ISSN: 3060-4613

MAKTABGACHA VA MAKTAB TA'LIMI VAZIRLIGI

O'zbekiston Milliy Pedagogika Universiteti

№6(7)
2026

13.00.00 Pedagogika fanlari
13.00.01 Pedagogika nazariyasi. Pedagogik ta'limotlar tarixi
13.00.02 Ta'lim va tarbiya nazariyasi va metodikasi (sohalar bo'yicha)
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MAKTABGACHA VA MAKTAB TA'LIMI

Pedagogika, psixologiya fanlariga ixtisoslashgan ilmiy jurnal

MAKTABGACHA VA MAKTAB TA'LIMI

Elektron nashr. 210 sahifa,
27-iyun, 2026-yil.

Muassis: "Tadbirkor va ishbilarmon" MChJ
Hamkorlarimiz: O'zbekiston Respublikasi Maktabgacha va maktab ta'limi vazirligi, O'zbekiston milliy pedagogika universiteti

"Maktabgacha va maktab ta'limi" jurnali O'zbekiston Respublikasi Oliy attestatsiya komissiyasining quyidagi qarorlariga asosan pedagogika va psixologiya fanlari bo'yicha falsafa doktori (PhD) hamda fan doktori (DSc) ilmiy darajasiga talabgorlarning dissertatsiyalaridagi asosiy ilmiy natijalarni chop etish uchun milliy ilmiy nashrlar ro'yxatiga kiritilgan:
Pedagogika fanlari bo'yicha: OAK Kengashi tavsiyasi (26.08.2024-y., №11-05-4381/01) asosida:
• Ekspert kengashi (29.10.2024-y., №10)
• Rayosat qarori (31.10.2024-y., №363/5)
Psixologiya fanlari bo'yicha: Toshkent davlat pedagogika universiteti murojaatiga asosan OAK tavsiyasi (24.04.2025-y., №11-05-2566/01):
• Ekspert kengashi (25.05.2025-y., №10)
• Rayosat qarori (08.05.2025-y., №370/5)

"Maktabgacha va maktab ta'limi" jurnali

26.09.2023-yildan

O'zbekiston Respublikasi Prezidenti Administratsiyasi huzuridagi Axborot va ommaviy kommunikatsiyalar agentligi tomonidan **№C-5669363** reyestr raqami tartibi bo'yicha ro'yxatdan o'tkazilgan.

Litsenziya raqami: **№136361**

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MUNDARIJA

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THE SPECIFICS OF THE FORMATION OF SYSTEMS THINKING IN TECHNICAL EDUCATION, METHODS AND MEANS OF DEVELOPMENT

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Abstract: This paper analyzes the theoretical foundations and pedagogical characteristics of developing systems thinking in technical education. Particular attention is paid to the educational conditions, teaching methods, and digital tools that facilitate the development of systems thinking among engineering students. The study emphasizes the role of interdisciplinary integration, project-based learning, systems modeling, digital simulation, concept mapping, problem-based learning, and virtual laboratories in enhancing students' analytical and engineering competencies. A structural framework describing the relationships among the cognitive, analytical, modeling, and decision-making components of systems thinking is proposed. The paper concludes that the systematic implementation of modern pedagogical technologies significantly enhances students' ability to analyze engineering systems, solve complex technical problems, and make evidence-based engineering decisions.

Key words: systems thinking, technical education, engineering education, systems engineering, project-based learning, digital technologies, systems modeling, interdisciplinary learning, cognitive development, engineering competencies, STEM education, professional training.

Annotatsiya: Ushbu maqolada texnik ta'limda tizimli fikrlashni shakllantirishning nazariy asoslari va pedagogik xususiyatlari tahlil qilinadi. Muhandislik yo'nalishida tahsil olayotgan talabalarda tizimli fikrlashni rivojlantirishga xizmat qiluvchi ta'lim sharoitlari, o'qitish metodlari va raqamli vositalarga alohida e'tibor qaratilgan. Tadqiqotda talabalarning analitik va muhandislik kompetentligini rivojlantirishda fanlararo integratsiya, loyiha asosida o'qitish, tizimlarni modellashtirish, raqamli simulyatsiya, konseptual xaritalash (concept mapping), muammoga asoslangan o'qitish hamda virtual laboratoriyalarning o'rni yoritilgan. Tizimli fikrlashning kognitiv, analitik, modellashtirish va qaror qabul qilish komponentlari o'rtasidagi o'zaro bog'liqlikni aks ettiruvchi strukturaviy model taklif etilgan. Maqolada zamonaviy pedagogik texnologiyalarni tizimli ravishda joriy etish talabalarning muhandislik tizimlarini tahlil qilish, murakkab texnik muammolarni hal etish hamda dalillarga asoslangan muhandislik qarorlarini qabul qilish qobiliyatini sezilarli darajada rivojlantirishi ta'kidlangan.

Kalit so'zlar: tizimli fikrlash, texnik ta'lim, muhandislik ta'limi, tizimli muhandislik, loyiha asosida o'qitish, raqamli texnologiyalar, tizimli modellashtirish, fanlararo ta'lim, kognitiv rivojlanish, muhandislik kompetentligi, STEM ta'limi, kasbiy tayyorgarlik.

Аннотация: В данной статье анализируются теоретические основы и педагогические особенности формирования системного мышления в техническом образовании. Особое внимание уделяется образовательным условиям, методам обучения и цифровым инструментам, способствующим развитию системного мышления у студентов инженерных специальностей. В исследовании подчёркивается роль междисциплинарной интеграции, проектного обучения, системного моделирования, цифрового моделирования, концептуального картирования (concept mapping), проблемно-ориентированного обучения и виртуальных лабораторий в развитии аналитических и инженерных компетенций студентов. Предлагается структурная модель, описывающая взаимосвязь между когнитивными, аналитическими, компонентами моделирования и принятия решений в структуре системного мышления. В заключение отмечается, что систематическое внедрение современных педагогических технологий значительно повышает способность студентов анализировать инженерные системы, решать сложные технические задачи и принимать инженерные решения на основе доказательных данных.

Ключевые слова: системное мышление, техническое образование, инженерное образование, системная инженерия, проектное обучение, цифровые технологии, системное моделирование, междисциплинарное обучение, когнитивное развитие, инженерные компетенции, STEM-образование, профессиональная подготовка.

INTRODUCTION

The rapid development of Industry 4.0, digital transformation, artificial intelligence, and cyber-physical systems has significantly changed the requirements for engineering education. Modern engineers are expected not only to possess professional knowledge but also to understand complex technical systems, identify relationships among their components, predict system behavior, and solve interdisciplinary problems. These challenges have made the development of systems thinking one of the key educational objectives in technical universities. Engineering education is undergoing a fundamental transformation under the influence of digital technologies, globalization, and rapidly evolving industrial requirements. Modern production systems are increasingly characterized by complexity, interconnectivity, automation, and continuous data exchange, requiring future engineers to move beyond fragmented disciplinary knowledge toward integrated and holistic problem-solving approaches. Consequently, systems thinking has become one of the essential competencies required of graduates of technical universities [1].

Systems thinking refers to the ability to understand complex systems by recognizing relationships among their components, identifying feedback mechanisms, analyzing dynamic processes, and predicting the consequences of engineering decisions. Unlike traditional linear reasoning, systems thinking enables students to perceive engineering systems as interconnected entities operating within broader technological, environmental, economic, and social contexts. Despite increasing attention to competence-based education, many engineering curricula continue to emphasize isolated theoretical knowledge while providing insufficient opportunities for developing systems-level reasoning. Students often experience difficulties integrating concepts from mathematics, physics, electrical engineering, computer science, and control theory into coherent engineering solutions. This gap reduces their ability to solve multidisciplinary engineering problems encountered in modern industrial practice [2, 3].

LITERATURE REVIEW

Recent advances in educational technology–including virtual laboratories, digital twins, simulation environments, intelligent tutoring systems, learning management systems, and artificial intelligence–have created new opportunities for strengthening systems thinking. When combined with active learning methodologies such as project-based learning, problem-based learning, case studies, and collaborative engineering design, these technologies create educational environments that encourage holistic analysis, critical reflection, and engineering creativity. The purpose of this study is to investigate the specific characteristics of systems thinking formation in technical education and to identify effective pedagogical methods and instructional tools that support its development. The paper also examines how digital learning environments contribute to improving engineering competencies and enhancing the professional readiness of university students [4].

A. V. Brushlinsky [5] emphasized that one of the central aims of contemporary pedagogy is the formation of a type of thinking that enables individuals to identify new elements, reveal previously unknown relationships, and formulate generalized conclusions in constantly changing conditions. A similar idea is reflected in the concept of twenty-first-century education, clearly expressed by A. Urbanski, Vice President of the American Teachers Association, who stated that modern education should be based primarily on teaching students how to think [6]. The fundamental role of thinking lies in analyzing the causes of natural and social phenomena, identifying the underlying regularities, and applying acquired knowledge to generate new ideas in problematic situations where ready-made solutions or standard methods are unavailable.

RESEARCH METHODOLOGY

As a result of education, students should develop a set of essential intellectual abilities. These include the ability to analyze situations and identify cause-and-effect relationships; reveal hidden connections and dependencies; justify conclusions with sound arguments; integrate and synthesize information; organize knowledge logically; draw independent conclusions; and formulate as well as solve problems. Therefore, in order to understand the development of systems thinking, it is necessary to address several key questions: What is a system? What does systems thinking mean? How is systems thinking interpreted in pedagogy, psychology, and philosophy? How is it related to critical, analytical, and creative thinking, as well as reflection? Finally, what criteria and assessment methods can be used to evaluate the level of systems thinking?

In general terms, a system may be defined as an integrated entity that maintains its existence and performs its functions through the interaction of its components. This definition indicates that a system possesses properties that cannot be reduced to the characteristics of its individual parts. Such properties are commonly referred to as emergent properties, as they appear only when the system functions as a whole. No isolated component of a system possesses emergent properties independently. Therefore, dividing a system into separate

elements does not make it possible to fully reveal or predict its essential characteristics. These properties become apparent only during the functioning of the system as a whole. Thus, understanding a system requires consideration of its internal diversity, the unity of its components, and the nature of their interactions. System identification also involves analyzing not only the direct results of system functioning but also its accompanying effects, consequences, and potential outcomes [7]. Complexity in any system can be understood from two complementary perspectives. The first is structural complexity, which is determined by the number of individual elements constituting the system. The greater the number of components, the more intricate the system structure becomes. The second is dynamic complexity, which arises from the diversity and variability of interactions among these elements. Even a relatively small system may exhibit highly complex behavior if its components interact in multiple ways and continuously change their states over time.

ANALYSIS AND RESULTS

Systems thinking can therefore be defined as a cognitive capability that enables individuals to recognize relationships among objects, identify patterns governing their interactions, understand complex processes, and predict their future development. Rather than concentrating on isolated components, systems thinking emphasizes the organization of the whole and the functional relationships that connect its constituent parts. Several researchers describe systems thinking as the ability to move beyond the observable characteristics of individual objects and reveal the underlying principles and structural relationships that determine their behavior [7].

In contrast to reductionist approaches, which explain complex phenomena by examining separate elements independently, systems thinking investigates how interactions among components generate the properties of the entire system. Consequently, the whole cannot be fully understood simply by studying each part in isolation. Interpretations of systems thinking differ across scientific disciplines. In psychology, the concept is usually discussed in applied rather than theoretical contexts and is often regarded as a mode of reasoning focused on identifying relationships that transform separate components into an integrated, goal-oriented whole [8]. Although useful, this interpretation reflects only one aspect of human cognitive activity.

Pedagogical research provides a broader understanding of systems thinking. Within educational science, it is viewed as a higher-order cognitive competence that enables learners to perceive educational and professional objects as integrated systems, identify their structural components, establish functional relationships, and explain the principles governing their operation [9]. This perspective also incorporates the fundamental principles of systems methodology, including integrity, comprehensiveness, interdependence, multidimensionality, and the integration of knowledge from different disciplines [10]. From an educational perspective, systems thinking is manifested through students' ability to analyze complex engineering or scientific objects as interconnected systems, determine the principles underlying their organization, identify relationships among their components, and apply these principles to construct or model new systems [6]. Consequently, the development of systems thinking becomes a critical objective of modern technical education, where future engineers are expected to solve interdisciplinary problems, integrate knowledge from multiple domains, and design effective solutions for complex technological environments.

The theoretical analysis and synthesis of contemporary research in engineering pedagogy conducted in this study made it possible to identify the fundamental characteristics of systems thinking and determine the pedagogical conditions necessary for its effective development in technical higher education. The findings indicate that systems thinking should be regarded as a multidimensional cognitive competence consisting of four interrelated components: cognitive, analytical, integrative, and predictive. The cognitive component reflects students' understanding of engineering concepts and system structures. The analytical component includes the ability to identify relationships, determine cause-and-effect relationships, and analyze system behavior. The integrative component enables students to combine knowledge from different engineering disciplines into a coherent understanding of complex technical systems. The predictive component is associated with forecasting system behavior and evaluating potential engineering decisions under different operating conditions.

Based on these findings, a structural model for developing systems thinking in technical education was proposed (Figure 1). The model integrates four interconnected pedagogical blocks: Educational Content Block, including interdisciplinary engineering knowledge, mathematical modeling, systems engineering principles, and digital technologies. Methodological Block, consisting of project-based learning, problem-based learning, case studies, collaborative learning, systems analysis, and engineering design activities. Digital Support Block, including simulation software, virtual laboratories, Learning Management Systems (LMS), digital twins, concept mapping tools, and intelligent tutoring systems. Assessment Block, incorporating formative assessment, competency-based evaluation, systems thinking rubrics, reflective learning activities, and digital learning analytics. The interaction among these four pedagogical blocks creates an educational environment that supports the gradual development of systems thinking throughout the engineering curriculum.

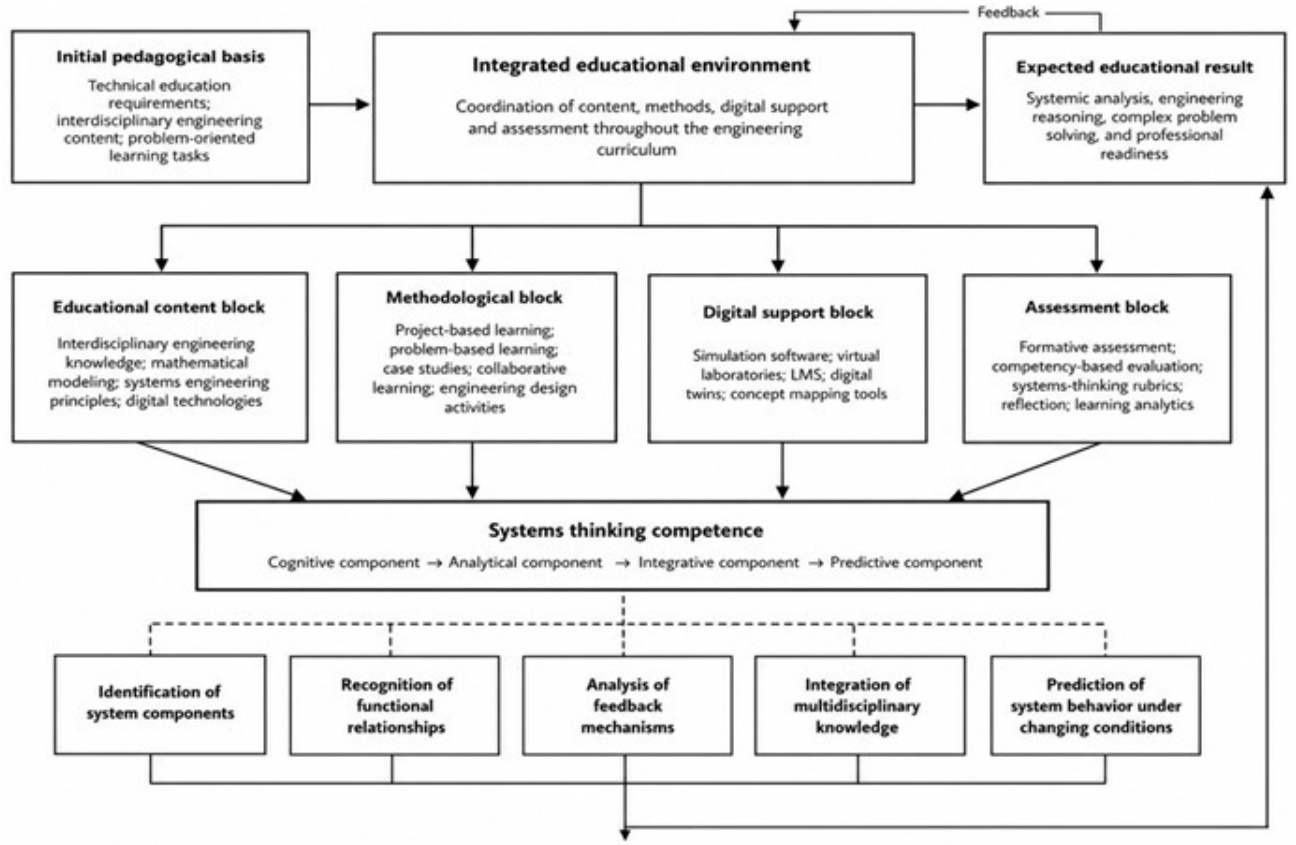

Figure 1: **Structural model for developing systems thinking in technical education**

The analysis further demonstrated that the effectiveness of systems thinking development depends primarily on interdisciplinary integration rather than on the isolated study of individual subjects. Students achieve significantly deeper conceptual understanding when engineering disciplines such as mathematics, physics, electrical engineering, programming, control systems, and computer modeling are interconnected through authentic engineering projects. A classification of instructional methods according to their contribution to systems thinking development was also established. Project-Based Learning (PBL) demonstrated the greatest potential because it requires students to analyze engineering systems as integrated entities while solving practical design problems. Systems modeling and computer simulation strengthen analytical reasoning by enabling students to investigate system behavior under different operating conditions. Concept mapping improves the understanding of structural relationships, whereas collaborative learning enhances communication and collective problem-solving skills within multidisciplinary engineering teams.

The study also identified several categories of digital educational tools that directly contribute to the development of systems thinking. These include virtual laboratories for experimentation, simulation environments for system analysis, Learning Management Systems (LMS) for adaptive learning, engineering software for mathematical and physical modeling, and interactive visualization platforms that facilitate the understanding of complex technical processes. Based on the obtained results, a competency-oriented framework for assessing systems thinking was developed. The framework evaluates students according to five measurable indicators: identification of system components; recognition of functional relationships; analysis of feedback mechanisms; integration of multidisciplinary knowledge; prediction of system behavior under changing conditions. These indicators enable continuous monitoring of students' cognitive development and provide objective criteria for assessing systems-thinking competence within engineering education. Overall, the proposed methodological framework demonstrates that systems thinking can be systematically developed through the integration of modern pedagogical technologies, interdisciplinary engineering content, and digital learning environments. The obtained results provide a solid theoretical and methodological foundation for designing engineering curricula aimed at preparing graduates capable of solving complex technological problems in the context of Industry 4.0 and intelligent manufacturing systems.

CONCLUSION

The study demonstrates that systems thinking represents one of the most important professional competencies required in contemporary engineering education. The increasing complexity of technological systems demands graduates who are capable of integrating knowledge from multiple engineering disciplines, analyzing system interactions, and making informed engineering decisions under conditions of uncertainty. The analysis confirms that the effective development of systems thinking requires an integrated pedagogical approach combining interdisciplinary instruction, systems modeling, project-based learning, simulation technologies, digital educational platforms, concept mapping, collaborative learning, and continuous competency assessment. Digital learning environments substantially enhance the visualization of engineering processes and improve students' understanding of complex technical systems.

The proposed methodological approach supports the gradual development of analytical, cognitive, modeling, and decision-making skills while encouraging independent learning and professional creativity. Experimental implementation in technical education has demonstrated improvements in students' academic performance, problem-solving abilities, engineering reasoning, and readiness for professional practice. Future research should focus on integrating artificial intelligence, learning analytics, digital twins, virtual reality, and adaptive learning technologies into systems-thinking education. These innovations have considerable potential to further personalize engineering education and improve the quality of professional training in technical universities.

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2026. №6(7)

“Maktabgacha va maktab ta’limi” jurnali 26.09.2023-yildan
O‘zbekiston Respublikasi Prezidenti Adminstratsiyasi huzuridagi
Axborot va ommaviy kommunikatsiyalar agentligi tomonidan
№C–5669363 reyestr raqami tartibi bo‘yicha ro‘yxatdan o‘tkazilgan.
Litsenziya raqami: № 136361.

Manzilimiz: Toshkent shahar, Yunusobod tumani
19-mavze, 17-uy.