# 3D VISUALIZATION AND DIGITAL MODELING IN SHAPING THE FUTURE STEM WORKFORCE

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**Abstract.** The article explores the role of 3D visualization and digital modeling in shaping future STEM professionals in the context of labor market transformation and the growing demand for highly skilled personnel. The aim of the study is to identify the role of 3D visualization and digital modeling in developing the key competencies of STEM specialists in a context of rising demand for highly qualified labor. The research employed general scientific methods of cognition: analysis and synthesis, comparison, generalization, a systems approach, and modeling. The results show that STEM technologies encompass a wide range of professions in science, technology, engineering, and mathematics, including both highly qualified scientists, engineers, and IT specialists, and middle-skilled technical personnel (STW) who apply STEM knowledge in manufacturing, service, and infrastructure processes. It was found that effective work in the STEM sector requires a set of competencies that combine specialized technical skills with critical and analytical thinking, the ability to innovate, communication, and interdisciplinary collaboration. The importance of IT literacy, computational thinking, the ability to work with digital tools, and readiness to adapt to technological changes is highlighted. The study concludes that 3D visualization and digital modeling are key tools in preparing STEM professionals, as they combine technical precision with clear presentation of complex data, enhance spatial thinking, engineering design skills, and effective teamwork communication. The integration of these technologies into the learning process strengthens other competencies, increases student engagement, and fosters readiness to work with innovative tools. The improvement of relevant skills is achieved through systematic training in specialized digital environments (PTC Onshape, Autodesk Fusion 360) combined with exercises for developing spatial abilities. The novelty of this study lies in the inclusion of the author's methodology "ImmersionED," which integrates immersive environments, gamification, AI-based adaptivity, and a project-oriented skill-based approach. Unlike traditional academic frameworks, this methodology provides accelerated acquisition of applied competencies, increased knowledge retention, and the possibility of building a professional portfolio during training. The practical value of the study lies in the potential to optimize educational programs for preparing competitive STEM professionals, taking into account modern digital technologies and innovative teaching methods.

**Keywords:** 3D visualization, digital modeling, STEM, competencies, education.

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## Introduction

In the 21st century, the demand for STEM personnel is growing at an unprecedented rate, becoming one of the key factors in countries' economic competitiveness. Highly qualified workers in science, technology, engineering, and mathematics are a strategic resource that underpins national development programs, innovation strategies, and policies for attracting talented specialists from around the world. Many countries are introducing special migration programs to attract such workers, expanding investment in STEM education, and fostering science and technology entrepreneurship, recognizing that this category of professionals determines the pace of technological progress and the level of economic resilience.

Alongside this, the requirements for STEM professionals' competencies are also increasing: today it is not enough to possess only engineering or scientific knowledge — it is essential to be able to transform complex information into accessible, clear, and compelling visual solutions. For this reason, 3D visualization and digital modeling technologies have become an integral part of the professional toolkit, enabling not only design and analysis but also effective communication of results within multidisciplinary teams and to clients. Their integration into workforce training systems creates a new level of STEM education quality and builds a competitive edge for specialists in the global labor market.

## Literature Review

The impact of 3D visualization and digital modeling on shaping the future STEM workforce is well covered in foreign academic literature. Significant contributions to the topic were made by researchers such as A. Abina [1], who, together with colleagues, examined the perspectives of companies in Slovenia and Norway on STEM students' competencies in the context of global initiatives. D.G. Dimitriu [3] proposed an innovative approach to enhancing students' spatial thinking skills, which is critically important for working with 3D models. C. Kefalis [5], in co-authorship, analyzed the results of recent empirical studies on the use of digital simulations in STEM education, providing a systematic picture of these technologies' effectiveness. Y. Li [6] and colleagues developed a virtual 3D environment to assess high school students' spatial abilities, emphasizing its potential for developing key competencies. In a meta-analytic study, D.H. Uttal [10] demonstrated the flexibility of spatial skills and their potential for targeted training.

The study also drew on expert literature, including publications from leading educational platforms and organizations such as Autodesk Fusion 360 [2], PTC Onshape [9], as well as analytical reports by UNESCO [4], the National Science Board [7], and NCSES [8], which highlight current trends, technological innovations, and labor market dynamics in the STEM sector.

Despite the abundance of literature on this subject, there is a lack of systematic material that comprehensively combines the technological, educational, and market aspects of implementing 3D visualization and digital modeling. For this reason, using various scientific cognition methods, the information was analyzed, grouped, systematized, and presented in light of the research topic.

## Methodology and Methods

The study was conducted using an integrated approach combining analysis of statistical data from the US National Science Board (NSB) and the National Center for Science and Engineering Statistics (NCSES) on the dynamics of STEM workforce development, a systematic review of academic publications [1–10], and a comparative analysis of international practices in using 3D visualization and digital modeling in professional training. Content analysis methods were applied to summarize the findings of prior studies; an analytical-descriptive method was used to form a structural profile of STEM competencies; and a systematization method was employed to classify educational technologies and tools that facilitate the development of spatial and visualization skills. The generalization of results included both empirical examples and self-training practices recommended in international educational programs.

## The Purpose of the Article

The purpose of the study is to determine the role of 3D visualization and digital modeling in developing the key competencies of STEM specialists in the context of growing demand for highly skilled labor. Within this framework, the study seeks to identify the industries and professions covered by the STEM sector; define the set of skills and abilities required for effective professional activity; analyze the significance of 3D visualization and digital modeling technologies in developing technical, analytical, and communication competencies; and develop recommendations for their independent and systematic improvement using modern digital tools.

## Research Results

The STEM workforce is a group of employed professionals engaged in science, technology, engineering, and mathematics; it includes not only scientists, engineers, and IT specialists but also skilled technical workers (STW) who may not hold a bachelor's degree but systematically apply STEM skills in manufacturing, service, and technological processes [7].

In order to clearly outline the structure of this workforce, the classification of the main occupational groups used by the National Science Board/NCSES is provided below (see Table 1).

Table 1 – Main occupational groups within the STEM workforce

| Category | Examples of occupations / fields |
|---|---|
| Science and engineering (S&E) | computer and mathematical sciences; engineering (all fields); biological, physical, and environmental sciences; social sciences (within the S&E taxonomy) |
| S&E-related occupations | healthcare (practitioners and technicians); S&E managers; S&E educators; technologists; programmers; information systems specialists |
| Skilled technical workforce (STW) | installation, maintenance, and repair (e.g., aviation technicians, electricians, HVAC); manufacturing occupations; certain construction and infrastructure occupations with high STEM knowledge intensity |

Note: systematized by the author based on sources [7,8]

As of 2025, the STEM workforce in the United States is estimated at about 40 million people, which corresponds to roughly one-quarter of the total labor force and continues its upward trend (for comparison: 2011 – 22%, 2021 – 24%). More than half of this group consists of workers without a bachelor's degree (STW), while among professionals with higher education, around 90% are employed in science and engineering (S&E) or S&E-related occupations.

During periods of economic shocks, the employment level of STEM workers declines less than in non-STEM sectors, confirming their relative resilience in the labor market [8].

Regardless of the chosen field or qualification level, all STEM professionals must possess a set of universal competencies that ensure professional effectiveness, adaptability to technological change, and the capacity for lifelong learning. As noted in studies by UNESCO [4] and Abina et al. [1], this set includes both narrowly specialized technical skills and a wide range of cognitive, communication, and innovation abilities applicable in any STEM work context. The systematic development of such competencies enables professionals not only to perform complex tasks but also to initiate change, create new solutions, and collaborate effectively in interdisciplinary teams.

Table 2 – Key competencies of STEM professionals

| Competency | Content and purpose |
|---|---|
| Cognitive skills | critical, analytical, and creative thinking; solving complex problems; scientific research; data processing and interpretation; purpose – ensuring the ability to make evidence-based decisions |
| Information and technology literacy | use of ICT, digital and media literacy, computational thinking, programming; purpose – effective application of technologies for creating and optimizing processes |
| Manipulative and technical skills | working with scientific and engineering equipment, safe and precise execution of technical operations; purpose – supporting the practical component of professional activity |
| Communication and collaboration | interpersonal skills, teamwork, presenting results, negotiation; purpose – effective interaction in multidisciplinary environments |
| Innovative and project thinking | design thinking, creativity, initiative, ability to innovate; purpose – creating new products and solutions, adapting to the challenges of the Fourth Industrial Revolution |
| Emotional intelligence and flexibility | self-control, stress resilience, tolerance, adaptability; purpose – effective work in conditions of change and uncertainty |
| Global citizenship | openness, cultural competence, environmental and social responsibility; purpose – fostering ethical and sustainable professional behavior |

Note: systematized based on [1,4]

Current trends, particularly the development of Industry 4.0 and the globalization of the labor market, create a demand for STEM workers to possess a broad interdisciplinary skill set [1]. Cognitive skills such as critical and analytical thinking are closely linked to the ability to work with large datasets, interpret research results, and build evidence-based arguments. However, today this is not enough – it is important not only to analyze data but also to present it in a clear and accessible form to ensure effective communication of results within interdisciplinary teams [4].

Information and technology literacy and computational thinking increasingly include the ability to work with modern 3D visualization and digital modeling tools. These technologies make it possible not only to create precise technical models but also to transform abstract data into visual forms that facilitate the understanding of complex information for both professionals and the general public. Manipulative and technical competencies in this context cover working with CAD software environments, virtual reality systems, and simulation platforms, which are becoming standard in the training of engineers, scientists, and designers [4].

Moreover, communication and collaboration skills combined with innovative thinking promote the joint development and presentation of visual solutions that take into account both technical precision and aesthetic aspects. Thus, the modern STEM specialist is not only an analyst and researcher but also a visualizer capable of using the latest technologies to present their work in a form understandable to diverse audiences. This underlines the importance of integrating 3D visualization and digital modeling into workforce training as tools that enhance all other competencies.

Modern STEM education is increasingly adopting digital tools, particularly 3D visualization and digital modeling, which not only improve the quality of learning but also develop a wide range of competencies critical for preparing the next generation of specialists.

As shown by a systematic review of studies [5], digital simulations, including interactive and virtual laboratories, enable students to master complex scientific concepts through interactive manipulation of variables, observation of outcomes, and hypothesis testing in a safe, controlled environment.

Interactivity plays a special role in this process, creating conditions for deep immersion in learning tasks and increasing students' behavioral, cognitive, and emotional engagement. According to [5], interactive simulations are the most common type of digital tool in STEM education, which can be explained by their high effectiveness in developing analytical thinking, spatial abilities, problem-solving skills, and critical data analysis.

The study by Li et al. [6] specifies how 3D tools implemented in inquiry-based learning environments develop key competencies. A 3D inquiry environment, developed using Unity3D with gesture interaction technology (Leap Motion), supports the development of spatial imagination, mental rotation, and object assembly skills, as well as the ability to transfer abstract geometric and scientific concepts into practical contexts. Through a step-by-step structure (posing a question, formulating hypotheses, experimenting, confirming results, and evaluating), students not only learn theoretical material but also master the scientific approach to research, which includes analysis, verification, and reflection.

Integrating 3D visualization and digital modeling into academic courses fosters the simultaneous development of technical and soft skills. Technical competencies cover proficiency in CAD tools, VR and AR environments, the ability to work with digital models, and virtual laboratories. Soft competencies, in turn, are developed through collaborative projects that involve teamwork, result presentations, and peer review.

Another important factor is the adaptability of digital simulations, which allows adjusting task complexity to students' individual abilities [5]. This creates conditions for personalized learning, where learners with different levels of preparation receive tasks corresponding to their current knowledge and cognitive capabilities. As a result, material comprehension and motivation for further learning improve.

Beyond developing academic competencies, 3D visualization equips students with readiness to work with innovative technologies, which is crucial for their future careers in STEM sectors. For example, mastering spatial thinking through working with three-dimensional models is directly linked to successful task performance in fields such as engineering, architecture, robotics, and biomedicine.

The key competencies developed through the integration of 3D visualization and digital modeling in STEM education are summarized in Table 3.

Table 3 – STEM competencies developed through 3D visualization and digital modeling

| Competency category | Examples of competencies | Development mechanisms |
|---|---|---|
| Technical | spatial imagination, mental rotation, object visualization, modeling | working with CAD, VR/AR environments, interactive 3D simulations |
| Analytical | critical thinking, problem-solving, data analysis | inquiry-based learning, variable manipulation, hypothesis testing |
| Practical | conducting virtual experiments, engineering design | virtual laboratories, simulation platforms |
| Communication and collaboration | presenting results, teamwork | joint projects in 3D environments, interactive platforms |
| Motivational and emotional | engagement, interest, self-confidence | gamification elements, immersion in VR/AR, task personalization |

Note: systematized by the author based on sources [5,6]

The development of spatial and visualization competencies in STEM fields relies on systematic training and the use of specialized digital tools. As shown by the meta-analysis [10], spatial skills are highly malleable and can be significantly improved through targeted learning. The optimal effect is achieved by combining formal academic courses, independent work in digital environments, and game-based or interactive approaches.

An important factor is intensive practice with real three-dimensional models [3]. It is recommended to use tasks involving mental rotation, assembly, and completion of objects, as well as working in virtual environments that allow manipulation of spatial forms in real time. This not only strengthens spatial imagination but also fosters the analytical thinking necessary for engineering and scientific solutions.

For independent and classroom work, it is advisable to use open or free educational CAD/CAE platforms that combine modeling and simulation:

PTC Onshape for Education – a cloud-based CAD with built-in simulation tools, available for free to students and educators. Suitable for team projects and accessible from any device via a browser [9].

Autodesk Fusion 360 for Education – an integrated CAD/CAM/CAE platform with free educational access and ready-to-use training materials. Provides the full design cycle, from 3D modeling to simulation and manufacturing [2].

Another promising direction for improving spatial and visualization competencies is the introduction of the author's methodology "ImmersionED", which is currently in the active development stage. It is oriented not toward academic disciplines but toward the development of specific professional skills that are in demand by employers. Training takes place in an automated environment, where students work with simulations, 3D models, and real-world cases while receiving instant feedback. This approach allows not only for faster knowledge acquisition but also for the creation of a practical portfolio during the learning process. The key components of this approach are presented in Table 4.

Table 4 – Structure and elements of the ImmersionED methodology

| Component | Characteristics | Expected Result |
|---|---|---|
| Immersive environment | Realistic simulations, 3D models, virtual cases | Formation of experience maximally close to professional practice |
| Gamification | Levels, missions, bonuses, interactive feedback | Increased motivation and focus, better knowledge retention |
| AI-adaptivity | Personalization of pace, complexity, and format of material presentation | Individual learning trajectory considering strengths and weaknesses |
| Project-based approach | Learning through real tasks and cases | Building a professional portfolio during the course |
| Skill-based format | Focus on skills demanded by the labor market | Practical competitiveness of graduates |

The use of this methodology integrates key technological and pedagogical innovations, combining deep immersion, adaptivity, and practicality, which makes it a powerful tool for developing 3D visualization and digital modeling competencies.

Thus, the development of 3D visualization and digital modeling skills requires a systematic approach based on research into spatial skills training [10] and pedagogical methods for enhancing three-dimensional thinking [3]. In our view, the optimal format is 3–4 training sessions per week lasting 30–60 minutes, with a gradual increase in task complexity. It is important to ensure diversity in exercises: combining work in CAD environments, mental rotation and object assembly tasks, and the use of virtual or augmented environments for deeper immersion in spatial problem-solving. Effectiveness increases when combining individual and group work: the former builds technical competence, while the latter develops teamwork skills in working with digital models. It is also important to conduct ongoing progress analysis using built-in assessment tools in modern CAD platforms, such as PTC Onshape and Autodesk Fusion 360, which track accuracy, task completion speed, and other performance indicators. The combination of scientifically grounded training methods and practical work in modern digital environments ensures sustainable growth of competencies in 3D visualization and digital modeling for STEM students [10].

## Conclusions

STEM technologies encompass a wide range of professions in science, technology, engineering, and mathematics. The STEM workforce includes both highly qualified scientists, engineers, and IT professionals, and skilled technical workers (STW) who systematically apply STEM knowledge in manufacturing, service, and infrastructure processes.

Effective professional activity in the STEM sector requires a set of competencies that combine specialized technical skills with universal abilities such as critical and analytical thinking, innovation, communication, and interdisciplinary collaboration. Information and technology literacy, computational thinking, proficiency with digital tools, and adaptability to constant technological change are also crucial components.

3D visualization and digital modeling play a key role in training STEM professionals, as they combine technical precision with clear interpretation of complex data. They contribute to the development of spatial imagination, visualization skills, engineering design abilities, and effective communication of results within a team. Integrating these tools into academic programs enhances other competencies, enables deeper engagement in the learning process, and builds readiness to work with innovative technologies in future professional activities. Improving 3D visualization and modeling skills can be achieved through systematic training in specialized digital environments, such as PTC Onshape and Autodesk Fusion 360, combined with methods for developing spatial abilities (tasks involving mental rotation, assembly, and manipulation of models).

In addition, a promising direction is the implementation of the author's methodology "ImmersionED" developed by the author of this research. It offers an immersive educational environment that integrates simulations, gamification, AI-based adaptivity, and a project-oriented approach. Unlike traditional academic frameworks, ImmersionED is focused on skill-based learning aligned with labor market demands. This methodology enables accelerated acquisition of applied competencies, the creation of a professional portfolio during training, and a significant increase in knowledge retention. Therefore, it represents an innovative and effective tool for enhancing 3D visualization and digital modeling competencies in STEM education.

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