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DIDACTIC MODEL OF IMPLEMENTING STEAM APPROACH BASED ON DIGITAL TECHNOLOGIES

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Abstract: This study develops the theoretical and methodological foundations for integrating the STEAM approach into the educational process based on digital technologies and proposes a corresponding didactic model. The research was conducted with 8th-grade students in a general secondary school, where experimental and control groups were established. During the study, students' cognitive, practical, and creative competencies were evaluated through diagnostic tests, observations, and surveys. The results demonstrated that the digital STEAM model significantly enhances students' problem-solving abilities, creative thinking, and digital competencies. Statistical analysis confirmed the effectiveness of the model at a significant level ($p < 0.05$). The study contributes both scientifically and practically to the digitalization of education, interdisciplinary integration, and the development of 21st-century competencies.

Keywords: STEAM, digital transformation, didactic model, interdisciplinary integration, competency-based approach, pedagogical modeling

Аннотация: В данном исследовании разработаны теоретические и методологические основы интеграции STEAM-подхода в образовательный процесс на основе цифровых технологий, а также предложена соответствующая дидактическая модель. Исследование проводилось с участием учащихся 8-х классов средней общеобразовательной школы с организацией экспериментальной и контрольной групп. В ходе исследования оценивались когнитивные, практические и творческие компетенции учащихся с помощью диагностических тестов, наблюдений и опросов. Результаты показали, что цифровая STEAM-модель значительно повышает навыки решения проблем, творческое мышление и цифровую компетентность учеников. Статистический анализ подтвердил эффективность модели на достоверном уровне ($p < 0,05$). Исследование имеет как научную, так и практическую ценность, способствуя цифровизации образовательного процесса, междисциплинарной интеграции и формированию компетенций XXI века.

Ключевые слова: STEAM, цифровая трансформация, дидактическая модель, междисциплинарная интеграция, компетентностный подход, педагогическое моделирование

Introduction. In the 21st century, societal development is closely linked to digital transformation processes, which place new qualitative demands on the education system. In a digital economy, key indicators of human capital include creative thinking, problem-solving, critical analysis, engineering thinking, and digital competencies. Consequently, traditional subject-oriented teaching models are gradually being replaced by interdisciplinary, practice-oriented approaches.

In recent years, the STEAM (Science, Technology, Engineering, Art, Mathematics) approach has been recognized as an effective tool for integrating educational content. This approach unites natural sciences, technology, engineering, art, and mathematics within a single project-based framework, fostering systematic thinking in students. The advantage of STEAM is its ability to link theoretical knowledge to real-life problems while engaging students as active participants in the learning process.

However, to implement the STEAM approach effectively, it must be integrated with digital technologies. A digital learning environment is not merely a set of technical tools but a comprehensive pedagogical system that includes interactive platforms, virtual laboratories,

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simulation software, 3D modeling systems, and AI-based learning tools. Such an environment creates broad opportunities for implementing STEAM projects.

A review of existing studies shows that while the theoretical foundations of STEAM have been explored, a systematic didactic model for implementing STEAM based on digital technologies has not been sufficiently developed. Specifically, structural components, assessment criteria, and effectiveness indicators of the model remain insufficiently systematized, which leads to fragmented implementation of STEAM in practice.

This study addresses this gap by developing a scientifically grounded didactic model for implementing STEAM through digital technologies.

The relevance of the study is determined by:

- The necessity of digitizing the educational process;
- The need to enrich the competency-based approach with practical mechanisms;
- The requirement to systematically organize interdisciplinary integration;
- The insufficient development of assessment criteria for STEAM education.

The **object of the study** is the general secondary education process.

The **subject of the study** is the didactic mechanisms for implementing the STEAM approach based on digital technologies.

The **aim** of the study is to develop a structural-didactic model that ensures effective implementation of the STEAM approach in a digital learning environment and to verify its effectiveness through experimental research.

The **hypothesis** states that if the STEAM approach is implemented using a didactic model integrated with digital tools and clear components of objectives, content, process, and outcomes, it will significantly enhance students' creative thinking, problem-solving skills, and digital competencies.

The **scientific significance** of the study lies in systematizing the theoretical foundations of digital STEAM integration and developing its didactic model. The **practical significance** is that the developed model can be applied in general secondary schools.

Literature review. Recent pedagogical research recognizes STEAM as an effective model for interdisciplinary integration. Initially developed as STEM, the concept was later expanded with the Arts component to enhance creative thinking, resulting in the STEAM approach.

Yakman (2008) developed the theoretical and practical mechanisms of STEAM, describing it as an integrative model reflecting natural connections between disciplines and fostering systematic and innovative thinking in students.

Bybee (2013) emphasized the importance of integrating science, technology, and engineering in education, highlighting the priority of problem-based learning and project-based activities as tools to develop 21st-century competencies.

The integration of digital technologies in education has been widely explored within the TPACK framework (Technological Pedagogical Content Knowledge) by Mishra & Koehler (2006), which emphasizes the need to harmonize pedagogical, content, and technological knowledge. This approach served as a methodological basis for developing the digital STEAM model.

Moreover, the European Commission (2017) systematized digital competencies through the DigComp framework, identifying information management, communication, content creation, and problem-solving as key components of digital literacy.

At the national level, Uzbekistan's Ministry of Higher and Secondary Specialized Education promotes digitalization in education, making the integration of STEAM with digital environments a highly relevant issue.

Analysis of previous studies indicates that while STEAM and digital technologies have been studied separately, a unified structural-didactic model for their integration has not been sufficiently developed. This study addresses this gap.

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Methodology. The study employed a quasi-experimental design. Students were divided into two groups: the control group followed traditional teaching methods, while the experimental group used the digital STEAM model. A total of 60 students participated (30 per group), and the groups were equalized in terms of initial knowledge through diagnostic pre-tests. The study lasted 16 weeks (4 months) in 8th-grade classes of a secondary school.

Students' cognitive, practical, and creative competencies were evaluated through diagnostic tests, observations, and surveys. Pre-tests and post-tests were conducted, and data were analyzed using mean scores, standard deviations, and Student's t-test, with significance level $p<0.05$.

The digital STEAM model included interdisciplinary integration, problem-based learning, project activities, and modeling principles using digital tools. Students engaged in projects connecting theory and practice, solved complex problems, generated creative ideas, and collaborated on digital platforms. Assessment criteria were based on cognitive, practical, and creative indicators, each evaluated at low, medium, and high levels. Internal validity was ensured by equal initial group knowledge and consistent curricula; external validity allows the model to be applied in other classes. Ethical considerations were observed: parental consent was obtained, and data were recorded anonymously.

Results. The implementation of the digital STEAM model led to significant improvements in students' competencies. Post-test results showed that the experimental group achieved:

- Cognitive competence: 76.5% (pre-test 54.2%), increase 22.3%
- Practical competence: 74.6% (pre-test 51.8%), increase 22.8%
- Creative competence: 72.9% (pre-test 50.7%), increase 22.2%

The control group showed smaller improvements: cognitive 11.9%, practical 13.5%, creative 11.1%. Student's t-test confirmed statistically significant differences between the groups (cognitive $t=3.12$, practical $t=3.45$, creative $t=3.08$; $p<0.05$). These results confirm that the digital STEAM model substantially enhances problem-solving, creativity, and digital competencies compared to traditional methods.

Discussion. The study confirms the pedagogical effectiveness of the digital STEAM approach. Cognitive gains reflect the effectiveness of interdisciplinary modules and problem-based learning in systematizing theoretical knowledge, consistent with Yakman (2008) and Bybee (2013). Practical gains demonstrate the impact of digital tools, virtual labs, and interactive platforms on applying knowledge in real-life contexts, aligning with TPACK principles (Mishra & Koehler, 2006). Creative gains show the importance of the Arts component and design thinking in fostering innovative problem-solving and idea generation.

Although the study was limited to one school and small sample size, the findings suggest that the model can enhance 21st-century competencies, and it is recommended for broader application across schools and grade levels.

Conclusion. The research demonstrates that the digital STEAM model is pedagogically effective in significantly enhancing students' cognitive, practical, and creative competencies. It enriches the learning process through interdisciplinary integration, problem-solving, project-based activities, and digital tools.

The model not only improves learning outcomes but also strategically develops 21st-century competencies, fostering creative and problem-oriented thinking. It provides teachers with opportunities to integrate lessons across subjects, organize projects and problem-based activities effectively, facilitate collaboration on digital platforms, and enhance students' analytical and creative skills.

The study recommends expanding the model to broader educational settings and further refining it by incorporating new interactive tools, virtual labs, and interdisciplinary approaches. This ensures that the digital STEAM model remains a reliable and scalable instrument for improving educational quality and strengthening students' professional and personal competencies.

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