capacities. The questionnaire focused on the following key areas: *General Perception of the Transformation*: Exploring the educators' fundamental conceptualization of AI, specifically examining whether it is viewed merely as an advanced digital tool or as a catalyst for a fundamental paradigm shift in academia. *Transformation of Teaching Planning and Preparation*: Analyzing how AI tools are utilized in the background to design curricula, prepare lectures, and streamline administrative or creative academic tasks. *Transformation of Teaching Delivery and the Role of the Professor*: Examining the shift in live classroom dynamics and the ongoing transition of the educator's identity from a traditional "transmitter of information" to a mentor and cognitive guide. *Transformation of the Student Learning Process*: Investigating how AI impacts student engagement, problem-solving approaches, and the growing reliance on automated shortcuts versus active, critical learning. *Transformation of Monitoring and Evaluation (Assessment):* Addressing the vulnerabilities of traditional assessment methods (e.g., essays and term papers) and exploring the introduction of new evaluation formats designed to preserve academic integrity. *Local Context and Institutional Transformation:* Assessing the systemic readiness, resource deficits, and institutional capacities of universities within the specific regional contexts, alongside projections for the core challenges facing higher education over the next five years.

It is important to acknowledge the limitations of this study. Given the qualitative nature of the research, the sample size (N=46) is not intended to be statistically representative of the entire academic population across North Macedonia, Romania, and Bosnia and Herzegovina. Therefore, the findings should be interpreted as contextual rather than universally generalizable. However, this study serves as a critical foundational step. By capturing these initial, deep-dive perspectives, the research establishes a vital baseline and identifies core themes that will directly inform and guide future, larger-scale studies aiming to deepen and expand the understanding of AI's impact on regional higher education.

4.1 Participant Profile

The qualitative study included a diverse cohort of university professors from Bosnia and Herzegovina, North Macedonia, and Romania. The participant pool represents a broad cross-section of the regional higher education landscape, encompassing various institutional backgrounds, academic hierarchies, and pedagogical experience levels. The demographic and institutional profile of the participant cohort is summarized in Table 1.

Table 1. Demographic and Institutional Profile of the Participant Cohort

Country	N	Key Affiliated Institutions	Academic Ranks	Teaching Experience
Bosnia and Herzegovina	34	Univ. of Sarajevo (Pedagogical Faculty, Academy of Fine Arts), Univ. of Tuzla, Univ. of Banja Luka, Sarajevo School of Science and Technology	Teaching Assistants to Full Professors (min. 7 Full Profs.)	1 – 25 years *(Avg: 13.5)*

North Macedonia	7	Goce Delchev Univ. (n=5), St. Clement of Ohrid Univ., International Slavic Univ.	Assistant Professors to Full Professors	5 – 36 years *(Avg: 17.1)*
Romania	5	Bucharest Univ. of Economic Studies (n=4), Bioterra Univ.	Academic Professionals	5 – 40 years *(Avg: 20.0)*

While the participant distribution reflects a higher concentration of respondents from Bosnia and Herzegovina due to established academic networks, the cohort remains balanced in terms of pedagogical experience and hierarchical representation across all three countries.

4.2 Results

4.2.1 General Perception of the Transformation

The following section explores the general perception of the AI-driven transformation within the regional academic community. Specifically, it examines two foundational aspects of this transition: first, identifying the most radical changes AI has introduced to the daily teaching process compared to traditional methods; and second, analyzing how educators philosophically conceptualize AI—whether they view it merely as a supplementary digital tool or as a fundamental paradigm shift that redefines higher education.

Regarding the first question (When you reflect on your teaching process today compared to three or four years ago, what is the most radical change that Artificial Intelligence has brought to your work with students?), the data reveals a clear contrast between the perceived benefits for educators (faster preparation, increased efficiency) and the negative consequences on students' cognitive engagement. The data regarding the most radical changes identified by educators is synthesized in Table 2.

Table 2: The Most Radical Changes in the Teaching Process (Compared to 3-4 years ago)

Cohort	Dominant Trend / Observation	Characteristic Response (Direct Quote)
North Macedonia	**Obsolescence of Project Assignments:** Professors utilize AI for efficiency, but students misuse it, rendering traditional project-based tasks functionally obsolete.	*"The complete loss of meaning of project-based assignments, which are now done entirely through artificial intelligence."*
Romania	**Academic Passivity and Laziness:** A unanimous observation that students have ceased investing cognitive effort, relying heavily on quick, automated solutions.	*"The most radical change is that [students] don't have to put a lot of effort to think because they ask AI and they get the answer more simple."*
Bosnia and Herzegovina	**Decline in Autonomy and Assessment Shift:** The illusion of "quick help" compromises students' ability to synthesize facts, necessitating a fundamental shift in how knowledge is verified.	*"The illusion of 'quick help' [...] has compromised the independence of forming a meaningful whole... The most radical change is the complete transition from assessing knowledge to assessing the thinking process."*

The responses to the second question (Is AI merely another digital tool, or does it represent a fundamental paradigm shift?) reveal a fascinating regional divide in the philosophical conceptualization of artificial intelligence within academia. Table 3 illustrates the regional perspectives on how AI is conceptually perceived within higher education

Table 3: Conceptualizing AI in Higher Education

Cohort	Dominant Perception	Characteristic Response (Direct Quote)
North Macedonia	**Paradigm Shift:** An overwhelming majority views AI as a profound systemic change, although they remain uncertain about its ultimate long-term impact.	*"Much more than a tool; the change is massive and fundamental, without it being entirely clear just how massive it is and whether it is ultimately positive or negative."*
Romania	**Digital Tool:** A highly pragmatic approach. Almost all respondents view AI simply as the next technological step, lacking elements of a radical transformation.	*"Just another digital tool."*
Bosnia and Herzegovina	**Highly Polarized:** Two extremes are observed—ranging from the belief that the educator's role is entirely transformed, to sharp criticisms that AI is merely a "chatbot" that regresses educational standards.	**On the Shift:** *"The teacher is no longer the primary source of information, but a person who directs students toward critical thinking..."* **On the Tool:** *"A detailed study of the technology will actually show that it is a downgrade... we are talking about 1980s technology with updated databases."*

4.2.2. Transformation of Teaching Planning and Preparation

To understand the logistical and creative impact of Artificial Intelligence in the background of the educational process, respondents were asked to reflect on how AI transforms the creation of their daily teaching materials, including syllabi and case studies. Table 4 synthesizes their perspectives, highlighting a central pedagogical tension: whether AI primarily serves as an efficient time-saving mechanism and creative enhancer, or conversely, acts as a catalyst for dangerous uniformity and generic academic content. Table 4 synthesizes the educators' perspectives on the impact of AI on creating teaching materials, balancing efficiency against content uniformity.

Table 4: The Impact of AI on Creating Teaching Materials (Efficiency vs. Uniformity)

Category	Observation / Finding	Typical Response (Direct Quote)
The Shared Reality *(All Regions)*	**Consensus on Time Efficiency:** Educators across all three regions universally agree that AI significantly saves time, accelerating administrative tasks and formatting.	*"It definitely saves time, makes formatting documents easier."* (Bosnia & Herzegovina)
Divergence: North Macedonia	**Creative Enhancement:** Views AI through a positive lens. The tools are seen as actively enhancing the creative process by offering multiple options, especially for case studies.	*"It saves time and certainly improves creativity, especially through case studies."*
Divergence: Romania	**Pragmatic Assistance:** Exhibits a highly pragmatic stance. AI effectively serves a dual purpose (saving time and aiding creativity) with zero concerns raised regarding content uniformity.	*"It saves time, enhance[s] creativity."*
Divergence: Bosnia & Herzegovina	**The Uniformity Paradox:** Highly critical of pedagogical drawbacks. Warns that AI-generated materials lead to uniformity. Outright rejects AI for core syllabus creation.	*"By no means do I use AI to create a syllabus because a syllabus must be based on the students' needs, and AI does not know my students like I do."*

Beyond the creation of general materials, the study also explored the application of AI in highly specialized pedagogical contexts. Specifically, educators were asked about their reliance on AI for differentiated instruction—the practice of adapting content to match the varying levels of students' prior knowledge. Table 5 outlines the educators' willingness (and frequent reluctance) to trust automated systems with this highly sensitive, individualized task. The educators' willingness to implement differentiated instruction via AI is outlined in Table 5

Table 5: Implementing Differentiated Instruction via AI

Category	Observation / Finding	Typical Response (Direct Quote)
The Shared Reality *(All Regions)*	**Consensus on Reluctance:** The overall response is heavily skewed toward non-reliance. Most educators do not trust AI to handle the sensitive pedagogical task of individualizing learning paths.	*"I do not rely [on AI] in that segment."* (Bosnia & Herzegovina)
Divergence: North Macedonia	**Early-Stage Caution:** Implementation is non-existent to minimal. Success is seen as strictly dependent on the professor's professional expertise to critically curate the AI's suggestions.	*"I use AI tools but do not rely on them completely. It is very important what you search for and whether you have a good command of the subject matter..."*
Divergence: Romania	**The Optimistic Exception:** Demonstrates the highest level of acceptance. Unlike the other regions, educators successfully use AI to adapt content for different knowledge levels.	*"Yes... personalizing the documents in function of levels of prior knowledge is important and help[s] students."*
Divergence: Bosnia & Herzegovina	**Human Element as Irreplaceable:** Overwhelmingly rejects AI for differentiated instruction, arguing that genuine assessment and human connection are irreplaceable by an algorithm.	*"I can only differentiate if I know the students and their needs... AI cannot do that, I think that even when it offers [differentiated content], it is uniform and not individualized."*

4.2.3 Transformation of Teaching Delivery and the Role of the Professor

As generative AI easily automates the delivery of theoretical concepts, the live classroom dynamics are experiencing unprecedented disruption. This section examines how educators maintain student engagement when facts are instantly accessible, and how this technological shift fundamentally alters their professional identity—forcing a transition from traditional lecturers to cognitive mentors. Strategies for maintaining student engagement in the AI era are detailed in Table 6.

Table 6: Maintaining Engagement in the AI Era (Classroom Delivery)

Category	Observation / Finding	Typical Response (Direct Quote)
The Shared Reality *(All Regions)*	**The Shift to Interactive Pragmatism:** Educators universally agree that reciting theoretical concepts is no longer sufficient to hold attention. Across all regions, the strategy to maintain engagement has shifted entirely toward interactive, practical, and problem-based learning.	*"The attention of students rarely depends on tools for theory, but on how the teacher presents it, animates, and motivates them in class."* (North Macedonia)
Divergence: North Macedonia	**Focus on External Expertise:** Relies heavily on practical exercises, specifically emphasizing the inclusion of external practitioners and structured case studies to keep the material relevant.	*"I maintain students' attention with practice (case studies) and by including a person from practice [industry professional] in the lecture."*
Divergence: Romania	**Socratic Questioning & Role-Play:** Focuses heavily on continuous communication. Uses constant feedback loops, direct questioning, and active role-playing to force student participation.	*"Trying to put a lot of questions in order to keep them communicating with me... and case studies by role-playing."*
Divergence: Bosnia & Herzegovina	**Experiential & Emotional Connection:** Emphasizes that true engagement depends on the "human factor"—using humor, empathy, and real-life experiences that an AI cannot replicate. Highlights the need to teach principles rather than bare knowledge.	*"Teaching essentially depends on the human factor... A combination of humor in the classroom and connecting with real content that students have experienced together with the teacher."*

The data reveals that AI is acting as a forcing function for pedagogical evolution. Because students can instantly access theoretical explanations, the value of a professor is no longer measured by the volume of information they can deliver. Instead, across the Balkans, the contemporary educator's value lies in their ability to foster critical thinking, facilitate debate, and provide the human context—empathy, humor, and practical experience—that algorithms inherently lack. As the Bosnian cohort acutely noted, the modern academic must guide students not merely in acquiring information, but in knowing how to critically process and ethically utilize it. The transformation of the educator's identity from a traditional lecturer to a mentor is summarized in Table 7.

Table 7: The Transformation of Educator Identity (Lecturer to Mentor)

Category	Observation / Finding	Typical Response (Direct Quote)
The Shared Reality *(All Regions)*	**The Rise of the Mentor:** There is a clear, widespread acknowledgment of the shift toward a mentorship role. Students generally react very positively to this change, as it grants them greater autonomy and a more active learning experience.	*"My identity as a teacher is transforming from a transmitter of information to a mentor... students generally react positively because it gives them greater autonomy."* (Bosnia & Herzegovina)
Divergence: North Macedonia	**The Teacher as a 'Mediator':** Educators perceive themselves as a bridge between the digital content and the student, adopting a highly student-centered approach suited for a tech-native generation.	*"I try my best to be a mediator between the content and the student, following their needs inherent to generations raised in the age of technologies."*
Divergence: Romania	**The Hybrid Experience:** Acknowledges the transformation but views it more as a blending of old and new paradigms, attempting to mix traditional academic authority with AI assistance.	*"Is a noticeable transformation and students are pleased that I combine both my experience and the AI."*

Divergence: Bosnia & Herzegovina	**The Illusion of the "New" Shift:** A significant subset of this cohort pushes back against the premise of the question. They argue that good professors were *never* mere "transmitters of information," and that true mentorship existed long before AI. However, they acknowledge the mentor role is now more crucial than ever due to students struggling to process the flood of AI data.	*"I was never a traditional teacher who simply transmits information. My role as a teacher is to make a change, not to deliver information."* *"Students possess a certain level of information, but very often they do not know how and where to use it."*

4.2.4 Transformation of the Student Learning Process

As Artificial Intelligence becomes deeply embedded in the academic routine, this section examines its direct impact on student cognition. The educators were asked to evaluate whether students are utilizing generative AI as a constructive brainstorming partner or merely exploiting it as an automated shortcut. Furthermore, the study explores the subsequent impact of these tools on the students' broader digital competencies and critical thinking skills. Table 8 analyzes how students utilize AI tools, distinguishing between their use as a brainstorming partner versus an automated shortcut.

Table 8: How Students Utilize AI (Brainstorming Partner vs. Shortcut)

Category	Observation / Finding	Typical Response (Direct Quote)
The Shared Reality *(All Regions)*	**The "Shortcut" Epidemic:** A striking consensus exists across all three countries. Educators overwhelmingly report that the vast majority of students use generative AI almost exclusively as a shortcut for quick answers rather than a tool for genuine brainstorming or cognitive exploration.	*"Unfortunately, in most cases it is a shortcut for quick answers, without any critical thinking or checking of what is written."* (Bosnia & Herzegovina)
Divergence: North Macedonia	**The Danger of Blind Trust:** Identifies the shortcut behavior but heavily emphasizes the lack of foundational knowledge. Students trust the AI answers completely because they lack the expertise to evaluate if the generated response is actually correct.	*"Students rely on AI to complete tasks, but they do not have enough prior knowledge to judge whether it is correct or not."*
Divergence: Romania	**The Onset of Academic Laziness:** Romanian educators strictly equate the use of AI shortcuts with a direct decline in academic work ethic, consistently framing the behavior as an increase in "laziness."	*"They start to lose their thinking by becoming more lazy... merely as a shortcut for quick answers."*
Divergence: Bosnia & Herzegovina	**The Necessity for Higher-Order Tasks:** While acknowledging the shortcut problem, this cohort suggests a pedagogical counter-measure. They argue that professors must now design tasks that strictly require higher-order thinking to bypass the AI's ability to provide quick solutions.	*"As a shortcut for solving tasks... therefore it is important to create tasks at higher levels of learning that will overcome these quick solutions."*

The impact of AI on students' digital competencies and critical thinking is presented in Table 9.

Table 9: Impact on Digital Competencies and Critical Thinking

Category	Observation / Finding	Typical Response (Direct Quote)
The Shared Reality *(All Regions)*	**The Decline of Critical Thought:** Despite being "digital natives," the integration of AI has severely damaged students' critical thinking. Across all regions, educators report that students are increasingly passive, accepting AI outputs without skepticism or analytical scrutiny.	*"The more they use it, the less they doubt, and science without doubt is useless."* (Bosnia & Herzegovina)
Divergence: North Macedonia	**The Institutional Void:** Observes the decline in critical thinking but attributes it to a systemic failure. The educators highlight a severe lack of institutional training, noting that students are left to "fend for themselves" without ethical guidelines.	*"They manage on their own, they have no training on how to use them correctly... we need institutional policies for proper, ethical, and critical use."*
Divergence: Romania	**Digital Skills vs. Cognitive Effort:** Acknowledges a slight improvement in basic digital skills (learning to prompt), but reiterates that this comes at the severe cost of their willingness to engage in independent cognitive effort.	*"Some have developed better digital skills... [but] they are more lazy."*
Divergence: Bosnia & Herzegovina	**The "Digital Native" Illusion:** Provides a sharp critique of the modern student. Educators argue that the assumption that students are digitally competent is a myth. They use AI for quick answers but severely lack foundational digital literacy (e.g., basic Office software), leading to a state of mental "laziness" and shortened attention spans.	*"We look at the new generations as digital natives, but actually... I notice complete clumsiness with digital technology, starting with elementary knowledge of the Office suite. Quick solutions destroy all meaning of education."*

4.2.5 Transformation of Monitoring and Evaluation (Assessment)

When addressing the transformation of knowledge verification, the survey results indicate a profound crisis in traditional assessment methodologies across all three regions. There is a universal consensus that conventional take-home written assignments—specifically essays, term papers, and seminar papers—have become functionally obsolete due to their high vulnerability to AI generation. To preserve academic integrity, educators are aggressively shifting toward dynamic, in-person, and process-oriented evaluation methods.

North Macedonia: The "Analog" Regression and Interactive Defense The North Macedonian cohort expressed the strongest systemic disillusionment with legacy formats, with one respondent bluntly stating that *"everything traditional is completely dysfunctional."* Consequently, essays, homework, and seminar papers are being actively phased out. To counter AI-generated submissions, educators are implementing a dual strategy. First, there is a pronounced shift toward oral exams, live case study analyses, and problem-solving tasks. Second, and highly notably, some professors are deploying "analog" countermeasures, explicitly replacing digital homework with *"hand-drawn and hand-written assignments, such as maps and tables,"* to guarantee authentic student engagement and bypass digital generation entirely.

Romania: The Pragmatic Shift to Reflective and Practical Work While a small minority of Romanian educators stubbornly cling to traditional methods, the majority acknowledge that standard essays and term papers are no longer viable metrics of student capability. To ensure fair assessment, this cohort is transitioning toward evaluation forms that require personal internalization of knowledge. The introduction of *"reflective journals,"* alongside practical projects and an increased frequency of oral exams, indicates a deliberate pedagogical move to assess a student's personal cognitive journey rather than a polished, potentially AI-generated final text.

Bosnia and Herzegovina: Live Defense, In-Class Execution, and Cumulative Assessment The Bosnian cohort provided the most extensive array of countermeasures, reflecting a deep structural adaptation to the AI era. Many respondents reported that they have officially *"abolished seminar papers"* or now consider them entirely outdated. To fill this evaluative void, the cohort utilizes several rigorous strategies:

- *Live Verification:* If written papers are still assigned, they must now be accompanied by a *"live analysis and defense,"* ensuring the student can verbally articulate and defend the written arguments.
- *In-Class Execution:* To prevent home-based AI use, professors report that *"essays are mostly written during class,"* shifting the evaluation to supervised, real-time performance.
- *Continuous and Practical Formats:* The cohort heavily relies on cumulative assessment models—portfolios, formative evaluations, field reports, and highly practical projects. Furthermore, educators in the arts and music highlighted that their disciplines remain naturally immune to this crisis, as evaluation is based strictly on live *"playing, singing, and practical skills."*

Overall, the advent of AI has forced a critical paradigm shift in higher education assessment: the focus has decisively moved away from evaluating the final written product and toward evaluating the live, observable process of student comprehension.

4.2.6 Local Context and Institutional Transformation

Beyond individual pedagogical adaptations, the successful integration of AI heavily depends on institutional readiness. Educators across the three regions identified a universal need for training, software, and regulations, though their assessment of institutional capacity varied significantly. Table 10 provides a regional comparison of institutional readiness and the primary deficits identified by the academic participants.

Table 10. Regional Perspectives on Institutional Readiness and Key Deficits

Cohort	Institutional Capacity to Adapt	Primary Deficits & Missing Resources
North Macedonia	**Moderate:** Theoretical capacity exists, but severely restricted by finances.	Premium software funding, regulations, and urgent need for **student training** (specifically regarding AI hallucinations).
Romania	**Optimistic:** The majority believe universities have the capacity to keep pace.	Continuous staff training and standard software integration.
Bosnia and Herzegovina	**Low:** Widespread pessimism due to systemic unpreparedness and lack of control mechanisms.	Ethical frameworks, institutional policies, and crucially, human factors (a reported lack of "will" and "open-mindedness" among staff).

When projecting the single greatest challenge AI will pose to the teaching process over the next five years, educators across the Balkans converged on three fundamental threats:

1. **Erosion of Cognitive Skills:** The most prominent fear is the deterioration of students' independent intellect and critical thinking, as access to instant information is increasingly mistaken for actual knowledge.
2. **Crisis of Academic Verification:** The escalating operational difficulty in accurately distinguishing between authentic student comprehension and AI-generated outputs.
3. **Relevance of Higher Education:** The profound risk that if AI is consistently utilized merely as a shortcut, it will lead to the "creation of unqualified personnel," threatening the foundational purpose and meaning of the higher education system itself.

The author(s) utilized an AI tool strictly for language translation, stylistic refinement, and structural editing of the manuscript. The authors take full responsibility for the data analysis and validity of the research

5 Conclusion

The integration of Artificial Intelligence into higher education is not merely a technological upgrade; it is a fundamental pedagogical reconfiguration that challenges the core purpose of the university. This study has demonstrated that while AI offers unprecedented opportunities for administrative efficiency and personalized learning, it simultaneously triggers a shared regional crisis in traditional assessment methodologies and a growing concern regarding the erosion of students' critical thinking—what we have identified as the "shortcut epidemic."

Our findings across North Macedonia, Romania, and Bosnia and Herzegovina highlight a unified consensus that the teacher's role is shifting from a traditional "transmitter of information" to a "cognitive mentor." In an era where facts are instantly accessible, the authority of the educator must now be rooted in the ability to foster critical inquiry, provide emotional context, and facilitate the ethical processing of data. It is crucial to emphasize that the transmission of knowledge is not merely a mechanical process. In an era where facts are instantly accessible, the authority of the educator must be rooted in authentic human communication, empathy, emotional intelligence, and direct human connection—elements that constitute the foundation of the pedagogical process and which no algorithm can replicate.

Ultimately, the findings suggest that the future of higher education lies in a harmonious coexistence between human instructional expertise and technical AI capabilities. To safeguard the value of the university degree, institutions must move beyond fragmented experimentation toward structured, ethical frameworks. Policymakers and academic leaders are urged to prioritize the redesign of curricula—shifting the focus from evaluating static written products to verifying live, observable cognitive processes. As AI continues to evolve, the university must remain, above all, a space for the development of human judgment, intellectual autonomy, and ethical responsibility.

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