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Integration of AI tools in education: a TPACK analysis and pedagogical implications

Abstract
Artificial intelligence (AI) requires a more profound methodological understanding of its integration within pedagogical frameworks. This theoretical study aims to analyze the didactic and methodological implications of applying AI tools in education through the framework of the TPACK model (Technological, Pedagogical, and Content Knowledge). A comparative analysis of 23 studies published between 2020 and 2025 were conducted according to inclusion and exclusion criteria and also through TPACK model, focusing on identifying the key pedagogical implications. Findings indicate that expert and intelligent tutoring tools demonstrate the strongest pedagogical implications, particularly in student monitoring, personalization, assistive support, reducing administrative tasks for teachers, and diagnostic assessment. The role of linguistic-generative tools in adaptive learning and feedback is narrower but remains important, while VR simulation and meta tools show selective effects, proving most effective in immersive and experiential learning contexts. Given the theoretical nature of the study, the findings represent conceptual rather than empirically confirmed implications. Future research should use longitudinal and empirical approaches to examine the long-term effects of AI in education, informing regulatory frameworks for its responsible integration and helping educators effectively incorporate AI tools to support students' lifelong learning.

Keywords**:** *AI tools, pedagogical implications, TPACK model, innovative education.*

Introduction

Education is a dynamic process that is constantly evolving, facing methodological challenges that encompass the preservation of traditional paradigms as well as the adoption of constructivist approaches aimed at fostering active student engagement. In response to these challenges, educational systems worldwide are transitioning from reproductive teaching methods to personalised learning models that adapt to the diverse needs of students at all levels of education (Huang et al., 2023, p. 194). The applications of AI in education include different kinds of AI tools for personalised learning, evaluating, and monitoring students' development. The effective integration of AI requires a structured framework that incorporates an understanding of technical capabilities (core AI concepts) along with pedagogical methodologies and content knowledge. The digital transformation of education calls for changes in learning approaches, teaching methods, and student assessment and evaluation practices (Mandić et al., 2024, p. 7). This approach places the educational component at the forefront, which is often overlooked in the modern educational system (Mandić, 2024, p. 84). The Digital Competence Framework – Teacher for the Digital Age (2024) highlights the increasing role of AI at various levels of education, emphasising its potential to enhance teaching quality through personalised learning, data-driven decision-making, and intelligent support systems.

It becomes increasingly clear that further research is needed to explore how AI can be effectively utilised in educational practices. National and global strategies foresee the application of AI in education as one way to enhance it in the future. The Artificial Intelligence Development Strategy of the Republic of Serbia (2020–2025) emphasises the dual role of AI in education: training professionals to advance AI technologies and adapting the educational system to technological changes that shape the learning environment for students. The next Artificial Intelligence Development Strategy (2025–2030) aims to further integrate AI methodologies into national educational policies and teaching practices.

This study uses the TPACK model (Mishra & Koehler, 2006, p. 1025): technological, pedagogical, and content knowledge as a theoretical framework to analyse AI tools in education. By exploring the intersections of AI opportunities through the TPACK model, the findings contribute to the broader discourse on the transformation of education under the influence of AI and provide insights into its effective application to support pedagogical innovations. Using the TPACK framework, this research offers a structured approach to understanding how the implications of AI tools can be effectively implemented to support these transformative changes. A starting point for this research was found in recent studies (Gunder & Ford, 2025, pp. 3-5; Sahin, 2025, p. 4; Feldman-Maggor et al., 2025, p. 3), which indicate that the TPACK model can provide not only a foundation but also a valuable theoretical framework for further empirical research.

1. Review of educational ai tools

Most educational AI tools are based on machine and deep learning that works in the background of AI tools that enable the creation of adaptive learning environments, where the content is adapted to the needs of each student. A fundamental understanding of how machine learning and deep learning function serves as the starting point for comprehending the concept on which AI tools are based. These tools play the role of assistants or partners, which improve the learning process at all levels (Nguyen et al., 2021, p. 4223).

The concept of machine learning is regarded as a fundamental part of AI (Dhall et al., 2020, p. 49), grounded on the premise that computers should not be taught but should be allowed to learn independently (Samuel, 1959, p. 212). The term that was based then is now the commonly accepted definition of machine learning. One of the fields where machine learning has applications and can contribute to its advancement is education. Key areas of application include predicting student performance through data analysis, enabling the identification of weaknesses, and personalised learning recommendations. This reduces the impact of bias and the *Pygmalion effect* in classrooms, ensuring a more objective education process. Particular attention is given to the development of advanced assessment methods, which balance summative and formative evaluations by using algorithms to analyse test results, learning styles, and student engagement levels (Zhai, 2021, p. 141).

Deep learning (DL) is a subfield of machine learning that uses neural networks to model complex patterns in data, allowing systems to learn from large datasets. The core of DL consists of artificial neural networks (ANN), which are made up of interconnected layers of neurons that process and transform data neural networks are inspired by the structure of the human brain, with each neuron receiving input, applying mathematical transformations, and passing the result to the next layer. This hierarchical structure enables neural networks to learn progressively more abstract features, making them particularly effective in tasks such as pattern recognition (Okewu et al., 2021, p. 984). This approach enables effective pattern recognition, especially in areas like speech recognition, computer vision, and natural language processing (NLP). In NLP, deep learning is used in natural language generation (NLG), where neural networks are trained to recognise linguistic patterns and generate coherent text. These techniques enable advanced tasks such as machine translation, text summarisation, and sentiment analysis (Okewu et al., 2021, p. 990). Certain educational AI tools are built upon other AI concepts, such as big data analytics and computer vision. Firstly, predictive analytics driven by large datasets supports better decision-making and enhances student performance. Secondly, computer vision tracks student engagement through facial recognition.

In the literature review, researchers emphasise different classifications of AI tools for education. It depends on the perspective of analysis and the level of education (from kindergarten to university). From classifying educational AI tools in K-12 based on instructional, administrative, and analytical (Kwid et al. 2024, p. 8) to generative AI tools for planning, content creation, evaluation, and teaching assistants (Moundridou et al. 2024, p. 4), which can be adapted to different educational levels. AI educational tools, as identified in the selected studies included in the theoretical analysis (Table 1), represent the most prevalent tools in current educational practice and have demonstrated positive effects in enhancing various aspects of the educational process. These tools can be classified into five groups: linguistic generative tools, expert systems, intelligent tutoring systems, VR simulation tools, and meta tools. By classifying these tools, this study aims to provide a comprehensive understanding of their role in fostering intelligent learning environments.

Table 1. Review of AI Tools in Education and Associated Studies

EDUCATIONAL AI TOOLS	RELEVANT STUDIES
LINGUISTIC GENERATIVE	Fitria, 2021; Huang et al., 2022; Belda-Medina & Kokošková; 2023, Labadze et al., 2023; Mandić et al., 2024; Aldulaimi et al., 2024; Huang et al., 2024
EXPERT	Inusah et al., 2021; Sridharan et al., 2021, Lourdusamy & Gnanaprakasam, 2023; Yang & Zhu, 2024
INTELLIGENT TUTORING	Fitria, 2021; Yim, Su 2024; Chinnasamy et al. 2025; Yarlagadda K.C., 2025
VR SIMULATION	Radianti et al., 2020; Ristić, 2022; Ristić et al., 2023
META	Hirsh-Pasek et al. 2022; Hwang & Chien, 2022; Flores-Castañeda et al. 2024; Mandić et al., 2025a; Babić et al., 2025

1.1. Linguistic generative tools

The first thought of the concept of AI language generation tools is associated with the term *chatbots*. The development of chatbots dates back to the second half of the 20th century, when automated communication systems became essential for technological advancement. One of the first chatbots, ELIZA, operated by analysing user statements and providing responses through keyword recognition, creating the illusion of meaningful conversation (Weizenbaum, 1966:36; Labadze et al., 2023, p. 56). Modern chatbots like ChatGPT (Mandić et al., 2024, p. 13) are software systems based on AI, designed to conduct natural and interactive conversations with users via digital platforms. AI methods, such as speech recognition and semantic analysis, play a crucial role in their functionality, enabling the interpretation of user input and the generation of natural responses (Aldulaimi et al., 2024, p. 611).

Chatbots are widely used in education, particularly in providing personalised support to students by assisting with out-classroom learning, preparing assignments and tests, and encouraging discussion and collaboration (Labadze et al., 2023, p. 58). Key challenges in implementing chatbots include the repetition or provision of irrelevant responses, which complicates their application in educational contexts (Huang et al., 2022, p. 238). Additionally, chatbots often struggle with understanding complex questions and recognising the context of user requests. These limitations are caused by chatbot design rather than the technology itself, but advancements in AI are expected to improve their performance (Belda-Medina & Kokošková, 2023, p. 2). The effective application of chatbots in education requires teacher training for the appropriate use of AI-based technologies, as well as the development of their digital competencies, which should become an integral part of the curricula in teacher education programs (Matović, 2024b, p. 281). Also, these kinds of tools employ natural language processing (NLP) and are recognised as *voice assistants* (Fitria, 2021, p. 143) or *conversational agents* (Huang et al., 2024, p. 7), which leverage cloud computing technologies to simulate human dialogue and deliver spoken information and provide explanations in a manner resembling a personal assistant.

1.2. Expert tools

Expert systems (ES) are computer systems that use AI algorithms to mimic the human decision-making process (Lourdusamy & Gnanaprakasam, 2023, p. 218). Relying on sophisticated knowledge bases and reasoning mechanisms, these systems enable the resolution of complex problems with high accuracy and adaptability in specific contexts. Such systems facilitate the automatisation of decision-making in specialised domains, where expert evaluation plays a crucial role across various fields (Yang & Zhu, 2024, p. 88562). ES in the education area uses AI algorithms to support decision-making and the management of educational resources, enabling a more efficient and personalised learning process (Inusah et al., 2021, p. 434). These systems operate by analysing student data, identifying specific needs, and proposing appropriate educational interventions, such as tailored instructional materials or exercises. The use of *data mining* in educational systems allows for the identification of learning patterns, the detection of areas where students face difficulties, and the suggestion of targeted interventions based on these insights (Sridharan et al., 2021, p. 5898). Additionally, expert systems provide personalised feedback to help students better understand their strengths and weaknesses, thereby optimising their learning experience. Successful implementation of these systems requires ensuring infrastructure and continuous teacher training for the effective integration of digital tools into educational practice (Matović, 2024a, p. 288).

1.3. Intelligent tutoring tools

Through the combination of expert, student, and pedagogical domains with a specially designed interface, Intelligent Tutoring Systems (ITS) are digital agents that provide students with personalised feedback, guidance, and learning experiences tailored to their prior knowledge and individual needs. Also known as Intelligent Computer-Aided Instruction to provide teaching that can adapt to students' abilities (Fitria, 2021, p. 143) is based on techniques such as deep learning and neural networks, enabling them to analyse user behaviour, recognise intentions, and detect emotions, such as motivation or frustration (Winkler et al., 2021, p. 3). By applying machine learning and deep learning techniques, ITS follows students' responses, behaviours and emotional states to supply customised feedback (Winkler et al., 2021, p. 26). Rather than replacing teachers, ITS supports them by monitoring students' progress and enhancing the personalisation of the learning process (Graesser et al., 2018, p. 248). "Intelligent agents, such as Google Teachable Machine, Learning ML, and Machine Learning for Kids, which make decisions based on environmental inputs by using their sensors and actuators, are the most popular learning tools for enhancing students' computational thinking skills within K-12 contexts" (Yim, Su 2024, p. 10). In addition to ITS, robots are increasingly emerging as educational agents that promote the development of students' social and cognitive skills, enabling them to do problem-solving tasks (Yueh et al., 2020, p. 1987).

Intelligent tutoring systems provide step-by-step guidance through complex problem-solving processes (Yarlagadda, 2025: 15) and can deliver customized learning experiences, offering support that mimics human interaction and adjusts to learners' individual styles and paces (Chinnasamy et al. 2025: 239). As such, they are becoming integral components at the core of AI literacy activities and programs, transitioning from supplementary tools to central elements within the broader educational framework.

1.4. VR simulation tools

Virtual Reality (VR) represents one of the key tools of AI for creating an immersive environment that is becoming increasingly prevalent in education, thanks to more accessible hardware and advanced software solutions (Ristić et al., 2023, p. 275). It is a technology that creates interactive three-dimensional (3D) environments, simulating real or fictional situations that users experience in a highly realistic way (Mikropoulos & Natsis, 2011, p. 770). In the context of education, VR simulation tools are used for teaching, learning, and training in the development of specific skills (Radianti et al., 2020, p. 4). Through immersive experiences and learning from experience, VR offers the opportunity for active learning that fully engages students' abilities and contributes to their individual achievement development (Ristić, 2022, p. 292). Thanks to the advanced hardware components of the Oculus Go or HTC Vive headsets, users are fully immersed in virtual environments and experience every interaction as if it were occurring in the real world. AI algorithms within virtual scenarios enable users' decision-making, while the virtual environment provides feedback based on the results of machine learning. Additionally, the algorithms follow the environment's activities and generate statistical reports on students' achievements.

1.5. Meta tools

Metaverse infrastructure is still under construction (Hirsh-Pasek et al. 2022, p. 2) as 3.0. web platform (UNESCO IITE & NetDragon, 2023), which could represent a completely new paradigm of creating 3D teaching scenarios through a high level of hyper-realistic experiences (UNICEF & DIPLO, 2023; Babić et al., 2025, p. 9) and interaction with avatars (Mandić et al., 2025a, p. 903). These AI meta tools will incorporate all the benefits of extended reality and predictive AI algorithms, as well as network computing, digital twins, and blockchain. The distinction between the virtual and physical realms will be significantly reduced, or potentially eradicated, within the metaverse. This convergence will enhance user experiences, rendering them more immersive, multi-sensory, and increasingly akin to real-world interactions. Both students and teachers can participate in the metaverse from entirely different physical locations by using avatars, which they can customise to alter their appearance. Within this virtual space, they can interact not only with other real users represented by avatars but also with AI-driven avatars capable of assuming various roles, such as non-player character (NPC) tutors, tutees or peers (Hwang & Chien, 2022, p. 1). These technologies will facilitate immersive experiences by simulating real-world environments within virtual spaces, enabling dynamic interaction among users. Additionally, they will enhance the educational landscape through innovative content delivery methods while simultaneously fostering learner engagement by capturing and maintaining attention (Flores-Castañeda et al. 2024, p. 61).

2. Methodology

A comprehensive review of relevant literature was carried out, and the 23 studies included in the theoretical analysis (Table 1) were chosen based on the following inclusion criteria: 1) the level of education addressed by the research; 2) keywords: education, AI tools, TPACK model; 3) availability of the article in English; 4) open access to the full text of the article; 5) publication period (2020–2025). Although the inclusion criteria encompassed studies from all educational levels, the majority focused on the use of educational AI tools in higher education settings, particularly at the university level (Zhai et al., 2021). In contrast, the K-12 level has received comparatively less attention (Kwid et al., 2024; Yim & Su, 2024), while the preschool education level remains the least explored (Huang et al., 2024). Meta-analyses served as the initial foundation for identifying and mapping relevant studies and defining key educational AI tools. The exclusion criterion referred to studies that do not address the application of AI tools in education, lack a scientific character, or are not available in full text.

This theoretical study aims to analyze AI tools in education, with a particular focus on their pedagogical implications in enhancing the learning process and developing strategies for the effective application of AI technologies in teaching. For each of the analysed AI tools, key advantages were identified through the integration of the TPACK model. Technological, pedagogical and content knowledge represent three key components for effective teaching (Moreno et al., 2019, p. 2): 1) Technological Knowledge (TK) refers to the purposeful use of technology in teaching to enhance educational processes; 2) Pedagogical Knowledge (PK) includes teaching methods and strategies for achieving educational goals; 3) Content Knowledge (CK) refers to the content knowledge that the teacher possesses in specific teaching areas. This model is commonly represented in the literature through the intersection of a Venn diagram, illustrating the union of pedagogical-psychological, didactic-methodological, and digital technology competencies within blended teaching models (Ristić, 2019, p. 118).

Based on the main aim, the following research tasks were defined: 1) to identify the most prevalent educational AI tools; 2) The application of the three-phase TPACK model (Technological Knowledge-TK, Pedagogical Knowledge-PK and Content Knowledge-CK) served as an analytical framework for examining the three fundamental forms of knowledge that teachers need in order to effectively integrate technology into the educational process (Maor, 2017, p. 73), particularly in the context of AI educational tools; 3) to determine which pedagogical implications emerge based on the TPACK model and 4) to conduct a comparative analyse of AI educational tools and their pedagogical implications in order to evaluate their applicability for specific educational purposes. The instrument of analysis is a TPACK scheme adapted for examining AI tools through the TK, PK, and CK components (Mishra & Koehler, 2006, p. 1025). Each AI tool was assessed in relation to the identified pedagogical implications using a theoretical evaluation scale with the categories STRONG and WEAK, representing the extent to which a given tool supports the corresponding TPACK-implications. Since the study does not include an empirical sample, the findings remain within the domain of theoretical implications derived from the literature.

3. Results & discussion

The advantages of integrating AI into the educational process were determined after analysing five groups of AI educational tools using the TPACK model (Table 2). Each analysed tool group contributes to enhancing teaching through the synergistic interaction of technological, pedagogical and content knowledge, enabling the development of more effective educational strategies. This integration not only improves the quality of teaching but also brings benefits for both students and teachers to use advanced technologies in improving various aspects of the educational process.

Table 2. Technological, Pedagogical and Content Knowledge analysis for AI tools in Education.

TOOLS GROUP	Technological Knowledge (TK)	Pedagogical Knowledge (PK)	Content Knowledge (CK)
linguistic generating	Speech recognition and generating responses.	Engagement in dialogue-based learning.	Providing individualised explanations.
expert	Simulate human decision-making.	Recommending tailored learning strategies.	Personalised educational content and support.

intelligent tutoring	Monitoring activity and detecting intentions and emotions.	Identifying learning gaps and providing adaptive support.	Make suggestions for challenging learning content and assessment.
VR simulation	Creating immersive learning with interactive simulations.	Experiential learning by immersing and doing by trial and error.	Simulation of abstract, temporally and spatially distant contents.
meta	Building a hyperrealistic environment for real-time avatar interaction.	Opportunity for collaborative learning using avatars.	Generating and visualising abstract concepts through interactive collaboration.

After analysing technological, pedagogical and content knowledge separately, there has been a TPACK analysis to examine how AI education tools could be integrated into teaching. This process involved analysing each component of the TPACK model in the context of specific AI educational tools and then synthesising these components to form a comprehensive understanding of how technology, pedagogy, and content interact in the educational process and contribute to define a framework of TPACK-implications.

TPACK-implications

The TPACK analysis enabled us to identify the key implications of integrating AI tools into the educational process, representing a significant step toward innovative education. The cross-analysis conducted within the TPACK framework revealed numerous implications that AI educational tools bring, not only in terms of improving teaching quality but also in supporting educators in implementing more creative and effective pedagogical strategies. In the context of applying AI tools in education, the key TPACK-implications have been identified, indicating the areas in which these tools can contribute most to improving the teaching and learning process: 1) Continuous Monitoring and Evaluation; 2) Personalized and Adaptive Learning; 3) Assistive Support to Inclusion; 4) Reducing Administrative Tasks for Teachers; 5) Immersive Learning by Experience and 6) Diagnostic Assessment.

To provide a clear overview, the following table cross-references different AI tools with the pedagogical implications they support, highlighting areas where each tool can most effectively contribute to the teaching and learning process.

3.1. Continuous monitoring and evaluation

Expert and intelligent tools integrated into AI-driven platforms provide a transformative approach to continuous monitoring and evaluation of student progress (Meng, 2023, p. 18). *Coursera* has integrated AI tools which use machine learning algorithms and ensure the course recognises every incorrect answer and provides feedback in the form of explanations or suggestions (Verma, 2018, pp. 6-7). These systems offer real-time feedback that enables students to take an active role in their learning journey, allowing them to track their performance and make informed decisions regarding areas that require further attention. From the perspective of teachers, AI-powered platforms offer a more nuanced and accurate assessment of individual student strengths and weaknesses compared to traditional evaluation methods. In practice, *Quizizz AI, Eduaide.ai, and MagicSchool* are very useful for generating assessment content or the assessment items themselves (Moundridou et al. 2024, p. 5). Linguistic generating tools provide instant feedback allows for timely adjustments in instructional strategies, addressing specific learning gaps and ensuring more personalised support for each student. Furthermore, these platforms provide detailed analytics that offers educators valuable insights into broader patterns of class performance (Mahmood et al., 2022, p. 1). This data-driven approach empowers teachers to make informed decisions about teaching methodologies, curriculum modifications, and targeted interventions. By continuously tracking and evaluating student progress, AI-driven platforms with specific tools contribute to more precise, informed, and effective evaluations, ultimately leading to improved educational outcomes.

3.2. Personalised and adaptive learning

AI tools for education are most often described through the concept of individualised or adaptive learning because they provide "automatisation of support for students in learning" via AI tools for personalised and/or adaptive learning (Standen et al., 2020, p. 1750). An analysis of numerous studies reveals that the boundary between these two processes is becoming increasingly unclear, meaning that they are often used as interchangeable terms (synonyms) when associated with AI-enhanced learning (Xie et al., 2019, p. 14).

The present capabilities of AI-driven avatars (Mandić et al., 2025b, p. 122) in education can be categorised into three primary areas: Adaptive Teaching, Personalised Instruction, Instant Feedback. When AI tools are described from the perspective of empowering individualisation in the learning process, it is assumed that the intelligent tutoring system's algorithms will identify the individual characteristics of the learner and, based on this, initiate the next steps in providing support. If we analyse this from the perspective of offering adaptive assistance to students in the learning process (adaptive learning), it is sufficient to identify only the outcomes, i.e., learning results, without identifying relevant, personalised information, including individual characteristics and preferences that may further influence on their progress or achievements (Xie et al., 2019, p. 3). Scheiter and colleagues emphasise that adaptive systems differ in how they collect information about students, i.e., whether they diagnose their process behaviour or identify their current level of knowledge, skills, or motivation (Scheiter et al., 2019, p. 33), and their pace during learning activities (Lancrin & Vlies, 2020, p. 7; Verma, 2018, p. 6), time spent on tasks, and the number of attempts and errors. Based on this data, the teacher can more effectively initiate the zone of proximal development. According to this, they note relevant information can be collected explicitly (by asking students to respond to a questionnaire or test) or implicitly (by analysing how students interact with the system). Moundridou et al. (2024, p. 5) emphasise tools to accommodate diverse student needs and differentiate instruction for various learning styles and abilities: *Learnt.ai* and *MagicSchool* with accommodation suggestion generators and behaviour intervention suggestions.

3.3. Assistive support to inclusion

It is widely observed that teaching methods are not tailored to the developmental needs of students with speech or motor difficulties (Neamtu et al., 2019, p. 2). There are AI educational tools that detect dyslexia, dyscalculia, speech impairments, and attention deficit hyperactivity disorder (ADHD) (Drigas & Ioannidou, 2013, p. 387), as well as those designed for students with visual, hearing impairments, or certain forms of autism. *AI Seeing* application (Microsoft): automatically detects and shows in textual form any content within a photograph (e.g., a picture of a classroom board) thanks to optical character recognition technology, subsequently, using text-to-speech technology to process an audio message. AI education ensures students with autism, disabilities, or learning difficulties can develop and enhance social skills through "judgment-free environment" (Mandić et al., 2025a, p. 903; Verma, 2018, p. 7,) through trial and error in interaction with virtual characters (avatars) and digital objects (Lancrin & Vlies, 2020, p. 13). Research findings (Porayska-Pomsta et al., 2018, p. 6) support the idea that AI can be used as an assistive technology in working with children aged 4 to 14 years with Autism Spectrum Conditions (ASC). With the technology known in the literature as ECHOES, conditions are created for educational staff, together with the AI system, to foster a more stimulating environment for learning and the development of socio-communicative skills.

3.4. Reducing administrative tasks for teachers

The use of AI in education allows teachers to significantly reduce administrative tasks, which in turn lowers their overall workload (Nikitina & Ishchenko, 2024, p. 98). AI tools integrated into *NetDragon's One Stop learning platform,* can automatically handle key tasks, such as tracking student attendance, recording their activities during class, monitoring homework completion, and grading. Additionally, these tools make it easier to generate reports on student progress, plan lessons, and document activities. *Curipod* and *Auto Classmate* (AI-powered Lesson Plan Generator) are tools designed to create learning activities or complete lesson plans based on specific teaching methods, such as project-based learning and direct instruction (Moundridou et al., 2024, p. 4). By using these technologies, teachers can improve the efficiency of the educational process and dedicate more time to working with students. This allows them to focus more on the pedagogical aspects, such as developing students' socio-emotional skills, critical thinking, and value-based attitudes (Polak, 2022, p. 2).

3.5. Immersive learning by experience

In practice, the most advanced AI educational tools are found in the field of natural sciences (STEAM education). For example, subjects such as mathematics, physics, and chemistry provide sufficiently precise content, meaning they contain adequate data that can be used to train, test, and later implement AI systems in education. This implies that intelligent tutoring tools will be better equipped to monitor students' achievements in the natural sciences than in subjects like history, philosophy, or poetry (Schiff, 2021, p. 348). However, virtual reality, as a distinct branch of AI, offers solutions for learning not only natural but also social phenomena. From a didactic perspective, virtual reality provides conditions for learning through exploration, applying the principle of obviousness. 3D simulations in *NetDragon's SandBox* or *101VRLab* platform are particularly useful when it is necessary to illustrate abstract natural phenomena such as the rotation and revolution of the Earth, distant regions (e.g., another continent, the appearance of other planets), or risky situations (e.g., simulating experiments in a virtual laboratory). Through the immersive experience in virtual reality or the metaverse via VR glasses, various senses are activated (Ristić, 2022, p.

282), and interaction with avatars and digital objects takes place, thereby enhancing a deeper experience and motivation, which are essential factors for the effective acquisition of knowledge.

Traditional pedagogical approaches should be strengthened with the capabilities of AI technology in combination with an integrative teaching method and content for STEAM education, as well as content related to cultural heritage (Ristić, 2019, p. 43). Various metaverse scenarios have been proposed, such as Ancientcraft, where students can learn from experience and develop cultural identity by raising cultural awareness and heritage in learning situations where the student, as an avatar, creates a "ćilim" (type of Serbian traditional rug or carpet) (Ristić et al., 2022, p. 164). The purposes of learning in the metaverse can closely align with the learners' real-life needs if they do not have opportunities to experience or practice in the real world. NPCs can play key roles such as tutors or advisors, providing specialised guidance in learning, but also NPC tutees could be of great help to pre-service teachers to simulate typical student behaviour and create a teaching environment where they need to exercise pedagogical decision-making (Hwang & Chien, 2022, p. 5).

3.6. Diagnostic assessment

Information systems in educational institutions should provide notifications not only about past conditions but also data and information about the current state and future possibilities (Lalić et al., 2011, p. 68). Various methods of machine learning and deep learning are successfully used to predict potential outcomes in educational work, making them a reliable diagnostic tool in educational policy and practice. These methods can predict the decisions of high school graduates regarding further education (Miljkovic et al., 2011), the success of student achievement (Chen et al., 2014), identify students who may potentially drop out of education (Tsai et al., 2020), or detect students who need a higher level of motivation during the learning process (Đurđević-Babić, 2017). All studies used real data from school and university information systems to train prediction models with machine learning and deep learning techniques. A comparative analysis of the results was conducted, identifying the most effective methods. The findings confirm that AI methods are valuable tools for predicting outcomes in education. Recent studies also highlight the role of diagnostic assessment in identifying students' strengths and weaknesses and supporting the design of personalized interventions and learning strategies (Kholid et al., 2024, pp. 445-458).

Table 3. *Theoretical Assessment of AI Educational Tools Based on Key TPACK-Implications*

TOOLS GROUP	**continuous monitoring and evaluation**	**personalized and adaptive learning**	**assistive support to inclusion**	**reducing administrative tasks for teachers**	**immersive learning by experience**	**diagnostic assessment**
linguistic generating	STRONG	STRONG	WEAK	WEAK	WEAK	STRONG
expert	STRONG	STRONG	STRONG	STRONG	WEAK	STRONG
intelligent tutoring	STRONG	STRONG	STRONG	STRONG	WEAK	STRONG
VR simulation	WEAK	WEAK	STRONG	WEAK	STRONG	WEAK
meta	WEAK	STRONG	WEAK	WEAK	STRONG	STRONG

Based on the theoretical assessment presented in the table, expert systems and intelligent tutoring tools demonstrate the strongest pedagogical implications for educational use, as they are rated STRONG in almost all identified TPACK domains. These tools most effectively support continuous monitoring and evaluation, personalized and adaptive learning, assistive support to inclusion, reducing administrative tasks for teachers and diagnostic assessment, indicating their significant potential to enhance the quality and improving of the teaching process. On the other hand, linguistic generative tools have a more limited but still meaningful impact, mainly in personalized learning and assessment, showing that they can effectively support communication and feedback in teaching. VR simulation and meta tools have more specific implications, being most effective in immersive and experiential learning. However, their weaker link to administrative and evaluative functions suggests they are better suited for specific contexts than for overall instructional support.

Conclusion

Building on the theoretical framework provided by the Technological Pedagogical Content Knowledge (TPACK) model, this study highlights the pedagogical implications of educational AI tools and their potential to enhance teaching and learning processes. The analysis emphasizes that the effective application of each AI tool relies on teachers' mastery of technological, pedagogical, and content knowledge (TK, PK, and CK), which together enable purposeful integration of AI into educational practice. (Moreno et al., 2019, p. 2). The results confirm that AI has the potential to significantly enhance the educational process through the integration of various AI educational (linguistic generative, expert, intelligent tutoring, VR simulation and meta) tools. By leveraging these technologies, AI-driven education facilitates personalised and adaptive learning, continuous student assessment, and assistive support for inclusive education. It is expected that AI tools further enhance learning environments, particularly for students with developmental challenges, enabling more inclusive and supportive educational experiences through avatar support (Mandić et al., 2025a, p. 903). Additionally, AI reduces the administrative workload of teachers, allowing them to focus more on pedagogical work and the development of students' critical thinking and value-based attitudes. Different levels of education necessitate a tailored application of AI tools, ensuring their selection aligns with students' developmental characteristics (Yim, Su 2024, p. 28), the specific demands of individual subjects, and the pedagogical activities undertaken by teachers, such as monitoring, assessment, evaluation, and reporting. In this context, teachers can develop their models for the purposeful integration of AI tools adapted to the specific educational level. This process requires a comprehensive consideration of three key aspects of technology implementation in education: technological knowledge (TK), pedagogical knowledge (PK), and content knowledge (CK). However, the effective implementation of educational AI tools depends on teachers' ability to recognise and purposefully integrate AI into their practice.

In conclusion, expert systems and intelligent tutoring tools demonstrate the strongest pedagogical implications, showing high applicability across most TPACK domains. Their capability to support monitoring, personalized learning, inclusion, and assessment highlights their potential to enhance teaching quality. Linguistic generative tools have a more limited yet valuable role, mainly in communication and feedback, while VR simulation and meta tools show selective implications, proving most effective in immersive and experiential learning contexts.

IMPLICATIONS

Given the rapid development of artificial intelligence, measuring the effects of educational AI tools on the quality of pedagogical implications requires a thoughtful and purposeful integration of AI as an educational technology. This process involves the continuous development of valid methodological instruments and the implementation of longitudinal research designs adapted to diverse participant groups, age levels, and educational contexts. Therefore, future research should adopt a longitudinal perspective and place emphasis on establishing national regulatory frameworks that define clear guidelines for the responsible and ethical use of AI technologies in education.

To ensure the early achievement of positive pedagogical effects, continuous professional development programs are essential, aiming to enhance teachers' digital competencies (Mandić, 2023, p. 12). In addition, initial teacher education programs should systematically integrate both theoretical foundations and practical applications of AI in education, ensuring that future educators are adequately prepared to harness its full pedagogical potential (Matović, 2024a, p. 288).

LIMITATIONS

Despite the promising implications, the integration of AI in education also poses certain risks (Babić & Matović, 2025). These include concerns related to the over-reliance on AI systems, which could reduce teachers' agency and impact their connection with students. To effectively mitigate these risks, future research should report evidence of the reliability and validity of their findings where applicable since such data are crucial to evaluating the quality of their recommended learning tools (Yim, Su 2024, p. 28).

The main limitation of this study is its theoretical nature, based on literature interpretation without empirical validation. Consequently, the findings represent the potential capabilities of educational AI tools rather than conclusively proven effects.

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Интегрисање алата вештачке интелигенције у образовање: ***TPACK*** **анализа и педагошке импликације**

Кроз оквир TPACK (енг. Technological, Pedagogical, and Content Knowledge) модела, ова студија бави се квалитативним сагледавањем могућности интеграције вештачке интелигенције у наставни процес и заснована је на компаративној анализи образовних AI алата, са фокусом на лингвистичко-генеративне и експертне алате, алате за интелигентно туторисање, виртуелне симулације и мета алате. Анализа наглашава да ефикасна примена сваког од ових алата захтева од наставника знања о техничким могућностима алата (TK), педагошким импликацијама за наставу (PK) и могућностима алата да подрже конкретне садржаје предмета (CK).

Вршењем унакрсне анализе унутар компоненти TPACK модела, идентификоване су импликације које се односе на примену алата вештачке интелигенције за потребе поучавања на свим нивоима образовања: континуирано праћење и вредновање, персонализовано и адаптивно учење, асистивна подршка инклузији, дијагностичка процена, смањење административних послова за наставнике и имерзивно искуство учења.

Лингвистичко-генеративни алати у литератури су приказани као алати чији потенцијал може да буде доминантан у пружању синхроне повратне информације за персонализовано и адаптивно окружење. Експертни и алати за интелигентно туторисање могу да олакшају административне послове, подрже наставничке одлуке и омогуће континуирано праћење, формативно вредновање и дијагностичку процену у инклузији. Алати за VR (virtual reality) симулације и мета алати, према релевантној литеаратури, погодни су за пружање имерзивног искуства које подстиче критичко размишљање, креативност и активно решавање проблема.

Полазећи од низа импликација према TPACK моделу, интеграција образовних алата вештачке интелигенције може да допринесе оснаживању позиције наставника, али захтева континуирано стручно усавршавање за сврсисходну примену ових алата у наставној пракси у циљу стварања предуслова за равијање не само дигиталних већ и компетенција за целоживотно учење код ученика.

***Кључне речи*:** *алати вештачке интелигенције, педагошке импликације, TPACK модел, иновације у образовању.*

Integracja narzędzi AI w edukacji: analiza w modelu TPACK i implikacje pedagogiczne

Niniejsze badanie prezentuje jakościową analizę możliwości integracji sztucznej inteligencji w procesie nauczania w oparciu o ramy modelu TPACK. Opiera się ono na analizie porównawczej edukacyjnych narzędzi AI, koncentrując się na narzędziach językowo-generatywnych, eksperckich, systemach inteligentnego nauczania, symulacjach wirtualnych i narzędziach meta. Z analizy wynika, że skuteczne wykorzystanie każdego z tych narzędzi wymaga od nauczycieli znajomości zarówno technicznych możliwości narzędzi (TK) i ich implikacji pedagogicznych dla procesu nauczania (PK), jak też sposobów, w jakich narzędzia te mogą wspierać określoną treść przedmiotową (CK).

Przeprowadzona analiza krzyżowa komponentów modelu TPACK pozwala zidentyfikować implikacje związane z zastosowaniem narzędzi AI w dydaktyce na wszystkich etapach edukacji, takie jak: ciągłe monitorowanie i ocenianie, uczenie spersonalizowane i adaptacyjne, wspomaganie inkluzji, ocenianie diagnostyczne, redukcja zadań administracyjnych nauczycieli oraz immersyjne uczenie się poprzez doświadczenie.

Narzędzia językowo-generatywne w literaturze przedstawiane są jako te, których potencjał jest najbardziej widoczny w zapewnianiu synchronicznej informacji zwrotnej w środowiskach uczenia się spersonalizowanego i adaptacyjnego. Systemy eksperckie i inteligentnego nauczania mogą ułatwiać zadania administracyjne, wspierać proces podejmowania decyzji przez nauczycieli, a także umożliwiać ciągłe monitorowanie i ocenianie zarówno formatywne, jak i diagnostyczne, sprzyjające inkluzji. Symulacje VR i narzędzia meta, zgodnie z literaturą, nadają się do tworzenia immersyjnych doświadczeń, sprzyjających myśleniu krytycznemu, kreatywności i aktywnemu rozwiązywaniu problemów.

W oparciu o szeroki zakres implikacji wynikających z modelu TPACK integracja edukacyjnych narzędzi opartych na AI może przyczynić się do wzmocnienia roli nauczyciela, lecz jednocześnie wymaga ciągłego rozwoju zawodowego, aby zapewnić celowe i świadome wykorzystanie tych narzędzi w praktyce dydaktycznej ? z zamiarem tworzenia warunków dla rozwoju nie tylko kompetencji cyfrowych, lecz także kompetencji uczenia się przez całe życie u uczniów.

Słowa kluczowe*: *narzędzia AI; implikacje pedagogiczne; model TPACK; innowacyjna edukacja.

Integriranje alata umjetne inteligencije u obrazovanje: TPACK analiza i pedagoške implikacije

Ova studija, kroz okvir TPACK modela (engl. Technological, Pedagogical, and Content Knowledge), kvalitativnom analizom, razmatra mogućnosti integracije umjetne inteligencije u nastavni proces. Temelji se na komparativnoj analizi obrazovnih AI alata, s fokusom na jezično-generativne i ekspertne alate, alate za poučavanje, virtualne simulacije i meta alate. Analiza naglašava da učinkovita primjena svakog od ovih alata zahtijeva od nastavnika poznavanje tehničkih mogućnosti alata (TK), njihovih pedagoških implikacija za poučavanje (PK) te načina na koje ti alati mogu podržati konkretne predmetne sadržaje (CK).

Provedbom unakrsne analize unutar komponenti TPACK modela identificirane su implikacije koje se odnose na primjenu alata umjetne inteligencije u svrhu poučavanja na svim razinama obrazovanja: kontinuirano praćenje i vrednovanje, personalizirano i adaptivno učenje, asistivna podrška inkluziji, dijagnostička procjena, smanjenje administrativnih poslova nastavnika te imerzivno iskustveno učenje.

Jezično-generativni alati u literaturi se opisuju kao alati čiji potencijal može biti najizraženiji u pružanju sinhronizirane povratne informacije u personaliziranom i adaptivnom okruženju. Ekspertni alati i alati za inteligentno poučavanje mogu olakšati administrativne zadatke, podržati odlučivanje nastavnika te omogućiti kontinuirano praćenje, formativno vrednovanje i dijagnostičku procjenu koja podupire inkluziju. Alati za VR (virtual reality) simulacije i meta alati, prema relevantnoj literaturi, pogodni su za pružanje imerzivnog iskustva koje potiče kritičko mišljenje, kreativnost i aktivno rješavanje problema.

Polazeći od niza implikacija prema TPACK modelu, integracija obrazovnih alata umjetne inteligencije može pridonijeti osnaživanju uloge nastavnika. Zahtijeva kontinuirano stručno usavršavanje kako bi se osigurala svrhovita primjena ovih alata u nastavnoj praksi. Cilj je stvaranje preduvjeta za razvoj ne samo digitalnih, nego i kompetencija za cjeloživotno učenje pojedinca.

Ključne riječi**:** *alati umjetne inteligencije, pedagoške implikacije, TPACK model, inovacije u obrazovanju.*