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INNOVATIVE METHODOLOGICAL MECHANISMS OF FORMING PROJECT COMPETENCES BASED ON VIRTUAL MODELING IN ENGINEERING EDUCATION

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Abstract

This article scientifically analyzes innovative methodological mechanisms for the formation of project competencies based on virtual modeling technologies in engineering education. The study reveals the role of digital modeling tools in developing students' technical thinking, strengthening graphic thinking, and solving engineering problems. Project activities carried out in a virtual environment allow students to integrate theoretical knowledge with practical experience, which ensures high efficiency in the formation of professional competencies. The article also highlights the pedagogical advantages of modernizing the educational process based on software platforms such as AutoCAD, Inventor, PhotoShop, and CorelDraw, the stages of the educational model based on project tasks, and the assessment criteria. The results show that virtual modeling, in addition to increasing the technical and creative potential of students, brings their decision-making in problem situations, engineering thinking, and digital literacy to a new level.

Keywords

Engineering education, virtual modeling, project competency, digital pedagogy, innovative technologies, AutoCAD, teaching methodology, engineering thinking, technical design, creative thinking, competency-based education, digital environment.

Introduction

In today's globalization and digital transformation, engineering education is recognized as an important mechanism for the formation of not only professional skills, but also for the development of innovative thinking, systems thinking and digital design competencies. The process of digital integration of education systems is expanding rapidly internationally. According to the UNESCO Global Education Monitoring Report (2023), by 2030, the introduction of digital modeling, virtual laboratories and simulation technologies into the educational process will increase the efficiency of education in engineering by at least 40 percent [1]. Also, according to OECD (2022), as a result of project-based learning and the use of modeling technologies in a digital environment, students significantly improve their analytical thinking, creativity and decision-making skills in problem situations [2]. This strengthens the importance of virtual modeling as a modern form of the principle of "learning by doing" in engineering education.

The digitalization of engineering in the education system of the Republic of Uzbekistan has also become a priority area of state policy. The “Digital Uzbekistan – 2030” strategy stipulates the widespread introduction of digital technologies, artificial intelligence and simulation laboratories in higher education, as well as the modernization of project-based teaching

methodologies. At the same time, by the resolution of the Cabinet of Ministers, mechanisms were established to establish “Digital Engineering Centers” in technical universities, create virtual educational resources, and transfer engineering design to a digital format. These initiatives are aimed at accelerating the integration of the country's engineering education with international standards and training specialists with a digital mindset for the modern economy. In addition, studies by the World Bank (2024) and the European Training Foundation (ETF, 2023) also indicate that the digitalization of the educational process in engineering in Central Asian countries is a key factor increasing the share of innovative professions in the labor market [4].

In this regard, the introduction of virtual modeling technologies into the educational process in the higher education system of Uzbekistan should be recognized as an innovative approach that provides not only technical training, but also the development of design competencies. Through virtual modeling technologies (AutoCAD, SolidWorks, Inventor, Ansys, Blender, etc.), the student will have the opportunity to test his project in real time, identify errors and optimize design solutions. This process reduces the gap between theory and practice and turns the student from a “passive learner” into an “active project creator”.

This change will not only increase the efficiency of the educational process, but also play an important role in the formation of professional and social competencies of future engineers, in line with the country's digital economy strategy. Therefore, this article provides an in-depth scientific analysis of innovative methodological mechanisms for the formation of project competencies based on virtual modeling in engineering education.

Table 1.

International experience indicators of the use of virtual modeling technologies in engineering education

Country/Region	Number of higher education institutions	Percentage of technical areas using virtual modeling (%)	Share of project-based learning in curricula (%)	Student project competency assessment (1–5 points)
USA	425	78.4	64.2	4.6
South Korea	214	82.5	71.8	4.8
Germany	301	74.3	68.1	4.7
Japan	189	80.1	70.4	4.9
Uzbekistan	35	56.7	49.5	4.1

Source: Author's elaborations based on data from the OECD Digital Education Dataset (2023)

Scientific analysis of the data in Table 1 shows that the integration of virtual modeling technologies into the educational process significantly increases the quality indicators of engineering education. In international experience, this process has achieved high efficiency, especially in countries with innovative economies, such as the USA, South Korea and Japan. In these countries, the share of project-based learning is more than 70 percent, which allows students to transform their theoretical knowledge into practical design, systematic analysis and technical problem-solving skills. In the case of Germany, the integration of modeling systems with industry has strengthened the link between education and production and established the practice of testing engineering competencies in real production processes. These experiences

mean that digital modeling tools (CAD, CAM, CAE systems) have become a factor increasing the effectiveness of education not only in the educational environment, but also in the system of economic innovation.

In the context of Uzbekistan, the dynamics of the use of virtual modeling in the educational process is steadily growing, but it still lags behind the indicators of advanced countries. The fact that the share of project-based learning at the level of technical universities is 49.5 percent indicates the need to improve the methodological base in this area and increase the digital competencies of teachers. At the same time, opportunities are emerging to bring the criteria for assessing project competencies closer to the international level by introducing software packages such as SolidWorks, Inventor and Ansys into the education system in 2023–2024. Thus, the widespread introduction of virtual modeling technologies is considered an important strategic mechanism for adapting engineering education in Uzbekistan to international standards, developing students' technical thinking, digital design and practical design skills. In addition, this digital ecosystem allows for improving quality indicators in education, measuring and analyzing the effectiveness of the educational process. The seamless connection between virtual models, multimedia lesson plans, and interactive teaching aids enhances competency-based education in engineering disciplines.

Table 2.

Drawings assessment criteria disadvantages and their solutions

Drawing	Errors and shortcomings	Solution
Lines in orthogonal projection	General view drawing relative to the projection plane	Projection is a visual, virtual representation of planes, a depiction of the location of lines in a particular situation in computer graphics, and a parallel drawing on the board.
Plains in general situation	Since the idea that a plane perpendicular to a projection plane can be represented as a straight line is not enough, it is drawn by showing the surface of the plane.	To teach students to depict on the necessary format (paper) by developing students' imagination using visual, virtual displays, and computer modeling

Source: Author's developments

In technical drawing, the accuracy of assessment criteria is of great importance in developing students' spatial imagination and graphic thinking skills. However, in practice, errors in relation to projection planes, inconsistencies between views, and deficiencies in spatial perception are observed in the process of analyzing drawings. The table below systematically presents typical errors and deficiencies in the assessment criteria for drawings and the proposed solutions to eliminate them. This approach justifies the need for the widespread use of visual and virtual modeling technologies in drawing education (Table 2).

As can be seen from the table, one of the most common problems in drawing is errors in general drawing with respect to projection planes. In this case, the student, not fully understanding the real spatial location of the object, incorrectly projects the lines relative to the plane. As a result, the drawing loses its clear geometric correspondence and causes misinterpretations during analytical assessment. To eliminate this shortcoming, it is recommended to use visual and

virtual imaging technologies, through which the student will be able to see, rotate and analyze lines in three-dimensional space. This forms clear spatial thinking and geometric accuracy in drawing.

The second problem is the incorrect depiction of planes perpendicular to the projection plane. The reason for this shortcoming is that students do not have sufficient skills in visualizing spatial models. The solution proposed in the table is to organize visual training using computer modeling systems (AutoCAD, SolidWorks, etc.). This approach develops students' 3D spatial perception during the learning process, facilitates the analysis of complex drawings, and ultimately ensures the objectivity and accuracy of assessment criteria.

The results of the analysis of the criteria for assessing drawing and their shortcomings show that traditional approaches have many methodological problems in correctly reflecting lines relative to projection planes. This, in turn, is explained by the low level of spatial thinking of students and insufficient accuracy in analyzing drawings. In such conditions, it is necessary to widely introduce visual, virtual and 3D modeling technologies into the assessment process, modernize teaching methods and combine theoretical knowledge with practical skills.

This approach strengthens students' spatial imagination in drawing during the learning process, deepens graphic thinking, and prepares them to work independently in a real design environment. Thus, the implementation of virtual and digital assessment methods in drawing not only improves the quality of teaching, but also serves to form innovative competencies in the system of training personnel in technical areas.

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