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PEDAGOGICAL EFFECTIVENESS AND COGNITIVE OUTCOMES OF ADAPTIVE LEARNING TECHNOLOGIES: OPPORTUNITIES AND LIMITATIONS

Annotation

The article examines the pedagogical effectiveness of adaptive learning technologies and their impact on cognitive outcomes. A narrative review of studies published mainly in 2020–2026 classified the evidence by outcome type and reliability. Adaptive systems reliably save learning time, largely by presenting less content; engagement gains rest on self-reports, achievement gains are mixed, evidence on cognitive outcomes is scarce, and adaptation alone does not guarantee better learning. Five didactic conditions for achieving cognitive outcomes are proposed as a hypothesis.

Key words: adaptive learning, adaptive learning technologies, pedagogical effectiveness, cognitive outcomes, personalized learning, metacognition.

ПЕДАГОГИЧЕСКАЯ ЭФФЕКТИВНОСТЬ И КОГНИТИВНЫЕ РЕЗУЛЬТАТЫ АДАПТИВНЫХ ОБРАЗОВАТЕЛЬНЫХ ТЕХНОЛОГИЙ: ВОЗМОЖНОСТИ И ОГРАНИЧЕНИЯ

Аннотация

В статье рассматриваются педагогическая эффективность адаптивных образовательных технологий и их влияние на когнитивные результаты обучения. На основе аналитического обзора исследований преимущественно 2020–2026 гг. доказательства классифицированы по типу результата и степени надёжности. Адаптивные системы надёжно экономят учебное время, главным образом за счёт сокращения содержания; рост вовлечённости подтверждается самооценкой, данные об успеваемости неоднозначны, доказательства когнитивных эффектов немногочисленны, а адаптация сама по себе не гарантирует улучшения обучения. В качестве гипотезы предложены пять дидактических условий достижения когнитивных результатов.

Ключевые слова: адаптивное обучение, адаптивные образовательные технологии, педагогическая эффективность, когнитивные результаты, персонализированное обучение, метакогниция.

ADAPTIV TA’LIM TEXNOLOGIYALARINING PEDAGOGIK SAMARADORLIGI VA KOGNITIV NATIJALARI: IMKONIYATLAR VA CHEKLOVLAR

Annotatsiya

Maqolada adaptiv ta’lim texnologiyalarining pedagogik samaradorligi va kognitiv natijalarga ta’siri o‘rganiladi. Asosan 2020–2026-yillardagi tadqiqotlarning tahliliy sharhi asosida dalillar natija turi va ishonchlilik darajasiga ko‘ra tasniflandi. Adaptiv tizimlar o‘quv vaqtini, asosan mazmunni qisqartirish hisobiga, ishonchli tejaydi; faollikning oshishi o‘quvchilarning o‘z bahosiga tayanadi, o‘zlashtirish natijalari bir xil emas, kognitiv natijalar bo‘yicha dalillar kam, adaptatsiyaning o‘zi esa o‘quv natijalarini kafolatlamaydi. Kognitiv natijaga erishishning beshta didaktik sharti gipoteza sifatida taklif etiladi.

Kalit so‘zlar: adaptiv ta’lim, adaptiv ta’lim texnologiyalari, pedagogik samaradorlik, kognitiv natijalar, shaxsiylashtirilgan ta’lim, metakognitsiya.

Introduction. Digitalization of education increasingly focuses on adapting learning to each learner: AI-based platforms analyse learners’ responses and select the next task, its difficulty and the type of support. This is seen as a transition from mass education to personalized learning [1].

In Uzbekistan, this is part of state policy: President Sh.M. Mirziyoyev’s book “Strategy of New Uzbekistan” treats education reform and human capital as priorities [2], and the “Uzbekistan – 2030” Strategy [3] and the Strategy for the Development of Artificial Intelligence Technologies until 2030 (Resolution No. PQ-358 of 14.10.2024) [4] prioritize human resources in artificial intelligence, which adaptive learning technologies can support.

Yet the pedagogical effectiveness of adaptive learning technologies is usually judged by engagement and achievement, while cognitive outcomes, such as independent thinking, problem solving and the regulation of one’s own cognition, are often ignored. The article therefore aims to analyse the evidence on the pedagogical effectiveness and cognitive impact of these technologies and to identify their opportunities and limitations by clarifying the concept and structure of adaptive learning, classifying the evidence by outcome type and reliability, and substantiating, as a hypothesis, didactic conditions for achieving cognitive outcomes.

Literature review. The term “adaptive learning” has two senses: in some post-Soviet works, the student’s adaptation to a new learning environment [5]; in digital education, the adaptation of the learning system to the learner. Yu.V. Vaynshteyn defines personalized adaptive learning as a process that dynamically changes content and forms according to the learner’s needs, outcomes and individual characteristics [6]. We adopt the second meaning: adaptive learning technology is a pedagogical and technological system that collects learner data and adjusts content, task difficulty, sequence and support accordingly.

Summarizing 142 empirical studies, Hariyanto et al. identify learner classification, intelligent agents, an affective module and feedback as the main components [7]; Kassenkhan et al. propose five layers: interaction capture, data

acquisition, user modelling, AI-based decision-making and adaptive feedback [8]. Figure 1 generalizes these approaches.

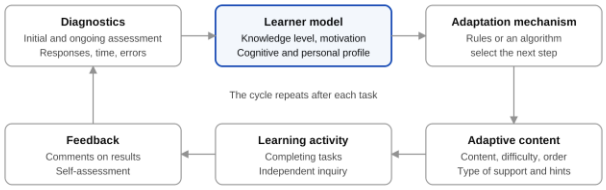


Figure 1. Operating cycle of an adaptive learning system

Systems differ in what is adapted and when: one-time adaptation chooses the learning path by an initial test, whereas continuous adaptation decides after each task. The learner model is the key link, yet 77% of the 22 systems analysed by Ezzaim et al. rely on a single factor [9].

Reviewing 45 studies in higher education, Merino-Campos notes gains in engagement, grades and motivation but also a reliance on self-reports and a lack of standard evaluation criteria [10]. In a systematic review of AI in vocational education, Deutscher et al. found random assignment in only 5 of 26 studies and self-report in at least one outcome measure in 21 [11]. In Uzbekistan, Kobulova reported 15% higher achievement with an online adaptive system in medical universities, without statistical testing in the dissertation abstract [12], and Qarshiyev studied the development of cognitive competencies with AI tools in in-service teacher training [13]; neither work reveals the pedagogical mechanism of adaptation.

Research Methodology. The study uses an inductive approach; its design is a narrative review of secondary sources using comparative analysis and content synthesis. Only published sources were used, so ethical approval was not required. Sources, namely international journal articles and dissertations defended in Russia and Uzbekistan mainly in 2020–2026, had to concern both an adaptive or AI-based educational technology and learning or cognitive outcomes. Of more than 60 sources screened, 51 were analysed, and 18 that directly linked adaptive technology to learning outcomes were used as evidence. Algorithms tested on non-educational data were excluded, and results without statistical testing are flagged.

Cognitive outcomes are understood as thinking, problem solving and metacognition; engagement is treated as a process indicator. Studies were classified by outcome type, level of education and type of adaptation, and evidence was rated as high (at least one large randomized study, no contradicting results), moderate (controlled studies or reviews with inconsistent or mainly self-reported results) or low (isolated, short-term or fragmented). Limitations: one author selected and rated the sources, only English, Russian and Uzbek publications were included, and no meta-analysis was performed.

Analysis and results. Opportunities. Of the 69 studies reviewed by du Plooy et al., 41 (59%) reported improved achievement and 25 (36%) increased engagement [14]; this is a share of positive studies, not an effect size. The most reliable experimental result is time saving: in Italian technical high schools, with 2,064 randomly assigned students, skipping topics mastered according to a pre-test substantially reduced learning time in all seven courses [15], mainly because less content was presented. In a quasi-experiment with 109 art students, where the control group used the same game without adaptation, the adaptive group achieved significantly more (partial $\eta^2 = 0.286$) [16].

Cognitive outcomes. According to Deutscher et al., cognitive outcomes are most consistently supported by intelligent tutoring systems and adaptive learning platforms [11]; Kassenkhan et al. report moderate gains in executive functions and higher-order thinking from adaptive gamification, with evidence on metacognition limited to isolated studies [8]. Increased cognitive engagement [9] is a process indicator, not a learning outcome. Reviewing 85 studies, Halkiopoulos and Gkintoni acknowledge a lack of solid empirical evidence on the cognitive effects of AI-based learning [17]. Cognitive outcomes are measured through fragmented indicators rather than as an integral construct. Cognitive diagnostic models are promising, as the system of Zhang et al. estimates each learner’s probability of mastering each cognitive attribute [18], but they are used mainly in school mathematics and without control groups.

Limitations. First, adaptation alone does not guarantee better learning. In the Italian study, outcomes favoured the adaptive group in one module and the traditional group in two [15]. Sibley et al., comparing systems that differed only in continuous difficulty adaptation, found no differences in achievement, cognitive load or enjoyment among primary school pupils [19]. Among 1,281 engineering students in Mexico, the adaptive platform was consistently superior in only one of four subjects, success being linked to content design, active platform use and teacher involvement [20].

Second, poorly designed technology may hinder cognitive development: ready-made answers may weaken independent thinking, whereas guiding questions support metacognition [21]. In Thomann’s meta-analysis of 68 experiments, guiding prompts had a moderate effect ($d = 0.394$), which fell to $d = 0.22$ after correction for publication bias; in his vocational experiment, learners found too many prompts distracting, and results improved when their number was reduced [22]. Third, the evidence base is weak: randomized studies are few, and delayed measurements are almost absent [10; 11]. Table 1 summarizes the results.

Table 1. Reliability of evidence on the outcomes of adaptive learning technologies

Outcome	Main finding	Reliability	Evidence (level, source)
Time efficiency	Much less time (mainly less content)	High	1 large RCT, high school [15]
Engagement, motivation	Increases in most studies	Moderate: mainly self-report	3 reviews, mostly university [10; 14; 17]
Achievement	Often positive; depends on subject and adaptation	Moderate: inconsistent	1 review, 4 experiments; school, university [6; 14–16; 20]
Cognitive	Moderate gains in executive functions, thinking	Low: fragmented, short-term	3 reviews, mixed levels [8; 11; 17]
Metacognitive	Positive with question-based guidance	Low: few studies	2 reviews [8; 21]

Conclusion/Recommendations. 1. The pedagogical effectiveness of adaptive learning technologies varies by outcome type: time saving is the most reliable result but stems mainly from presenting less content; engagement gains rest on self-reports; achievement depends on the subject, adaptation type and implementation.

2. Cognitive outcomes are the least studied: thinking, problem solving and metacognition are measured separately rather than as an integral cognitive competence.

3. Adaptation alone, especially of difficulty or sequence only, does not guarantee cognitive development; the outcome depends on the didactic conditions of use.

The novelty of the article lies in assessing adaptive learning technologies by outcome type and reliability of evidence

and in showing that adaptation alone does not guarantee cognitive outcomes. Accordingly, five didactic conditions for achieving cognitive outcomes in personalized learning, relying on objective cognitive diagnostics and active teacher involvement, are proposed as a hypothesis (Table 2).

Table 2. Theoretical and empirical grounds of the didactic conditions

Condition	Theoretical basis	Empirical evidence (level)
Multi-factor adaptation	Zone of proximal development [23]	Indirect: 77% of systems use one factor [9]; difficulty-only adaptation had no effect [19]
Question-based guidance	Scaffolding [24]	Partial: review [21]; moderate effect of prompts [22]
Fading support	Scaffolding [24]; cognitive load theory [25]	Partial: review [17]; vocational experiment [26]
Integration with instructional strategy	Self-directed learning [26]	Partial: success in 1 of 4 subjects [20]
Objective cognitive diagnostics	Cognitive diagnostic models [18]	Partial: no control group [18]

None of the conditions has yet been fully confirmed experimentally. They can be implemented in Moodle through conditional access, adaptive quizzes and step-by-step hints and can guide the improvement of national personalized learning platforms [12]. Future research should define cognitive competence with its components, criteria and levels and test an adaptive methodology for developing it in a controlled experiment with delayed measurements.

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