EĞİTİM ve İNSANİ BİLİMLER DERGİSİ
Teori ve Uygulama
Cilt: 16 / Özel Sayı / 2025

JOURNAL of EDUCATION and HUMANITIES
Theory and Practice
Vol: 16 / Special Issue / 2025

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Üniversitelerde Kişiselleştirilmiş Öğrenme ve İnovatif Öğretim Yaklaşımları: Yapay Zekâ Destekli Fen Eğitimi

Makale Türü (Article Type): Araştırma / Research

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Personalized Learning and Innovative Teaching Approaches in Universities: Artificial Intelligence-Supported Science Education

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DOI: 10.58689/eibd.1754301

Abstract: This study aims to analyze AI-supported personalized learning applications in university science education and their integration with innovative teaching approaches by drawing on existing literature. The study examines how AI transforms learning environments, optimizes learning processes according to individual student needs, and influences teachers' pedagogical approaches. The methodology employed involves a thorough analysis of the relevant literature, evaluating the role of AI-supported systems in science education and the effectiveness of personalized and adaptive learning systems. The findings show that artificial intelligence improves conceptual understanding and problem-solving skills, but there are significant gaps and contradictions in the literature regarding long-term impact, scalability, applicability in different socioeconomic contexts, and faculty members' digital pedagogical competencies. It also emphasizes the need for further research on student autonomy and the risk of over-reliance on artificial intelligence. To address these gaps, comprehensive empirical studies, interdisciplinary collaborations, and designs that support student autonomy are recommended.

Keywords: Artificial intelligence, Personalized learning, Science education, Innovative learning

Geliş Tarihi: 30.07.2025; Kabul Tarihi: 01.10.2025

Kaynakça Gösterimi: Kılıç, M. S., Doğru, M. S., & Yüzbaşıoğlu, F. (2025). Personalized Learning and Innovative Teaching Approaches in Universities: Artificial Intelligence-Supported Science Education. *Eğitim ve İnsani Bilimler Dergisi: Teori ve Uygulama, 16*(Özel Sayı), 165-192

Türkiye'de Yükseköğretimin Yeniden Yapılandırılması: Yeniklikler, Sorunlar ve Çözüm Önerileri Kongresinde bildiri olarak sunulmuştur.

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Introduction

The rapid increase in digital technologies in today's century has brought about rapid changes in many areas. Significant advances have been made in education, particularly with the integration of information and technology. These developments have led to the redesign of learning environments. This design has particularly manifested itself within the framework of conceptual depth and applied learning. Within this framework, students' individual learning needs come into play. This is particularly evident in areas such as science education (Komalawardhana and Panjaburee, 2024; Salas-Pilco et al., 2022). Here, with the concept of personalized learning, needs can vary depending on students' learning pace, prior knowledge levels, interests, and learning styles. These needs are supported by differentiated content and methods (Hardaker & Glenn, 2025).

Artificial intelligence, a technology found among today's technologies, has also significantly increased its impact on personalized learning. Technologies such as smart tutoring systems, learning analytics, and machine learning can critically analyze student behavior. This allows for the proper management of individual learning paths and instructional processes (Dong et al. 2022). These technologies have been reported to serve many areas, including visualizing abstract concepts and modeling problem-solving processes (Özdemir & Ünal, 2025).

AI-based applications are transforming not only students' learning experiences but also faculty members' teaching styles. Learning analytics provide faculty with comprehensive data on student achievement and learning trends, enabling more timely and targeted pedagogical interventions (Sajja et al., 2023). However, for this transformation to be sustainable and effective, developing faculty members' digital pedagogical competencies is crucial (Yan et al., 2023).

In light of these developments, the aim of this study is to examine AI-supported personalized learning innovative teaching approaches, drawing on existing literature. Furthermore, the pedagogical opportunities and structural challenges presented by these technologies will be discussed, and recommendations for the future will be developed.applications in university science education and analyze how these applications integrate with

Theoretical Framework

In the process of individualizing and digitizing science education, artificial intelligence-supported learning systems have played a significant role in making learning processes more effective and student-centered. In this context, personalized learning and adaptive learning systems aim to optimize learning experiences by taking individual differences into account in education (Vorobyeva et al., 2025).

Personalized learning refers to instructional strategies tailored to students' individual needs, learning pace, and interests. AI technologies have increased the applicability of these strategies, analyzing student performance data and tailoring learning materials to individual needs (Vorobyeva et al., 2025). In this process, adaptive learning systems have dynamically shaped learning paths by taking into account students' knowledge levels and learning styles (Sezgin & Yüzer, 2022).

In the context of science education, AI-powered personalized learning approaches have increased students' conceptual understanding and improved problem-solving skills. These systems monitor students' learning progress, provide instant feedback, and adapt learning materials to student needs (Vorobyeva et al., 2025). Furthermore, these approaches have increased students' learning motivation and encouraged their active participation in the learning process (Vorobyeva et al., 2025).

The effectiveness of AI-enhanced learning systems has been closely linked to faculty members' digital pedagogical competencies. To effectively utilize these technologies, faculty members have developed their digital pedagogical skills and incorporated learning analytics into their pedagogical decision-making processes (Li et al., 2025; Rakisheva and Witt, 2023). This has enabled teaching processes to become more data-driven and student-centered.

In conclusion, AI-powered personalized learning and adaptive learning systems have individualized learning processes and transformed instructional strategies in science education. These systems have improved learning outcomes by providing learning experiences tailored to students' individual needs. Moreover, faculty members' development of digital pedagogical competencies has increased the effectiveness of these technologies

Deficiencies, Gaps, and Contradictions in the Literature

Although AI-supported personalized learning and innovative teaching approaches offer great potential in the field of science education, there are some significant shortcomings, gaps, and contradictions in the existing literature (Fu et al., 2024). These contradictions can be listed as follows.

First, empirical studies on the long-term effects of AI-powered personalized learning systems appear to be limited (Huang et al., 2024). Existing research generally emphasizes short-term success and increases in student motivation. However, more evidence is needed regarding the lasting effects of these systems on students' deep understanding, critical thinking, and problem-solving skills (Jose et al., 2025). In science education, in particular, examining the long-term effects on complex learning outcomes, such as the elimination of conceptual misconceptions and the development of science process skills, is believed to fill a significant gap in the literature.

Secondly, there is a lack of research on the scalability of AI-enhanced educational applications and their applicability across diverse socioeconomic and cultural contexts (Mustafa et al., 2024). Many developed models and platforms have been tested on specific pilots or limited samples. The structural and pedagogical challenges faced for the widespread adoption and successful integration of these technologies across diverse university environments require further investigation (Bond et al., 2024). In particular, issues such as technological infrastructure deficiencies, data privacy and security concerns, and potential biases in AI algorithms are controversial areas in the literature that deserve further discussion (Dignum, 2019).

Third, there is a gap in the literature regarding the development of digital pedagogical competencies necessary for faculty to effectively use AI-enabled tools (Fu et al., 2024). While existing studies examine faculty members' attitudes and awareness of these technologies, they provide less in-depth qualitative and quantitative data on how they integrate these tools into their course designs, teaching processes, and assessment approaches (Holmes et al., 2022). A significant research gap in this area is the extent to which and how faculty members utilize learning analytics provided by AI-enabled systems to make pedagogical decisions (Ifenthaler and Yau, 2020; Shneiderman, 2020). Furthermore, further discussion is needed in the literature regarding how AI is transforming the role of faculty and the ethical responsibilities this transformation brings (Dignum, 2021).

Fourth, the paucity of interdisciplinary approaches in AI-enhanced science education is noteworthy (Roll & Wylie, 2016). Studies promoting collaboration among AI experts, educational scientists, and field experts (science educators) are limited. This can lead to discrepancies regarding the pedagogical soundness of developed AI applications and their responsiveness to the unique needs of science education (Zafari et al., 2022). For example, more collaborative research and modeling is needed on topics such as how AI algorithms are designed to align with the nature of science concepts or how effective they are in developing students' scientific inquiry skills (Chen et al., 2020).

Finally, the complex relationships between students' autonomy, self-regulated learning skills, and motivation in AI-enhanced learning environments have not been adequately examined (Chen et al., 2020). While AI systems offer personalized pathways for students, there are differing opinions on how this impacts students' ability to manage their own learning and take responsibility. While some studies suggest that AI increases students' independence (Ng et al., 2023), others point to the risk of dependency (Zawacki-Richter et al., 2019). To resolve this discrepancy, more research is needed on how AI-enhanced systems can support students' self-regulated learning skills (Dignum, 2023).

Method

Research model

This study is a systematic literature review examining AI-enhanced personalized learning applications in university science education and their integration with innovative teaching approaches. The research methodological framework is structured as a review study, a qualitative research design that aims to synthesize existing knowledge on a specific topic. This approach provides a comprehensive perspective to identify current trends, research gaps, and future research directions in the field.

The study employed a systematic review design. Systematic reviews entail a rigorous and comprehensive analysis of existing research on a clearly defined topic or clinical question. This process involves applying predetermined inclusion and exclusion criteria, systematically organizing the selected studies, synthesizing their outcomes, and presenting the aggregated evidence (Burns & Grove, 2007; Pollock & Berge, 2018). Unlike traditional reviews, systematic reviews demand careful planning at every stage—from the initial protocol development to the final reporting—so that the entire procedure remains transparent, structured, and replicable (Cuijpers et al., 2022). Furthermore, methodological standards require that at least two independent researchers collaborate throughout the entire review process to enhance reliability and minimize bias (Yucesoy-Ozkan et al., 2024). Additioanally, systematic reviews aim to increase the replicability of research and the reliability of findings. Therefore, the research process followed the steps of the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) protocol (Moher et al., 2009).

Data collection tool

The data collection process for the research consisted of scanning and selecting relevant literature. The review covered national and international academic studies published between 2020 and 2025. Academic databases such as Web of Science, Scopus, and Google Scholar, which contain leading and peer-reviewed publications in the field, were used as data sources.

During the literature review, the following keywords and combinations of these words were used:

* "artificial intelligence in science education"

* "personalized learning with AI"

* "adaptive learning in higher education"

* "learning analytics"

* "AI-based pedagogy"

* “artificial intelligence in science education”

* “personalized learning”

Selection of Studies Reviewed

The studies retrieved from the relevant databases through keyword searches were initially downloaded and systematically archived by the research team. Subsequently, a two-phase screening procedure was employed in line with the predetermined inclusion and exclusion criteria. During the first phase, the titles and abstracts of all identified studies were examined, and any studies that failed to satisfy the criteria were excluded from further analysis. In the second phase, the full texts of the remaining studies were reassessed to ensure they met the eligibility requirements. The specific inclusion and exclusion criteria applied throughout this process are detailed in Tables 1 and 2.

Table 1. Inclusion Criteria for Study Selection

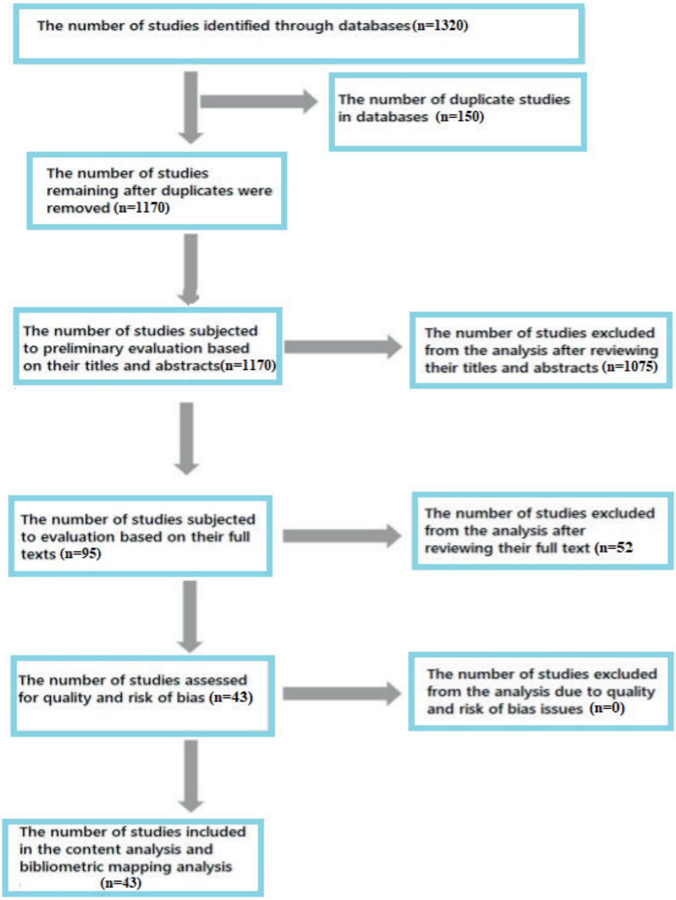
Research articles on science education indexed in the relevant databases were included in the review.
Only studies conducted with university students were included in the research sample.
If a study was indexed in multiple databases, only one version of the study (from a single database) was included.
Only studies published between 2020 and 2025 (the last five years) were included in the review.

Table 2. Exclusion Criteria for Study Selection

Publications that were not research articles—such as book chapters, book reviews, or letters to the editor—were excluded.
Studies conducted with students in pre-university educational levels were not included in the review.
Studies containing major methodological flaws were excluded from the analysis
Studies for which the full text could not be accessed due to accessibility issues were excluded.
Studies published in languages other than Turkish and English were not included in the review.

Following this criteria-based screening process, 43 scientific studies were included in the analysis. The selection process is detailed in the PRISMA flowchart in Figure 1.

Figure 1. PRISMA Flow Diagram of the Systematic Identification, Screening, Eligibility, and Inclusion of Studies



This flowchart increases the methodological transparency of the research and allows the reader to follow step by step how the researcher followed a selection process (Moher et al., 2009).

Assessment Quality and Risk of Bias

After completing the two-phase screening procedure guided by the inclusion and exclusion criteria, the remaining studies were critically assessed for potential sources of bias, methodological rigor, and overall quality (Gersten et al., 2005; Gough et al., 2017). For this purpose, the Mixed Methods Appraisal Tool (MMAT) developed by Hong et al. (2018) was employed. This tool was selected because it allows for the systematic appraisal of qualitative, quantitative, and mixed-method studies within a single, coherent framework, thereby ensuring methodological consistency across diverse research designs. For each of the studies included in the review (n = 43), researchers examined responses to two general screening items along with five additional criteria specific to the study design. The appraisal revealed that none of the evaluated studies exhibited notable quality concerns or bias risks; therefore, no studies were excluded at this stage of the analysis.

Data Coding

The analysis of the 43 selected studies was conducted using thematic content analysis, a qualitative data analysis method (Braun & Clarke, 2006). Thematic content analysis involves examining data in depth, creating meaningful codes, combining these codes into specific categories, and finally deriving main themes from these categories (Guest et al., 2012). This process aims to uncover patterns and relationships in the literature that will answer the research questions.

The analysis process included the following steps:

1. Coding of Data: Each study was carefully read and important statements, concepts and findings related to the research questions were coded.

2. Creating Categories: Similar codes were combined to create broader categories. For example, codes such as “smart tutoring systems,” “adaptive content,” and “automatic feedback” were grouped under the category “AI-supported learning technologies.”

3. Determination of Themes: By examining the relationships between the categories created, four main themes reflecting the main findings of the research were identified: (1) Personalized learning applications, (2) Adaptive content delivery and automatic feedback systems, (3) Effects on student success and motivation, (4) Digital pedagogical competencies of teachers.

Ensuring Inter-Coder Reliability

All stages of the study—from the screening procedures to the coding of descriptive data for the studies included in the review—were carried out concurrently by the research team. At each step, coding decisions were systematically documented, and inter-coder reliability was assessed to ensure consistency among researchers. Inter-coder agreement was calculated using Merriam’s (2015) formula: reliability = agreement / (agreement + disagreement) × 100. The resulting reliability coefficients were 93% for the screening phase, 98% for the application of inclusion and exclusion criteria, 86% for quality appraisal, and 99% for data coding, indicating a high level of consistency across all stages of the research process.

Ethics Approval

This research does not require ethics committee approval. Artificial intelligence applications were utilized in the study. We undertake that no violations of academic ethical rules were made in the preparation of this study.

Findings

As a result of the thematic content analysis, the findings from the reviewed studies were grouped under four main themes. These themes cover various aspects of AI-supported personalized learning applications in the context of science education. The tables below present the studies under each theme in chronological order.

Table 2. Studies Under the Theme of Personalized Learning Applications

Year	Authors	Title	Journal/Publication	Focus Area
2020	Erümit, AK, & Çetin, İ.	Design and Implementation of an Adaptive Intelligent Tutoring System for Physics Education	Journal of Computer Assisted Learning	Intelligent teaching system for physics education
2020	Koć-Januchta, MM, Schönborn, KJ, Tibell, LAE, Chaudhri, VK, & Heller, HC	Engaging with biology by asking questions: Investigating students' interaction and learning with an artificial intelligence-enriched textbook	Journal of Educational Computing Research	AI-supported textbook in biology education
2020	Yannier, N., Hudson, S. E., & Koedinger, K. R.	Active learning is about more than hands-on: A mixed-reality AI system to support STEM education	International Journal of Artificial Intelligence in Education	Mixed reality AI system for STEM education
2021	Maestrales, S., Zhai, X., Touitou, I. et al.	Using Machine Learning to Score Multi-Dimensional Assessments of Chemistry and Physics	J Sci Educ Technol	Machine learning in chemistry and physics assessments
2021	Ferrarelli, P., & Iocchi, L.	Learning Newtonian physics through programming robot experiments	Technology, Knowledge and Learning	Learning physics through robot experiments
2021	Aydin, F., & Yurdugul, H.	Examining the Trend in Postgraduate Theses on Intelligent Tutoring Systems : The Case of Turkey	Educational Technology Theory and Practice	Smart teaching systems research in Türkiye
2022	Graesser, A.C., Hu, X., & Sottilare, R.A.	Intelligent Tutoring Systems: A Systematic Review of Applications in Science Education	International Journal of Artificial Intelligence in Education	Intelligent teaching systems in science education
2022	Akyüz, H.İ., & Erdemir, M.	Preservice Science Teachers' Views of a Web-Based Intelligent Tutoring System	International Journal of Technology in Education	Opinions of prospective teachers about web-based intelligent tutoring system
2022	Murtaza, M., Ahmed, Y., Shamsi, J. A., Sherwani, F., & Usman, M.	AI-Based Personalized E-Learning Systems: Issues, Challenges, and Solutions	IEEE Access	AI-based personalized e-learning systems
2023	Hettiarachchilagea, K., & Haldolaarachchige, N.	Effective model with personalized online teaching and learning science in the era of ChatGPT	arXiv preprint	Personalized science instruction in the ChatGPT era
2025	Kanthimathi, S., Nanda, P., Venkatraman, S., Renganayagan, V., & Eswaran, S.	Transforming Education through AI-Powered Personalized Assessment Models	Adopting Artificial Intelligence Tools in Higher Education	AI-powered personalized assessment models

Table 2 presents chronologically the studies focusing on AI-supported personalized learning applications between 2020 and 2025. This table provides important data for understanding how personalized learning has evolved in the context of science education and in which areas it is concentrated. It is observed that intensive studies have been conducted on personalized learning applications in science education since 2020. Unlike other themes, personalized learning applications appear to have received more attention in 2020, 2021, and 2022. Studies conducted in 2020 (Erumit & Çetin, 2020; Koc-Januchta et al., 2020; Yannier et al., 2020) reveal that personalized learning applications vary both by discipline (physics, biology) and by technology (smart tutoring systems, AI-supported textbooks, mixed reality). Studies published in 2021 and 2022 (Akyüz & Erdemir, 2022; Aydın & Yurdugül, 2021; Ferrarelli & Iocchi, 2021; Graesser et al., 2022; Maestrales et al., 2021; Murtaza et al., 2022) indicate that the scope of personalized learning applications has expanded, focusing on more specific areas and adopting solution-oriented approaches. Studies conducted in 2023 and 2025 indicate that newer technologies have been integrated into personalized learning applications and that the evaluation of personalized learning applications has improved (Hettiarachchilagea & Haldolaarachchige, 2023; Kanthimathi et al., 2025).

Table 3. Studies Under the Theme of Adaptive Content and Automatic Feedback Systems

Year	Authors	Title	Journal/Publication	Focus Area
2020	Sezgin, S., & Yüzer, TV	Analyzing adaptive gamification design principles for online courses	Behavior & Information Technology	Adaptive gamification for online courses
2020	Wang, S., Christensen, C., Cui, W., Tong, R., Yarnall, L., Shear, L., & Feng, M.	When Adaptive Learning is Effective Learning: Comparison of an Adaptive Learning System to Teacher-Led Instruction	Interactive Learning Environments	The effectiveness of adaptive learning systems
2021	Deveci Topal, A., Dilek Eren, C., & Kolburan Geçer, A.	Chatbot application in a 5th grade science course	Educ Inf Technol	Chatbot application in 5th grade science class
2022	Cooper, G.	Examining Science Education in ChatGPT: An Exploratory Study of Generative Artificial Intelligence	Journal of Science Education and Technology	Science education review on ChatGPT
2023	Bitzenbauer, P.	ChatGPT in physics education: A pilot study on easy-to-implement activities	Contemporary Educational Technology	ChatGPT applications in physics education
2023	Elkhodr, M., Gide, E., Wu, R., & Darwish, O.	ICT students' perceptions towards ChatGPT: An experimental reflective lab analysis	STEM Education	ICT students' perceptions of ChatGPT
2023	Chuang, CH, Lo, JH, & Wu, YK	Integrating chatbot and augmented reality technology into biology learning during COVID-19	Electronics	Chatbot and AR in biology learning during COVID-19
2024	Hotar, N., Baran, B., Tokuç, A., Güzel, EB, Akdoğan, FS, Karagöz, E., & Bozdağ, Ö.	Designing Adaptive Learning Space by Integrating Technology to a Sustainable Classroom	Adaptive Learning Technologies for Higher Education	Adaptive learning space design in sustainable classrooms
2024	Steinert, S., Krupp, L., Avila, K. E., Janssen, AS, Ruf, V., Dzsotjan, D., & Wehn, N.	Lessons Learned from Designing an Open-Source Automated Feedback System for STEM Education	arXiv preprint	Open source automated feedback system for STEM education
2024	Mnguni, L., Nuangchalerm, P., El Islami, RAZ, Sibanda, D., Sari, I. J., & Ramulumo, M.	The behavioral intentions for integrating artificial intelligence in science teaching among pre-service science teachers in South Africa and Thailand	Computers and Education: Artificial Intelligence	AI integration intentions of prospective teachers in South Africa and Thailand
2025	Trajkovski, G., & Hayes, H.	Innovative Question Types and Formats	AI-Assisted Assessment in Education	Innovative question types in AI-supported education

Table 3 chronologically presents studies focusing on AI-supported adaptive content and automated feedback systems between 2020 and 2025. This table provides an important perspective for understanding how these systems have developed in the context of science education and which subfields they are focused on. It can be said that 2020 represents the beginning of research in the field of adaptive content and automated feedback systems (Sezgin & Yüzer, 2020; Wang et al., 2020). Studies conducted in 2021 and 2022 focused on the use of chatbots and their impact on science education (Cooper, 2022; Deveci Topal et al., 2021). 2023 saw a significant increase and diversity in the field of adaptive content and automated feedback systems. Studies published in this year (Bitzenbauer, 2023; Chuang et al., 2023; Elkhodr et al., 2023) include different technological approaches and global perspectives on chatbots. Studies conducted in 2024 (Hotar et al., 2024; Mnguni et al., 2024; Steinert et al., 2024) appear to be focused on adaptive learning space designs and classroom applications. A study conducted in 2025 (Trajkovski and Hayes, 2025) appears to be focused on investigating the contribution of artificial intelligence applications to measurement and evaluation.

Table 4. Studies under the Theme of Effects on Student Achievement and Motivation

Year	Authors	Title	Journal/ Publication	Focus Area
2023	Lee, J., An, T., Chu, H.E., Hong, H.G., & Martin, S.N.	Improving Science Conceptual Understanding and Attitudes in Elementary Science Classes through the Development and Application of a Rule-Based AI Chatbot	Asia-Pacific Science Education	Conceptual understanding with AI chatbot in primary school science classes
2023	Nja, CO, Idiege, KJ, Uwe, UE et al.	Adoption of artificial intelligence in science teaching: From the advantage point of the African science teachers	Smart Learning Environments	Integration of AI applications through the eyes of African science teachers
2024	Henze, J., Bresges, A., & Becker-Genschow, S.	AI-Supported Data Analysis Boosts Student Motivation and Reduces Stress in Physics Education	arXiv preprint	AI-assisted data analysis and student motivation in physics education
2024	Adli, M., Suriani, AB, Ibrahim, MM, Azzam, AB, Kusuma, HH, Dwandaru, WSB, & Dhanil, M.	Comprehensive Review on Technology-Based Learning Using Artificial Intelligence for Science Subjects and Its Implications in Teaching and Learning	EDUCATUM Journal of Science, Mathematics and Technology	AI-based technology-supported learning in science subjects
2024	Feng, C.	Analyzing Student Online Learning Behaviors and Academic Performance in Science Education Using Machine Learning Techniques	Applied and Computational Engineering	Analysis of student online learning behaviors in science education
2025	Lademann, J., Henze, J., & Becker-Genschow, S.	Augmenting learning environments using AI custom chatbots: Effects on learning performance, cognitive load, and affective variables	Physical Review Physics Education Research	Strengthening learning environments with AI chatbots
2025	Nurhikmah, H., Lu'mu, L.M., & Ridwan, M.	The Influence of Multimedia Learning and Students' Learning Motivation toward Biology Learning Outcomes	Brilliant: Konseptual from Jurnal Riset	The effect of multimedia learning on biology learning outcomes
2025	Choi, YS	Earth science simulations with generative artificial intelligence (GenAI)	Journal of University Teaching and Learning Practice	Earth science simulations with generative AI
2025	Li, M., & Wu, X.	Exploration of the Path of Artificial Intelligence Enabling Science Education	Open Access Library Journal	Ways AI can strengthen science education
2025	Bawaneh, AK, Al-Salman, SM, Salem, TMA, & Altarawneh, AF	AI Shaping the Future of Education: Science and Math Teachers' Satisfaction Level and Motivating Factors towards Integrating Artificial Intelligence in Teaching and Learning	International Journal of Information and Educational Technology	Satisfaction levels of science and mathematics teachers towards AI integration

Table 4 presents chronologically the studies examining the effects of AI-supported personalized learning systems on student achievement and motivation between 2023 and 2025. This table provides an important resource for understanding the positive effects of AI technologies on student learning outcomes and attitudes. Lee et al. (2023) and Nja et al. (2023) studied the effects of AI applications on students' conceptual development and attitudes. Studies conducted in 2024 (Adli et al., 2024; Feng 2024; Henze et al., 2024) examined the effects of AI-supported studies on learning, academic performance, and student motivation. Other studies conducted in 2025 focused on the application of more advanced technologies to science education, examining the effects of simulations and chatbots on student achievement, motivation, and satisfaction levels. The intensity of studies conducted in 2025, in particular, indicates that interest in and research in this field will continue to increase. In the future, AI has great potential to increase students' academic achievement and motivation to learn by further personalizing and enriching their learning experiences.

Table 5. Studies under the Theme of Teachers' Digital Pedagogical Competencies

Year	Authors	Title	Journal/Publication	Focus Area
2022	Ayanwale, MA, Sanusi, IT, Adelana, OP, Aruleba, KD, & Oyelere, SS	Teachers' readiness and intention to teach artificial intelligence in schools	Computers and Education: Artificial Intelligence	Teachers' preparation and intentions to teach AI
2022	Henze J, Schatz C, Malik S & Bresges A	How Might We Raise Interest in Robotics, Coding, Artificial Intelligence, STEAM and Sustainable Development in University and On-the-Job Teacher Training?	Front. Educ.	Increasing interest in robotics, coding, and AI in teacher education
2023	Chan, CKY	A comprehensive AI policy education framework for university teaching and learning	Int J Educ Technol High Educ	Comprehensive AI policy education framework for university teaching
2023	Tzafilkou, K., Perifanou, M., & Economides, A.A.	Assessing teachers' digital competence in primary and secondary education: Applying a new instrument to integrate pedagogical and professional elements for digital education	Education and Information Technologies	Assessing teachers' digital competencies in primary and secondary education
2024	Aflal, S.M., Shamugarajah, S., Thiruthanigesan, K., Balasubramaniam, B., Samarakoon, U., & Ragel, R.G.	The Impact of AI-Driven Educational Transformation in Sri Lanka's Higher Education	2024 6th International Conference on Advances in Computing (ICAC)	AI-powered education transformation in Sri Lankan higher education
2024	Alejandro, IMV, Sanchez, JMP, Sumalinog, GG, Mananay, JA, Goles, CE, & Fernandez, CB	Pre-service teachers' technology acceptance of artificial intelligence (AI) applications in education	STEM Education	Prospective teachers' acceptance of AI applications in education
2024	Han, S., & Lim, J.	An Exploratory Study of Elementary School Teachers' AI Competencies: Based on Teachers' Experiences and Perceptions	Educational Technology International	AI competencies of primary school teachers
2024	Damanik, J., & Widodo, W.	Unlocking teacher professional performance: exploring teaching creativity in transmitting digital literacy, grit, and instructional quality	Education Sciences	Teacher professional performance and digital literacy
2025	Azimkhan, S., Abildinova, G., Khamzina, A., Karymsakova, A., & Karaca, C.	Developing Teacher Digital Competence through Mobile and Interactive Technologies: A Systematic Review Using the TPACK Framework	International Journal of Engineering Pedagogy	Developing teacher digital competencies with the TPACK framework
2025	Coşgun-Demirdağ, M., & Taşgin, A.	The Relationship Between Teachers' Digital Literacy Levels and Research Literacy Skills	Journal of Theoretical Educational Science	The relationship between teachers' digital literacy levels and research literacy skills
2025	Hava, K., & Babayigit, Ö.	Exploring the relationship between teachers' competees in AI-TPACK and digital proficiency	Education and information technologies	Teachers' AI-TPACK competencies and the relationship between digital competence

Table 5 presents chronologically the studies focusing on teachers' digital pedagogical competencies in AI-enhanced education between 2022 and 2025. This table demonstrates how the knowledge, skills, and attitudes that teachers and instructors must possess for the effective use of AI technologies in education are addressed. Ayanwale et al. (2022) investigated teachers' preparation and intentions for teaching AI in schools. This study emphasizes the importance of teachers' attitudes and preparation levels toward technology for successful AI integration. Henze et al. (2022) examined how to increase interest in robotics, coding, AI, STEAM, and sustainable development in university and teacher education. These studies play a significant role in increasing teachers' awareness and interest in AI and related technologies. In 2023, it was observed that studies focused on the development of policy and evaluation frameworks in the field of digital pedagogical competencies of teachers (Chan, 2023; Tzafilkou et al., 2023). The year 2024 attracted attention with studies examining the global effects and competency development in the field of digital pedagogical competencies of teachers. The year 2025 focused on more specific competency models in the field of digital pedagogical competencies of faculty members. Azimkhan et al. (2025) examined the development of teacher digital competencies through mobile and interactive technologies using the TPACK framework. Coşgun-Demirdağ and Taşgin (2025) investigated the relationship between teachers' digital literacy levels and research literacy skills. Hava and Babayiğit (2025) studied the relationships between teachers' artificial intelligence-supported TPACK competencies and digital competencies. In the future, it can be expected that research in this area will deepen even further and develop models and training programs that will enable teachers to become more competent in AI-supported educational environments.

Discussion

The findings of this systematic review demonstrate that artificial intelligence (AI)-supported personalized learning applications in university-level science education offer significant potential for enhancing student engagement, conceptual understanding, and instructional adaptability. These findings are consistent with existing literature emphasizing AI's role in creating learner-centered environments and enabling real-time responsiveness to individual learning needs (Sezgin & Yüzer, 2022; Vorobyeva et al., 2025).

One of the most salient outcomes observed in the studies reviewed is the effectiveness of AI-based systems—such as intelligent tutoring systems and adaptive content platforms—in individualizing learning trajectories. These tools allow for the detection of misconceptions, deliver targeted interventions, and dynamically adjust instructional content based on learners' performance. This confirms prior studies suggesting that AI can facilitate deeper conceptual understanding in disciplines such as physics, biology, and chemistry (Graesser et al., 2022; Koć-Januchta et al., 2020; Yannier et al., 2020).

Moreover, the integration of AI tools has been associated with improved student motivation and increased participation in science learning contexts. Real-time feedback systems and analytics dashboards have been shown to empower students to monitor their progress and foster self-regulated learning behaviors (Bitzenbauer, 2023; Chuang et al., 2023). These findings are in alignment with theoretical models that support autonomy and engagement in learning through adaptive systems (Ng et al., 2023).

However, while AI-supported approaches show considerable promise, several systemic challenges must be addressed to ensure their effectiveness and sustainability. As highlighted in the findings, the success of these systems depends heavily on the digital pedagogical competencies of faculty members. Without adequate education and digital literacy, even the most sophisticated AI applications may fail to deliver pedagogical value (Rakisheva & Witt, 2023; Yan et al., 2023). This aligns with Dignum (2021), who stresses the ethical and instructional implications of integrating AI into formal education settings.

Additionally, the reviewed literature reveals contradictions regarding the long-term effectiveness of AI in improving science learning outcomes. While short-term gains in motivation and understanding are frequently reported, few studies examine the durability of these improvements over time (Jose et al., 2025). Furthermore, the scalability of AI-based learning tools across different socioeconomic and cultural contexts remains a significant research gap, suggesting a need for broader, more inclusive empirical investigations (Bond et al., 2024; Mustafa et al., 2024).

The lack of interdisciplinary collaboration between AI developers and science educators also emerged as a critical limitation. Few studies demonstrated co-designed or pedagogically validated AI tools, which raises concerns about their relevance and alignment with science learning goals (Roll and Wylie, 2016; Zafari et al., 2022). Finally, the ambivalent effects of AI on student autonomy deserve attention. While some systems enhance learner independence, others may foster passive learning habits or over-reliance on automated systems (Dignum, 2023; Zawacki-Richter et al., 2019)

Conclusion

In conclusion, AI-supported personalized learning applications offer valuable opportunities for transforming science education in universities. Through intelligent tutoring, adaptive feedback, and learning analytics, these systems can address individual learning differences, enhance engagement, and support conceptual mastery. The review affirms that, when effectively implemented, AI technologies can make learning more student-centered, data-informed, and responsive.

Nevertheless, to fully harness this potential, higher education institutions must invest in developing faculty members' digital pedagogical skills and infrastructure. Furthermore, long-term empirical studies and interdisciplinary research are needed to evaluate the sustainability, ethics, and equity of these innovations. Addressing these gaps will ensure that AI becomes not just a technological add-on, but an integral and pedagogically sound component of 21st-century science education.

Steps Toward a Solution

For AI-powered personalized learning to be effectively integrated into science education, long-term, multi-contextual, and empirical research is needed. Existing studies focus primarily on short-term outcomes, creating a significant gap in areas such as learning retention, conceptual development, and scientific thinking skills. Furthermore, the adaptability of these applications to different socioeconomic and cultural contexts has been limitedly addressed. Therefore, more comprehensive research focusing on issues such as scalability, data security, algorithmic biases, and infrastructure inadequacies is needed.

Moreover, developing faculty's digital pedagogical competencies is critical to the success of this process. To effectively use AI-based tools, faculty members must possess skills not only technical knowledge but also the interpret learning analytics, consider ethical responsibilities, and support student autonomy. In this context, AI applications should guide students while also supporting their ability to direct and manage their own learning, thus providing a more balanced and effective learning environment.

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Üniversitelerde Kişiselleştirilmiş Öğrenme ve İnovatif Öğretim Yaklaşımları: Yapay Zekâ Destekli Fen Eğitimi

Genişletilmiş Özet

Giriş

Dijitalleşmenin hızlandığı 21. yüzyılda yükseköğretim kurumlarının öğrenme-öğretme süreçleri de köklü bir dönüşüm geçiriyor. Bu dönüşümün merkezinde yer alan yapay zekâ uygulamaları; öğrencinin öğrenme hızına, önbilgisine ve ilgi alanına göre uyarlanabilen, veri temelli kararlar alabilen sistemlerle eğitim pratiklerini yeniden şekillendiriyor. Özellikle fen eğitimi gibi soyut kavramların, laboratuvar uygulamalarının ve süreç odaklı düşünmenin ön planda olduğu disiplinlerde, yapay zeka destekli kişiselleştirme hem kavramsal derinliği hem de uygulamalı becerileri geliştirme potansiyeli taşıyor. Bu bağlamda çalışmanın temel amacı; üniversitelerde fen eğitimi alanında kullanılan yapay zeka destekli kişiselleştirilmiş öğrenme uygulamalarını incelemek ve bunların inovatif öğretim yaklaşımlarıyla nasıl bütünleştiğini literatür temelinde değerlendirmektir.

Kişiselleştirilmiş öğrenme, eğitimin içeriğini, hızını ve yöntemini öğrencinin bireysel özelliklerine göre tasarlamayı hedefleyen pedagojik bir yaklaşımdır. Uyarlanabilir öğrenme sistemleri ve akıllı öğretim ortamları, makine öğrenmesi ve öğrenme analitiği sayesinde öğrencinin performansını gerçek zamanlı izleyip analiz ederek bireysel öğrenme yolları oluşturur. Fen eğitimi bağlamında bu, yanlış kavramların erken tespit edilmesi, ek açıklamalar ve simülasyonlar sunulması, deney tasarımlarının öğrenciye göre biçimlendirilmesi gibi pratikleri mümkün kılar. Literatürde yapay zekanın kavramsal anlama, problem çözme ve motivasyon üzerindeki olumlu etkilerine ilişkin bulgular bulunmasına karşın, bu etkiyi belirleyen faktörler arasında öğretim elemanlarının dijital pedagojik yeterlikleri, öğrenme ortamının tasarımı ve algoritmik şeffaflık gibi unsurların kritik rol oynadığı vurgulanmaktadır.

Yöntem

Bu çalışma, 2020–2025 yılları arasında yayımlanmış ulusal ve uluslararası akademik çalışmaları kapsayan sistematik bir literatür taramasına dayanmaktadır. Web of Science, Scopus ve Google Scholar gibi veri tabanlarında, "artificial intelligence in science education", "personalized learning with AI", "adaptive learning in higher education", "learning analytics", "fen eğitiminde yapay zekâ" ve benzeri anahtar kelimeler kullanılarak tarama yapılmıştır. PRISMA protokolü izlenerek bir eleme süreci uygulanmış, başlık/özet taramasından sonra tam metin incelemesi sonucunda 43 çalışma analiz kapsamına alınmıştır. Analiz aşamasında tematik içerik analizi (Braun & Clarke) kullanılarak veriler kodlanmış ve ana temalar türetilmiştir.

Bulgular

Analiz sonucunda dört ana tema belirlenmiştir: (1) Kişiselleştirilmiş öğrenme uygulamaları, (2) Uyarlanabilir içerik sunumu ve otomatik geri bildirim sistemleri, (3) Öğrenci başarısı ve motivasyonu üzerindeki etkiler, (4) Öğreticilerin dijital pedagojik yeterlikleri. Bu temalar çerçevesinde literatürdeki çalışmalara bakıldığında:

1. Kişiselleştirilmiş öğrenme uygulamaları: Akıllı öğretim sistemleri, yapay zeka zenginleştirilmiş dijital ders kitapları, karma gerçeklik ve simülasyon temelli uygulamalar fizik, biyoloji ve kimya gibi alanlarda kullanılmış; öğrencilerin önbilgisine göre farklı öğrenme yolları sunulmuştur. Bu uygulamalar, yanlış kavramların saptanması ve öğrenciye özel müdahalelerin yapılması açısından etkili bulunmuştur.

2. Uyarlanabilir içerik ve otomatik geri bildirim: Chatbotlar, otomatik değerlendirme ve açık kaynaklı geri bildirim sistemleri, öğrencilere anlık yönlendirme sağlayarak uzaktan ve hibrit öğrenme ortamlarında etkileşimi artırmıştır. Özellikle pandemi döneminde bu tür araçların kullanımının artış gösterdiği ve öğretim sürekliliğinde önemli bir rol oynadığı kaydedilmiştir.

3. Öğrenci başarısı ve motivasyonu: Yapılan çalışmalar yapay zeka destekli yaklaşımların kısa vadede kavramsal anlama ve öğrenme motivasyonunu olumlu etkilediğini göstermektedir. Veri analizine dayanan kişiselleştirilmiş uyarılar ve düzenlemeler, öğrencilerin performansını ve öğrenme tutumlarını iyileştirmiş; bilişsel yükü azaltma yönünde olumlu etkiler raporlanmıştır.

4. Öğreticilerin dijital pedagojik yeterlikleri: Öğretim elemanlarının yapay zeka teknolojilerini derse entegre edebilme becerileri, öğrenme analitiğini yorumlama yetenekleri ve etik sorumluluk bilinci, uygulamaların başarısını belirleyen önemli değişkenler olarak ortaya çıkmıştır. Literatürde, bu yetkinliklerin geliştirilmesine yönelik eğitim programlarına vurgu yapılmaktadır.

İncelenen çalışmaların çoğu kısa vadeli etkilere odaklanmış, dolayısıyla yapay zeka destekli kişiselleştirilmiş öğrenmenin uzun vadeli etkileri (derin kavramsal öğrenme, eleştirel düşünme, bilimsel süreç becerileri) hakkında sınırlı kanıt bulunmaktadır. Ayrıca, çalışmalarda ölçeklenebilirlik, farklı sosyoekonomik ve kültürel bağlamlara uygulanabilirlik, altyapı yetersizlikleri, veri gizliliği ve algoritmik önyargı gibi yapısal sorunlar yeterince ele alınmamıştır. Öğrenci özerkliği konusunda da çelişkili bulgular mevcuttur: Bazı araştırmalar yapay zekanın bağımsız öğrenmeyi desteklediğini bildirirken, diğerleri aşırı bağımlılık riskine dikkat çekmektedir. Ayrıca, geliştirilen araçların pedagojik açıdan alan uzmanlarıyla birlikte tasarlanmadığı durumlarda akademik uygunluk sorunları ortaya çıkabilmektedir.

Elde edilen bulgular, yapay zekanın fen eğitiminde güçlü bir araç olabileceğini, ancak bunun pedagojik ve etik çerçeveyle dengelenmesi gerektiğini göstermektedir. Teknolojik çözümler tek başına öğrenmeyi garantilemez; etkili kullanım, öğretim elemanlarının pedagojik yönlendirmesi, doğru veri yorumlama ve öğrenciyi öğrenme sürecinin aktif bir paydaşı haline getiren tasarımlarla mümkündür. Uzun vadeli etkiyi ölçen nicel ve nitel çalışmaların eksikliği, alandaki en kayda değer araştırma açığıdır. Ayrıca, farklı üniversite ve ülke bağlamlarında uygulama deneyimleri toplanarak ölçeklenebilir ve kapsayıcı modeller geliştirilmelidir.

Sonuç ve Tartışma

Bulgular ışığında ulaşılan sonuçlar, yapay zekâ destekli kişiselleştirilmiş öğrenme uygulamalarının üniversitelerde fen eğitimine yeni bir soluk getirme potansiyelini net bir şekilde ortaya koymaktadır. Çalışmalarda görüldüğü üzere bu sistemler, öğrenme sürecini yalnızca daha esnek hâle getirmekle kalmamakta, aynı zamanda öğrencilerin bireysel ihtiyaçlarına duyarlı, anlık geri bildirim sağlayan ve öğrenme motivasyonunu yüksek tutan bir eğitim ekosistemi yaratmaktadır. Özellikle akıllı öğretim sistemleri, uyarlanabilir içerik sunumu ve otomatik geribildirim mekanizmaları, öğrencilerin kavramsal anlamalarını derinleştirmekte, yanlış öğrenmeleri hızla tespit ederek telafi imkânı sunmakta ve böylece öğrenme kayıplarını en aza indirmektedir.

Bununla birlikte, bu teknolojilerin sunduğu fırsatlar kadar, sürdürülebilir ve adil biçimde uygulanabilmesi için dikkate alınması gereken önemli koşullar da bulunmaktadır. Bulgular, öğretim elemanlarının dijital pedagojik yeterliklerinin bu sürecin en kritik halkalarından biri olduğunu açıkça göstermektedir. Öğrenme analitiğinin doğru yorumlanması, yapay zeka araçlarının pedagojik hedeflere uygun biçimde entegre edilmesi ve öğrencilerin özerkliğini destekleyen bir yaklaşım geliştirilmesi, eğitsel etkinin sürekliliği açısından belirleyicidir. Eğer öğretim kadrosu bu teknolojileri yalnızca teknik bir yenilik olarak değil, ders tasarımının ayrılmaz bir parçası olarak görüp benimserse, yapay zekanın sunduğu potansiyel çok daha etkili bir şekilde ortaya çıkacaktır.

Diğer yandan, literatürdeki örnekler, yapay zeka tabanlı kişiselleştirilmiş öğrenmenin kalıcı öğrenme çıktıları üzerindeki etkilerinin hâlen yeterince incelenmediğini ortaya koymaktadır. Kısa vadede motivasyon ve başarıda artış gözlenmesine rağmen, bu etkinin uzun vadeye taşınıp taşınamayacağı, kavramsal derinleşmeye ve bilimsel düşünme becerilerine ne ölçüde katkı sağladığı henüz net değildir. Bu nedenle, çok merkezli ve uzun süreli ampirik çalışmaların yürütülmesi kaçınılmazdır. Ayrıca, farklı sosyoekonomik ve kültürel bağlamlarda uygulama yapılması, bu sistemlerin ölçeklenebilirliğini ve kapsayıcılığını test etmek açısından büyük önem taşımaktadır.

Bulgular aynı zamanda, erişim ve fırsat eşitliği konularının göz ardı edilmemesi gerektiğini göstermektedir. Teknolojik altyapı eksiklikleri, veri güvenliği sorunları ve algoritmik önyargılar, özellikle dezavantajlı bölgelerde bu sistemlerin verimli kullanımını sınırlayabilmektedir. Bu bağlamda, düşük maliyetli, erişilebilir ve kültürel bağlama uyum sağlayan yapay zeka çözümlerinin geliştirilmesi, hem eğitimin kapsayıcılığı hem de teknolojinin adil kullanımı açısından kritik bir ihtiyaçtır.

Etik boyut da üzerinde hassasiyetle durulması gereken bir diğer alandır. Yapay zekanın öğrenme süreçlerine derinlemesine entegre olduğu bir eğitim ortamında, öğrenci verilerinin gizliliği, algoritmik şeffaflık ve sistemlerin tarafsızlığı temel ilkelerdir. Bu ilkeler gözetilmeden geliştirilen uygulamalar, pedagojik kazanımların yanı sıra öğrencilerin güven duygusunu da zedeleyebilir. Dolayısıyla, etik standartların ve güvenlik protokollerinin yapay zeka tabanlı eğitim teknolojilerinin merkezine yerleştirilmesi gerekmektedir.

Son olarak, disiplinlerarası iş birliği ihtiyacı bulgularda sıkça vurgulanmıştır. Yapay zeka geliştiricileri, eğitim bilimciler, fen eğitimi uzmanları ve etikçiler bir araya gelerek, hem teknik olarak yetkin hem de pedagojik açıdan anlamlı çözümler üretebilirler. Ancak bu sayede geliştirilen sistemler, yalnızca teknoloji odaklı yenilikler olmaktan çıkarak, öğrenme süreçlerini bütüncül biçimde dönüştüren etkili araçlar hâline gelebilir.

Genel olarak değerlendirildiğinde, yapay zekâ destekli kişiselleştirilmiş öğrenme, doğru planlama, yeterli öğretmen eğitimi, güçlü bir etik çerçeve ve sürekli araştırma-geliştirme desteği ile üniversitelerde fen eğitiminin geleceğini şekillendirebilecek güçlü bir potansiyele sahiptir. Ancak bu potansiyelin gerçekleşebilmesi, teknolojiyi sadece bir araç olarak değil, pedagojik stratejilerin ayrılmaz bir bileşeni olarak gören vizyoner bir yaklaşımı zorunlu kılmaktadır.