https://www.doi.org/10.69927/DHDR5030

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PERSONALIZED LEARNING IN COMPUTER SCIENCE FOR GIFTED STUDENTS: A SYSTEMATIC REVIEW

Annotation

Personalized and adaptive learning is one of the key directions in digital pedagogy and is highly important in teaching computer science to gifted students. The aim of this systematic review is to analyze adaptive and personalized approaches to teaching computer science and to assess their effect on the formation of key competencies and academic performance of high-performing learners. Following the PICOC (Population, Intervention, Comparison, Outcome, Context) framework, the target population of this study is gifted students. The intervention is the use of adaptive and personalized methods in teaching computer science, in comparison with traditional instructional methods. The outcomes of the analysis include the development of key competencies and the improvements of academic performance.

The systematic review was conducted following the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) protocol and was based on studies published between 2014 and 2025 in academic databases such as Scopus, Web of Science, ERIC (Education Resources Information Center), SpringerLink, and ScienceDirect. The final review included studies assessing the effectiveness of adaptive digital platforms, personalized learning trajectories, intelligent tutoring systems, and learning analytics tools in computer science education.

The outcomes of the study indicate that personalized and adaptive instructional methods in teaching computer science result in the advancement of algorithmic and critical thinking. It can also be noted that these approaches contribute to the development of student independence and that gifted students demonstrate improved academic performance. However, the research has some limitations, such as fragmented studies, a lack of standard evaluation methods, and insufficient data from developing regions. This indicates that more research is needed on adaptive technologies and on fully integrating personalized teaching methods into computer science education.

Key words: computer science, personalized learning, adaptive learning, systematic review, PICOC, PRISMA, gifted learners.

Introduction. The rapid advancement of digital technologies has increased the demand for pedagogical models that take into account learners' individual characteristics and potential. This need is particularly relevant for gifted learners, who demonstrate accelerated mastery, high cognitive activity, and a sustained interest in complex intellectual tasks. In the field of computer science — which requires high levels of abstraction, constant renewal of knowledge, and engagement with complex concepts — personalized and adaptive learning has become one of the most promising directions.

In recent years, personalized learning has often involved intelligent tutoring systems (ITS), learning analytics, and adaptive digital platforms that automatically adjust content, difficulty, and pacing to fit each learner's profile. These technologies help create personalized learning paths, which is especially important for gifted learners who adapt quickly and need flexible, tailored support [1].

Studies show that adaptive digital tools enhance students' learning motivation and engagement, develop algorithmic thinking, and improve the quality of knowledge acquisition in computer science [2, 3]. Despite the growing number of studies in digital personalization, notable inconsistencies remain in the terminology and methodological approaches used. Moreover, there is a shortage of empirical data specifically related to gifted learners [4]. Most studies examine adaptive learning technologies at a broad level, without clearly demonstrating the direct impact of particular digital tools or personalized methods on the academic performance of gifted school students or university learners [5]. The effectiveness of personalized instruction in computer science also remains

insufficiently defined — both in terms of academic outcomes and the formation of core competencies such as computational thinking, digital literacy, and learning autonomy [6].

Personalized learning is based on the principle of flexible organization of the educational process, in which learning goals, content, pacing, and instructional strategies are adapted to individual learner needs. In such a model, instruction is not a linear process. It becomes a dynamic system where learners have an opportunity to choose, and where teachers play the role of facilitators who help to correct the educational trajectory depending on the students' competencies.

Adaptive digital platforms play a key part in connecting teachers and learners in this process. They help to generate individualized recommendations based on students' work with regard to task complexity, information-processing speed, and regularity of mistakes.

This approach is especially useful for gifted students, because traditional programs often do not match their learning speed and fail to provide the required level of intellectual complexity. In this context, adaptive systems help by gradually adding harder tasks and creative projects that fit each student's abilities. In these digital environments, students become more independent, think more about their learning, and take more responsibility for it. This leads to deeper and longer-lasting interest in learning computer science.

As a result, gifted learners will learn faster than their non-gifted peers, but also be able to gain in-depth knowledge regarding programming, algorithms, and computational thinking. Together, these abilities are the basis for future research and innovation in computer science.

Given these considerations, a systematic review is needed to synthesize existing research and identify which personalized and adaptive instructional methods demonstrate the highest effectiveness in teaching computer science to gifted learners. Accordingly, the following research questions (RQ) were formulated:

RQ1. Which personalized instructional methods are effective in enhancing academic achievement among gifted learners in computer science?

RQ2. How do adaptive learning methods influence the academic performance and development of key competencies in gifted learners?

This review aims to address existing gaps in the literature and provide a comprehensive understanding of the capabilities and limitations of adaptive approaches used to teach computer science to gifted learners.

Methods and Materials. This study was conducted in the format of a Systematic Literature Review (SLR) and was methodologically grounded in the PRISMA 2020 guidelines. The selection of literature followed the PICOC framework. In this model, the target population (Population) consisted of gifted learners; the intervention (Intervention) referred to adaptive instructional methods in computer science; the comparison (Comparison) involved traditional teaching approaches; the outcomes (Outcomes) included academic achievement and the development of core competencies; and the context (Context) was defined as the digital learning environment.

The search strategy was implemented using major international scholarly databases such as Scopus, Web of Science, ERIC (Education Resources Information Center), SpringerLink, and ScienceDirect. Combinations of relevant keywords were used, including *"adaptive learning," "personalized learning," "computer science education," "gifted students," "digital platforms," and "learning analytics."* To ensure the relevance of the review, the analysis was limited to publications from 2014 to 2025.

The criteria for *inclusion* in the study were defined as follows:

- Empirical studies on adaptive or personalized learning methods in computer science education;
- Studies with gifted learners or high-achieving student groups;
- Articles with clear research methods and data analysis procedures;
- Articles in peer-reviewed journals or conference proceedings.

We *excluded* articles for the following reasons:

- Publications without empirical data;
- Research not related to computer science;
-Articles published in non-peer reviewed journal;

- Studies where adaptive technologies were not clearly described.

First, the duplicate records were identified and removed. Then, titles and abstracts were screened for relevance. After that, we reviewed full-text articles and evaluated them using PICOC criteria. We documented each step of the selection process with a PRISMA flow diagram.

To systematize the data, a coding table was employed. It included the following categories: year of publication, country, study design, sample characteristics, type of adaptive or personalized technology used, study outcomes, and key conclusions reported by the authors. A thorough qualitative and content analysis made it possible to identify recurring methodological patterns, strengths and limitations of the reviewed studies, and general trends in the effectiveness of adaptive approaches in teaching computer science.

Results and Discussion. The initial search conducted across Scopus, Web of Science, ERIC, SpringerLink, and ScienceDirect for the period 2014–2025 identified a total of 1128 publications.

After removing duplicate records (n = 276), a total of 852 unique publications were retained for further screening.

During the initial screening of titles and abstracts, 617 studies were excluded based on the PICOC criteria because primarily because they did not address computer science education, did not involve gifted/high-ability learners, or described digitalization without a clear adaptive/personalized component.

Full-text assessment excluded an additional 213 articles due to insufficient methodological detail, lack of empirical outcomes, unclear intervention descriptions, weak linkage to gifted/high-achieving samples, or inconclusive findings. Ultimately, 22 empirical studies met all eligibility criteria and were included in the final synthesis.

The study selection process was carried out in accordance with the PRISMA 2020 methodology, and the full screening results are presented in Figure 1.

Characteristics of the included studies. The analysis of the 22 studies included in the review demonstrated several systematic structures characterizing the current state of personalized and adaptive approaches in the teaching of computer science to gifted students. The geographical scope of the studies includes 15 countries, including the United States, Germany, Spain, Austria, Greece, Türkiye, China, Japan, the Republic of Korea, Canada, Malaysia, and Australia. This broad geographical coverage indicates strong international interest in digital platforms that support personalized learning systems.

The rapid increase in the number of articles published on this topic during the period from 2020 to 2024 may serve as evidence of the accelerating digitalization of education and the widespread adoption of ITS. The steady growth of research interest in this area since the beginning of 2017 also indicates the increasing practical and scientific importance of the problem.

The literature review showed that research in this area is distributed across several directions, including personalized learning, adaptive digital systems and learning analytics. Most studies focused on personalizing the learning experience (42%), indicating the high significance of an individualized approach for gifted learners. Studies investigating ITS account for another major part of the reviewed articles (35%) and are mostly concentrated on adaptive feedback, automatic analysis, and mechanisms for regulating task complexity.

Around 23% of the publications were related to learning analytics and considered problem related to data-driven decision-making, prediction of learning outcomes, and optimization of learning trajectories. Studies directly focusing on adaptive digital platforms accounted for around 10% of the reviewed publications and addressed the role of digital learning environments in enhancing creativity and supporting personalized learning practices. These summarized data are presented in Table 1.

Overall, the percentage distribution indicates that personalized learning and adaptive technologies constitute one of the key directions in contemporary research on computer science education.

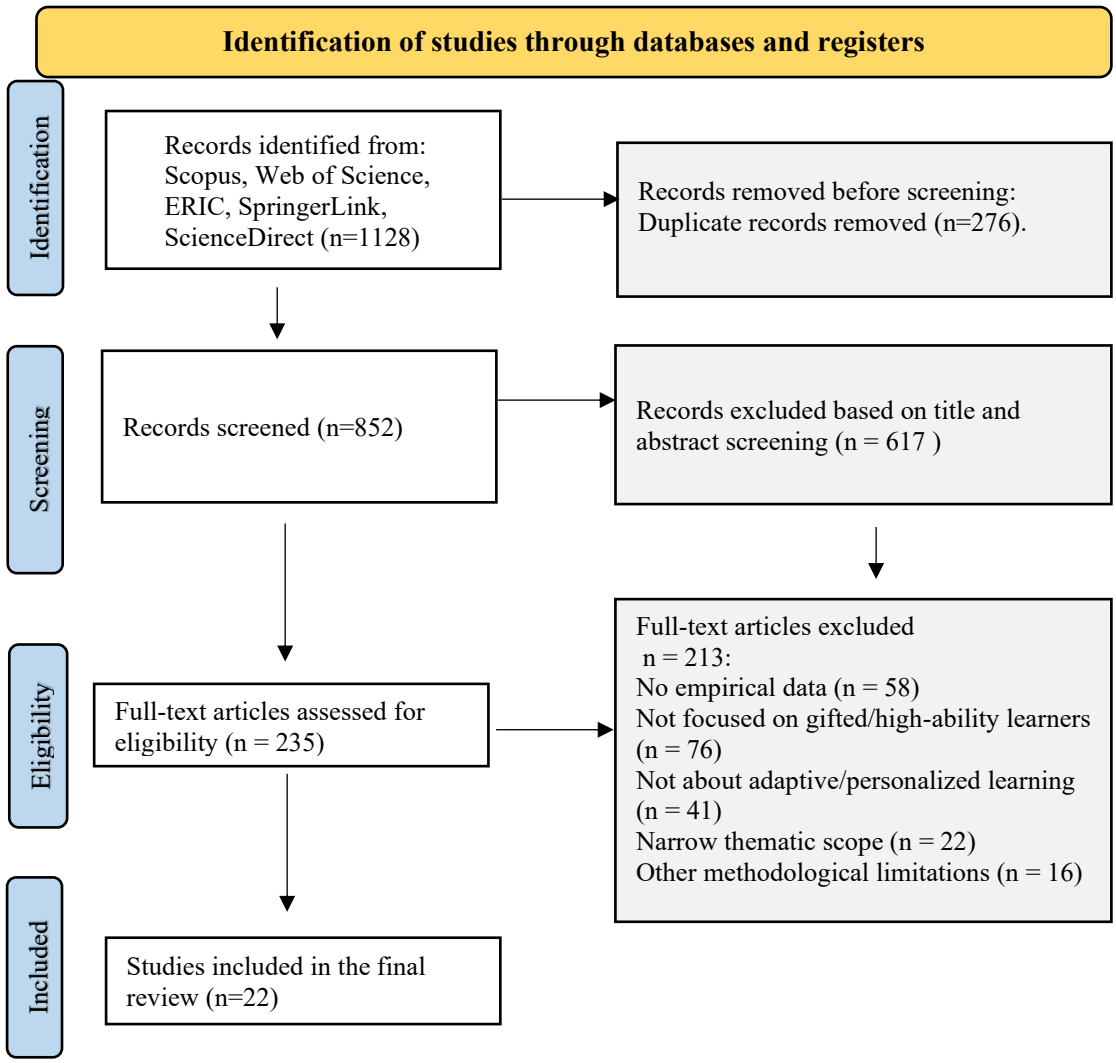

Figure 1. PRISMA flow diagram

Source: compiled by the author

Table 1. Summary Analysis of Studies on Personalized Learning Paths, ITS, and Learning Analytics

№	Author	Country	Year	Study Type	Research Focus	Technology / Approach
1	Renzulli	USA	2014	Conceptual	Personalized learning paths	Renzulli Learning
2	Eysink	Netherlands	2020	Experimental	Personalized learning paths	BE COOL!
3	Hinterplattner	Austria	2021	Experimental	Personalized learning paths + project-based learning	Interdisciplinary projects
4	Shubina	Turkey	2019	Practical study	Adaptive platforms	Pervasive learning
5	Gilson	USA	2023	Practical study	Personalized learning paths / gifted learners	Classroom differentiation
6	Mercimek	Turkey	2020	Experimental	Multimedia tasks	Multimedia load
7	Shemshack	USA	2020	SLR	Personalization terminology	Conceptual synthesis
8	Pane	USA	2017	Empirical	Personalized learning	RAND PL model
9	Koper	Netherlands	2014	Theoretical	Smart learning environments	Smart learning design
10	du Plooy	South Africa	2024	Scoping Review	Personalized adaptive learning	Adaptive design

11	Ma	Canada	2014	Meta-analysis	Effectiveness of ITS	ITS evidence
12	Aleven	USA	2016	Theoretical, Experimental	Example-Tracing Tutors	CTAT
13	Heffernan	USA	2014	Experimental	ASSISTments	ASSISTments
14	Wang	China	2023	SLR	ITS applications	Various ITS
15	Gutiérrez	Spain	2011	Experimental	ITS: adaptive feedback	Adaptive feedback selection
16	Le	USA	2016	Review	Feedback classification	Adaptive feedback taxonomy
17	Perikos	Greece	2017	Experimental	ITS feedback mechanisms	Feedback mechanisms
18	Papamitsiou	Greece	2014	SLR	Learning analytics	EDM + LA
19	Romero	Spain	2013	Review	Educational data mining	EDM
20	Banihashem	Netherlands	2022	SLR	LA & feedback	Learning analytics
21	Hooshyar	Iran	2023	SLR	LA & student agency	LA models
22	Pan	China	2024	SLR	Learning analytics	LA frameworks

Source: compiled by the author

Recent research shows that personalized learning pathways help gifted students make more academic progress. Studies also find that these paths help teachers better understand gifted students' needs and support their cognitive and creative growth. Many researchers point out that digital technologies make it easier to personalize learning, match tasks to students' interests and abilities, and create online environments that encourage social interaction and inquiry-based learning.

In their systematic analysis, Shemshack and Spector (2020) demonstrated that conceptual clarity in personalization-related terminology and methods enhances students' learning motivation and deepens their engagement with instructional content [7]. Similar findings were reported in RAND Corporation's large-scale study. Pane et al. (2017) confirmed, using robust empirical data, that personalized learning contributes to higher achievement levels and allows learners to regulate their own pace of study effectively [8]. Koper (2014) [9] described smart and adaptive learning environments as pedagogical models capable of supporting effective personalization through automated task adjustment mechanisms based on learner proficiency levels. According to the author, data-driven adaptation logic is one of the key determinants of the success of personalized learning pathways.

du Plooy (2024) further demonstrated that adaptive learning trajectories increase academic performance and subject motivation, highlighting the growing relevance of personalization in higher education [10]. Collectively, these findings indicate that personalized instructional methods strongly contribute to the development of creative thinking, analytical abilities, and problem-solving skills—competencies that are especially critical for gifted learners when engaging with complex, inquiry-focused tasks.

Research on ITS likewise illustrates the strong potential of personalization. The meta-analysis conducted by Ma et al. (2014) [11] confirmed that ITS-based instruction substantially outperforms traditional teaching approaches. Aleven, McLaren, and Koedinger (2016) [12] demonstrated, through the Example-Tracing Tutors model, that precise monitoring of learner actions and adaptive feedback can accelerate the acquisition of complex skills. Similarly, the ASSISTments ecosystem developed by Heffernan and Heffernan (2014) [13] was shown to enhance mastery of mathematical logic by providing timely, targeted feedback generated through automated error analysis. Wang et al. (2023) further highlighted that the dynamic adaptation capabilities of modern ITS platforms are particularly beneficial for gifted learners [14].

The role of adaptive algorithms within ITS has been a central topic of investigation. Gutiérrez et al. (2011) [15] found that selecting appropriate adaptive feedback strategies significantly increases instructional accuracy and efficiency. Le's (2016) classification of adaptive feedback types [16] provided a systematic framework for aligning feedback mechanisms with learners' cognitive levels, offering valuable guidance for effective application in individualized learning contexts. Perikos and

colleagues (2017) showed that targeted guidance and algorithmically tailored hints enhance performance on complex tasks, underscoring the importance of algorithmic adaptation in ITS [17].

Taken together, evidence from meta-analytic and systematic studies suggests that ITS support learning gains through continuous monitoring of learner actions, adaptive sequencing of tasks, and timely, targeted feedback. Meta-analytic findings indicate that ITS-based instruction outperforms traditional approaches in terms of learning outcomes, while empirical ITS designs show that step-by-step scaffolding and adaptive feedback accelerate the acquisition of complex skills. These effects are strengthened when feedback is aligned with learners' cognitive level and typical error patterns, enabling more accurate guidance in problem-solving contexts.

In the field of learning analytics (LA), research has focused on expanding the capabilities of data-driven monitoring, prediction, and feedback in digital learning environments. Papamitsiou and Economides (2014) showed that LA and educational data mining support instructional decision-making through the interpretation of learner performance and the optimization of personalized feedback [18]. Romero and Ventura (2013) emphasized that educational data mining methods can diagnose learning difficulties and generate tailored recommendations [19]. Banihashem et al. (2022) reported that LA can enhance feedback practices in higher education by enabling rapid, data-informed instructional adjustments [20]. Hooshyar et al. (2023) highlighted the role of predictive models and visualization in strengthening learner agency and academic outcomes [21]. Pan et al. (2024) summarized major LA frameworks and indicated that analytics-based interventions are increasingly used to predict learning trajectories, identify skill gaps, and support personalization in learning management systems [22].

Overall, the systematic comparison of existing studies revealed several leading pedagogical and technological approaches that support personalization in computer science education. These approaches enable the customization of learning content, dynamic adaptation to learner actions, automated error analysis, and data-driven instructional decision-making. Table 2 provides a structured synthesis of all studies, evaluating their impact on gifted learners and comparing the strengths and limitations of the applied research methods.

Table 2. Impact of personalized and adaptive approaches in Computer Science education for gifted learners

Method / Technology	Key Studies	Impact on Gifted Learners	Strengths of Effectiveness	Limitations
Personalized Learning Paths	Renzulli (2014), Eysink (2020), Hinterplattner (2021), du Plooy (2024)	Accelerated learning, increased motivation, creative development	Interest-aligned content; individualized pacing; reduced cognitive load	Complexity of diagnostics; high demands on teachers
Intelligent Tutoring Systems (ITS)	Ma (2014), Aleven (2016), Heffernan (2014), Wang (2023)	Development of algorithmic thinking; faster problem solving; logical precision	Dynamic task complexity; precise feedback; high adaptation accuracy	Infrastructure requirements; challenges in content localization
Adaptive Feedback	Gutiérrez (2011), Le (2016), Perikos (2017),	Rapid error correction; reflection; self-regulation	Feedback aligned with error types, adaptation to cognitive level	Limited large-scale validation; domain dependency
Learning Analytics (LA)	Papamitsiou (2014), Romero (2013), Banihashem (2022), Hooshyar (2023), Pan (2024)	Early identification of learning gaps; learning path prediction; learner autonomy	Automated trajectory prediction; targeted recommendations	Dependence on data quality; risk of misinterpretation
Smart Learning Environments	Koper (2014), 2022 Systematic Review	Inquiry-based learning; research engagement	Intelligent adaptation logic	Technical complexity

Online/ Digital Adaptive Platforms	Shubina (2019), Gilson (2023), Mercimek (2020), E-learning studies	High learning pace even in remote settings	Broad content coverage; accessibility	Internet quality constraints; multimedia overload

Source: compiled by the author

As shown in Table 2, each learning method has its own specific strengths and limitations. ITS and adaptive algorithms mainly contribute to the development of algorithmic, logical, and critical thinking skills, whereas approaches based on learning analytics assist in developing learning strategies and forming students' metacognitive skills. Accordingly, personalized learning trajectories enhance the speed of processing complex computer science content and stimulate the development of creativity and investigative skills.

Based on the results of the investigation, it can be noted that the answer to RQ1 indicates that the most effective personalized learning methods in computer science include personalized learning trajectories, ITS, adaptive feedback systems, and learning analytics methods. These approaches enable the provision of cognitively challenging tasks aligned with gifted learners' high intellectual potential, allow individualized pacing, and support the optimization of cognitive load.

With regard to RQ2, the findings demonstrate that these methods not only improve academic achievement among gifted learners but also contribute to the development of algorithmic thinking, problem-solving skills, metacognition, research abilities, and digital competencies. ITS platforms primarily strengthen logical and algorithmic reasoning, while learning analytics technologies enhance individualized prediction and management of the learning process. Adaptive feedback enables rapid error correction and reinforces reflective learning processes, whereas smart learning environments foster inquiry-based learning and creative potential.

Conclusion. This systematic review analyzed 22 high-quality empirical studies published between 2014 and 2025 and provided a comprehensive evaluation of the effectiveness of personalized and adaptive approaches to teaching computer science to gifted learners. The analysis enabled clear and evidence-based answers to the research questions.

Overall, the evidence confirms that personalization and adaptive learning have become important pedagogical phenomena in computer science education. Personalized learning paths, ITS, adaptive feedback mechanisms, and learning analytics technologies were found to enhance gifted learners' academic achievement, computational thinking, complex problem-solving abilities, and cognitive autonomy. These approaches support alignment of learning content with proficiency levels, dynamic task regulation, timely feedback, and data-driven prediction of learning trajectories.

At the same time in this review were identified methodological limitations including lack of standardized evaluation indicators, limited evidence from developing countries, and insufficient testing scope for some approaches. These factors constrain the generalization of the results. Nevertheless, the accumulated evidence indicates that adaptive and personalized instructional approaches remain a promising direction for supporting gifted learners in computer science education.

The findings imply the need to further enhance in personalization approaches, integrate ITS and learning analytics tools, and expand practical testing of digital platforms for gifted learners. Future research should broaden the empirical base, apply mixed-methods designs, and assess pedagogical effectiveness using standardized metrics. Adaptive and personalized learning thus demonstrates strategic importance in improving computer science education and strengthening the research and creative potential of gifted learners.

Acknowledgment. This study was conducted and published within the framework of the Professor–Researcher Program at Khoja Akhmet Yassawi International Kazakh–Turkish University.

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ДАРЫНДЫ БІЛІМ АЛУШЫЛАРҒА ИНФОРМАТИКАНЫ ДЕРБЕСТЕНДІРІП ОҚЫТУДЫҢ ТӘСІЛДЕРІ БОЙЫНША ЖҮЙЕЛІ ШОЛУ

Аңдатпа

Дербестендірілген және адаптивті білім беру – заманауи цифрлық педагогиканың негізгі бағыттарының бірі, әсіресе информатика саласында дарынды оқушыларды даярлау үдерісінде өзекті болып табылады. Бұл жүйелік талдаудың мақсаты – информатика пәнін оқытудағы адаптивті білім беру мен дербестендірілген оқыту әдістеріне шолу жасау және олардың дарынды білім алушылар мен студенттердің негізгі құзыреттіліктерінің қалыптасуы мен оқу жетістіктеріне әсерін бағалау. PICOC моделіне сәйкес зерттеудің мақсатты тобы ретінде дарынды білім алушылар айқындалды; интервенция ретінде – информатикадан адаптивті білім беру мен дербестендірген оқыту әдістері; салыстыру нысаны ретінде – информатиканы дәстүрлі оқыту тәсілдері; нәтижелер ретінде – негізгі құзыреттіліктердің дамуы мен оқу жетістіктерінің динамикасы қарастырылды.

Жүйелік талдау 2014–2025 жылдар аралығындағы халықаралық ғылыми дерекқор материалдары негізінде PRISMA хаттамасына сай жүзеге асырылды. Қорытынды деректер қорына адаптивті цифрлық платформалардың, жеке білім беру траекторияларының, интеллектуалды білім беру жүйелерінің және оқу деректерін талдауға арналған құралдардың тиімділігін бағалайтын зерттеулер енгізілді.

Шолу нәтижелері информатика пәнін дербестендірілген және адаптивті тәсілдер арқылы оқыту алгоритмдік және сыни ойлау дағдыларының қарқынды дамуын қамтамасыз ететінін, дарынды білім алушылардың өз бетінше жұмыс жасау қабілетін күшейтетінін және академиялық үлгерімін арттыратынын көрсетті. Сонымен қатар зерттеулердің фрагментарлығы, бірыңғай бағалау метрикаларының болмауы және дамушы аймақтар деректерінің жеткіліксіздігі сияқты әдіснамалық шектеулер айқындалды. Алынған нәтижелер информатика білім беру жүйесінде адаптивті технологияларды одан әрі зерттеу және дербестендірілген оқыту тәсілдерін кешенді енгізу қажеттілігін көрсетеді.

Түйінді сөздер: информатика, жекелендірілген оқыту, адаптивті оқыту, жүйелік талдау, PICOC, PRISMA, дарынды білім алушылар.

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СИСТЕМАТИЧЕСКИЙ ОБЗОР МЕТОДОВ ПЕРСОНАЛИЗИРОВАННОГО ОБУЧЕНИЯ ИНФОРМАТИКЕ ОДАРЕННЫХ ОБУЧАЮЩИХСЯ

Аннотация

Персонализированное и адаптивное образование является одним из основных направлений современной цифровой педагогики, особенно актуальным в процессе подготовки одаренных учащихся в области информатики. Целью этого систематического обзора является анализ методов адаптивного и персонализированного обучения в преподавании информатики и оценка их влияния на формирование ключевых компетенций и успеваемость одаренных учащихся и студентов. В соответствии с моделью PICOC в качестве целевой группы исследования определены одаренные обучающиеся; в качестве интервенции рассматривались адаптивное образование и персонализированные методы обучения информатике; в качестве формы сравнения – традиционные подходы к обучению информатике; в качестве результатов – развитие ключевых компетенций и динамика учебных достижений.

Системный анализ осуществлялся в соответствии с протоколом PRISMA на основе материалов международной научной базы данных за 2014–2025 годы. Окончательная база данных включала исследования, оценивающие эффективность адаптивных цифровых платформ, индивидуальных образовательных траекторий, интеллектуальных образовательных систем и инструментов для анализа данных обучения.

Результаты обзора показали, что преподавание информатики с помощью персонализированного и адаптивного подходов обеспечивает быстрое развитие алгоритмических навыков и навыков критического мышления, укрепляет способность одаренных учащихся работать самостоятельно и повышает успеваемость. Также были определены методологические ограничения, такие как фрагментарность исследований, отсутствие единых оценочных показателей и недостаточность данных развивающихся регионов. Полученные результаты свидетельствуют о необходимости дальнейшего изучения адаптивных технологий в системе обучения информатике и их комплексного внедрения в практику работы с одарёнными обучающимися.

Ключевые слова: информатика, персонализированное обучение, адаптивное обучение, системный анализ, PICOC, PRISMA, одаренные учащиеся.

Received: 17.12.2025
Approved after peer review: 20.02.2026
Accepted for publication: 26.03.2026