Features of engineering thinking development by means of 3D technologies

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Abstract. The problem that the study is aimed at is due to the need to create a special engineering style of thinking within the digital learning space, which implies a willingness to research, creativity, responsibility, intellectual skills, and supported by modern high-tech tools to provide resources for solving the problems of formation of Industry 4.0. The purpose of the study is to identify the features of the use of 3D technology for the formation of engineering thinking, as an important competence of the in-demand specialist in the digital society. The methodology is based on theoretical and methodological analysis and generalization of fundamental scientific works, the significance of which in the field of digitalization of education, training of engineering and technical personnel, three-dimensional modeling, application of software for the development of thinking, is recognized by the scientific community. The paper specifies the essence of the concept of “engineering thinking” precisely in the context of training specialists for Industry 4.0 and substantiates the potential of 3D-technologies for the formation of engineering thinking as an essential skill of in-demand professionals of the future. The authors formulate the principles and directions of support by the mentor of the research activities of students in 3D modeling. The system of work on an interdisciplinary project with the allocation of skills significant for the formation of engineering thinking is presented. In conclusion, the features of the formation of engineering thinking by means of 3D technologies are summarized in the process of the entire learning path from preschool education to professional retraining.

1. Introduction
Ensuring the innovative development of the country, supporting the use of automated devices in various activities is an actual direction of modernization of science and education. The essence of digitalization of education in the context of the formation of Industry 4.0 is to effectively and flexibly apply the latest technologies to the transition to a personality-oriented, continuous and non-linear educational process. The digital era requires not only new skills from graduates of schools and universities, but also a different approach to organizing the training itself in terms of training engineering personnel. Under these conditions, domestic and foreign researchers substantiate that the didactic process in the era of
automation and globalization should be focused on solving the problems of the country’s socio-economic development in the context of the formation of Industry 4.0.

As B. Ranger and A. Mantzavinou A [1] notes, the basis of the digital economy is a synthesis of previously existing material production and digital technologies, supporting the widespread use of artificial intelligence models and the development of the Internet of things. According to R. E. Paterson [2], “smart products” will be the norm in a world where intelligent computerized devices (robots), the systems consisting of them, get the opportunity to interact in the preparation and deployment of automated production processes.

The nature of the new industrial, or technological (digital) revolution makes special demands on the highly qualified specialists of the future. E. V. Soboleva et al. reasonably conclude that in the educational space the priority is the task of preparing an independent personality through the formation of high-order thinking, including engineering [3]. Engineering thinking in the new conditions of Industry 4.0 is perceived and interpreted as a specific form of active reflection of the morphological and functional relationships of the subject structures of practice, aimed at meeting the technical needs for knowledge, methods, techniques, with the aim of creating technical means and organization of technologies.

The digital transformation of the manufacturing sector is already underway. However, in the implementation of technological innovations problems arise due to insufficient training in terms of the formation of engineering thinking, which is based on the ability to analyze the composition, structure and operation principles of technical objects under new conditions. There is a practical need to change the principles of organizing a digital educational environment for the development of engineering thinking among professionals of the future. The indicated need implies the integration of new technical means into real projects, their advancing science and industry. In this regard, work on the potential of 3D modeling tools and technologies in terms of training engineers of the future is becoming relevant [4]. Support for engineering education is one of the strategic priorities of the development of Russia, for the solution of which engineering classes are being created, physics and robotics laboratories, 3D-modeling and prototyping workshops are being developed. By combining educational and extracurricular work, supporting students in the construction of 3D devices not only for an educational project, but also for professional self-determination, participation in competitions, a digital school teacher gets additional opportunities for developing their engineering thinking skills.

So, the goal of the work is to study the characteristics of the organization of training in a digital educational environment through attracting students to project activities in 3D modeling to form engineering thinking as a universal skill of the in-demand professional of the future.

2. Materials and methods

Research results of T.-Ch. Huang, M.-Y. Chen, Ch.-Y. Lin revealed the didactic capabilities of 3D technology [5]. When specifying the essence of “engineering thinking”, identifying its characteristics, features of manifestation, the conclusions were taken into account A. Rozhik A [6]. Appeal to materials E. V. Soboleva and N. L. Karavaev [7] revealed that three-dimensional modeling has a complex structure: it is a holistic result of many branched processes and should be considered in the unity of all their aspects. The core of 3D object modeling activity is specific engineering thinking that supports all stages of the development and implementation of projects / prototypes, ensuring their quality and productive practical application.

When studying the methodological aspects of using 3D technologies in the educational space for the development of engineering thinking, practical methods were used to describe, characterize, analyze the methods, means, forms of organization and control used; systematization and generalization of ideas and patterns, principles of didactics in teaching. A generalization of the A. Szymanski’s conclusions [8] contributed to the substantiation of the conclusion that, for the formation of engineering thinking, research experience and modeling practice in the field of modern science are effective didactic tools. The basis for the innovative activity of students in the development of 3D-projects adopted position that
there is no intellectual development without designing an appropriate educational space, without planning cognitive activity [9].

The object of the study is the technology of three-dimensional modeling. In the course of work, 3D technology tools (3D pens, 3D printers), 3D modeling environments (Blender, 3DSlash, SketchUp, Paint 3D), MS Office resources for presenting data, LEGO Mindstorms EV3 educational constructor tools, programming environment for Arduino-based controllers are used.

3. Results
The formation of Industry 4.0 defines the adoption of new business models, according to which the "factories of the future" will work. These are enterprises capable of providing a fundamentally new level of productivity and competitiveness. Such a strong impulse will be possible thanks to digital technologies that can process huge amounts of data and comprehensively manage production processes, from design and manufacturing to logistics and technical support for the product. Nowadays the requirements for technical professions related to industrial production are changing, they are rethinking the tasks of specialists who are to work at "smart" factories or conduct scientific research. Therefore, the school has a crucial task - to give future engineers, technologists, designers sufficiently deep knowledge and practical skills in the field of the latest technologies so that they enter the digital world fully equipped.

Also note that scientists in their studies, by the term “engineer of the future” consider a specialist who has a high culture, is well aware of modern technology and technology, economics and organization of production, knows how to use engineering methods to solve problems of Industry 4.0. In all the variety of approaches to the study of the formation of engineering thinking of a student, who consider its development using special conditions or using modern teaching technologies, there is no strategy for organizing specially directed activities. The main task of the modern education of an engineer of the future is not just the transfer of experience and knowledge, but the preparation of a competent specialist capable of self-development and self-realization, able to solve non-standard tasks, predict the outcome of future activities and focus on universal values. Summarizing all the approaches considered, we conclude that the concept of “engineering thinking” embraces the thought process leading to the solution of interdisciplinary engineering problems, the generation of creative ideas, innovations, and design projects.

An important result of the work for the study is the justification of the need for the practice of implementing projects in 3D format for the training of engineers of the future. T. N. Suvorova and E. A. Mikhlyakova present an interdisciplinary approach that integrates 3D modeling methods and tools in the educational process [4]. Developing their ideas, we conclude that work in 3D spaces is also necessary for the design of cyberphysical devices and the achievement of innovations in science and technology. We believe that this approach to design is very effective for strengthening intersubject communications, forming the foundations of constructive activity. A. I. Benzer and B. Yildiz prove that computer 3D-modeling, as one of the innovative digital technologies, can provide great opportunities for the formation of demanded skills of students [10]. In their works, the hypothesis about the influence of 3D technology on imagination, preparation for professional self-realization attracts attention. In practice, the didactic capabilities of 3D modeling are used to develop spatial thinking [9]. Huang T-Ch, Chen M-Y, Lin Ch-Y [5] note that with the development of 3D technology, 3D printers are also being introduced into education as a means of learning and teaching. In addition, students get the opportunity to observe and physically respond to the model, thereby improving the quality of design and understanding. Developing their ideas, we highlight the capabilities of 3D printing for the formation of an innovative type of thinking (3D thinking), as well as the advantages of using 3D printing resources in the educational process [5]. Next, we describe the principles that determine the content of research activities of students in 3D-modeling, contributing to the formation of engineering thinking.

The principle of the necessity to analyze the requirements of science and industry for the engineering and technical personnel of the future. In industries, it is possible to choose the materials that are best suited to solve specific problems of Industry 4.0 (functional prototypes or mass production). A new
scientific problem is likely to arise: there will be a need to standardize materials and improve equipment management, especially in industries with high quality requirements, such as the aerospace industry and the manufacture of medical devices. In these conditions, scope of application are becoming the focus rather than technology. In preparing the engineer of the future, projects that involve the use of 3D technology for profit in specific areas should be implemented.

The principle of competition, involving the inclusion of students in competitive activities in 3D-modeling, robotics. The implementation of the principle offers participation in seminars, competitions, research laboratories. It is these organizational forms of training for engineers of the future that are focused on the training of specialists who can think outside the box in the face of the uncertain future and work as a team.

The principle of consideration and activation of intersubject connections, involving the implementation of the interdisciplinary didactic potential of three-dimensional modeling activities to form professional skills and foundations of engineering thinking.

The principle of training through solving a system of practice-oriented tasks, the key idea of which is that the concept of “task” can be interpreted quite widely. In this case, the activity of 3D-modeling is presented as a process of resolving contradictions between the proposed course of study, cognitive and practical tasks and the level of formation of engineering thinking and acquired universal skills. The essence of applying the proposed approach to support the development of engineering thinking is that the acquisition of new knowledge in solving a technical problem is directed by the teacher through a system of specially selected tasks.

The principle of continuity between the levels of training of engineering and technical personnel (software, technology, methodological training system) suggests that the chain of cognitive tasks that supports the knowledge and formation of engineering thinking takes into account the educational results of students at all levels and stages of education. For example, in a preschool institution, a child masters a 3D pen and thanks to it develops fine motor skills; in the school course, the student receives 3D modeling skills; competitive activity allows you to organize the practice of working with 3D printers to present projects; the learning environment at the university develops universal competencies (collaborations, project activities, programming and work in the face of uncertainty, etc.) and personality traits that form the basis of engineering thinking.

At the same time, the range of software and digital technologies studied in the modern digital educational space is so wide and diverse that it is not always useful for training an engineer of the future. Indeed, the requirements of Industry 4.0 determine that a technician must be able to take on the functions of a designer, marketer, etc. Working with 3D technology just allows you to get this unique experience.

In the course of team work on an interdisciplinary project on 3D modeling, a participant in the framework can change from the role of an idea generator, designer to the role of a programmer, mechanic, etc. A digital school mentor is required to organize appropriate support and create the conditions for the development of engineering thinking.

The principle of practical application of the obtained prototypes, 3D-models in related promising industries (virtual and augmented reality, neuro-formation).

New training tools, such as the Leica BLK360 compact ground-based 3D laser scanner, provide a virtual 3D model of the school for efficient building lifecycle management (from design to operation), work in an information modeling environment (BIM technology), preservation of cultural heritage and restoration. The resulting 3D models can be used to organize training sessions in a virtual reality environment as independent objects for subsequent engineering activities.

We will reveal the implementation of these principles using an example of a description of the directions of pedagogical support for the development of a prototype of a smart frying pan that does not allow the decomposition of the Teflon layer. The practical problem that the project solves is determined by the following scientific fact: “When the fluoroplastic overheats (even once), thermal decomposition occurs with the release of toxic substances. Cookware with non-stick coatings is considered safe during normal use. Manufacturers consider the norm only heating with water or oil in a pan. The lack of a device for controlling and preventing overheating of pans and other similar utensils leads to overheating
of products, premature failure of them, and the release of toxic substances. "Description of the project content: the basic requirement is not to change the essence of the base product (pans), i.e. externally, functionally, etc. the pan should remain with her. It can be cooked, it can be washed, including in the dishwasher, it should not be “tied with wires”. If the temperature of the pan is determined, then it will be possible to modernize the stove, making it more convenient (quick heating of dishes and its contents to the required temperature, maintaining the temperature at a certain level, etc.). The cooking process will become safer. The dishes will become more durable, which will lead to savings in the family budget, more environmentally friendly (due to the absence of toxic emissions), more economical in terms of energy costs for cooking.

Educational result: a model of a "smart frying pan" implemented by various means of 3D technology.

Commercial result: a frying pan with a temperature indicator, as well as with an automatic device that does not allow heating above a given temperature.

The interdisciplinary nature of the project involves interaction with the customer; knowledge of the unique material used in high technology industries - fluoroplastic (properties, features, processing); knowledge of the physics of heat transfer (heating, heat sources, types of heat transfer); temperature measurement (means, features, contact and non-contact method); selection skills of primary measuring instruments (sensors); design of coordination circuits with microcontrollers; programming, regulators (integral, PID); engineering skills: drawing, modeling, circuitry; materials processing (mechanical milling, manufacturing of cases, soldering, etc.); testing (preparation, plan, implementation, processing of results).

Stages of work on a project organized by a teacher in order to form engineering thinking:

- I stage. Field problems and forecasting development options. Representation of a problem situation in the form of a physical and engineering constraint (response to an existing need). Analysis of the social significance of the project, generation and discussion of methods for its solution and the possibility of achieving an ideal end result for consumers.
- II stage. Multivariate analysis of a problem situation: studying the possibility of introducing a device into operation, minimizing resource costs.
- III stage. Circuit assembly: sequencing and connecting components.
- IV stage. Assembly of the structure. Making of the case.
- V stage. Application development. Testing the operation of the device in different operating modes.
- VI stage. Design solution. Testing the operation of the device in different operating modes.
- VII stage. Engineering book for design solutions. Preparation of speeches and presentations based on the results of work on the project. Reflection. Discussion of the project results.

The functions that an engineer of the future can carry out within the framework of the project are: a mechanic (designing in 3D, 3D printing, creating simple mechanisms), a programmer (initial skills in programming Arduino-based controllers), an electrician (assembling devices, soldering, connecting sensors), a project manager (organization of interaction, correspondence, maintaining a schedule, reporting results).

4. Conclusion
For the successful implementation of the proposed areas and the use of 3D technology in the formation of engineering thinking, it is recommended to adhere to a set of conditions, which include: building the educational process based on the integration of fundamental scientific theories and software / digital technologies; implementation of interdisciplinary research tasks of a problematic nature with a focus on the challenges of Industry 4.0; actualization of the needs of students in obtaining an in-demand profession of the future through the practice of 3D modeling activities, collaboration. When forming engineering thinking using 3D technology, it should be taken into account that the corresponding activity
involves the integration of innovative, technical, economic and constructive components [2]. Distinctive features of the “engineer of the future” are:

- the ability to see the structure where it is not visible to people without engineering thinking;
- the ability to be effective in conditions of restrictions that can be determined by nature (climate, physical laws, resistance of materials) or by a person (human behavior, constitution, finances);
- the ability to identify priorities in the project and efficiently allocate resources.

The results can be used to improve the quality of teaching 3D modeling in a digital school due to specially organized areas of support for creative, intersectoral, cognitive research activities of students, focused on the development of engineering thinking, and carried out in the conditions of training for the formation of Industry 4.0.

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