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Моделирование в среде трехмерной графики как метод формирования критического мышления обучающихся

Проблема и цель. Формирование критического мышления – одна из важнейших задач, которые стоят перед педагогами в системе профессионального образования. Сложность, многогранность изучаемых объектов, явлений и процессов действительности ставят наставников цифровой школы перед необходимостью искать универсальные методы познания. Авторы предлагают для формирования критического мышления как важного навыка, соответствующего вызовам глобализации и трансформации, использовать метод моделирования в средах трехмерной графики.

Методы исследования. Основным методом является моделирование, как общенаучный метод изучения явлений действительности с помощью аналогии между моделью и оригиналом. Исследование проведено на базе Вятского государственного университета для студентов по направлению подготовки 44.04.01 Педагогическое образование. Информатизация образования (уровень магистратуры). Программным средством для организации моделирования как метода обучения и научного познания является SketchUp. В качестве метода статистической обработки данных эксперимента использовался критерий χ^2 (хи-квадрат) Пирсона.

Результаты. В экспериментальной группе обучающиеся применяли моделирование в среде трехмерной графики на этапах: получения теоретической информации об объекте-оригинале, создания модели-заместителя, разработки системы исследовательских задач, рефлексии, проверки и корректировки полученных результатов в условиях объекта-оригинала, формулировании качественно нового знания. Произведена оценка уровней сформированности критического мышления и выявлены статистически достоверные различия о качественных изменениях, произошедших в педагогической системе, $\chi^2_{\text{набл. 2}} > \chi^2_{\text{крит0.05}}$ ($6,42 > 5,99$).

В заключение обобщаются условия, при которых трехмерное моделирование способствует развитию базовых свойств, обеспечивающих формирование критического мышления: применение вместе с другими методами научного познания; моделирование не только в программной среде для создания 3D-проекта, но и разработка Инструкции как модели для его практического применения; получение качественно нового знания и т.п.

Ключевые слова: научное познание, 3D-проект, модель, критическое мышление, востребованный специалист будущего, цифровая экономика, проект

Ссылка для цитирования:

Мамаева Е. А., Исупова Н. И., Машарова Т. В., Векуа Н. Н. Моделирование в среде трехмерной графики как метод формирования критического мышления обучающихся // Перспективы науки и образования. 2021. № 2 (50). С. 431-446. doi: 10.32744/pse.2021.2.30

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Modeling in the environment of three-dimensional graphics as a method of forming students' critical thinking

The problem and the aim of the study. The formation of critical thinking is one of the most important tasks that teachers face in the vocational education system. The complexity, versatility of the studied objects, phenomena and processes of reality make it necessary for the mentors of the digital school to look for universal methods of cognition. The authors propose to use the modeling method in 3D graphics environments to form critical thinking as an important skill that meets the challenges of globalization and transformation.

Research methods. The main method is modeling, as a general scientific method for studying the phenomena of reality using the analogy between the model and the original. The research was carried out on the basis of Vyatka State University for students of the training programme 44.04.01 Pedagogical education, profile Informatization of Education (master degree level). A software tool for organizing modeling as a method of teaching and scientific cognition is SketchUp. The Pearson's χ^2 (chi-square) criterion was used as a method for statistical processing of the experimental data.

Results. The students of the experimental group used modeling in the environment of three-dimensional graphics at the following stages: acquiring theoretical information about the original object, creating a substitute model, developing a system of research problems, reflection, checking and adjusting the results in the conditions of the original object, the statement of a qualitatively new knowledge. The assessment of the levels of formation of critical thinking was carried out and statistically significant differences in the qualitative changes that occurred in the pedagogical system were revealed, $\chi^2_{\text{emp.2}} > \chi^2_{\text{crit0.05}}$ ($6.42 > 5.99$).

In conclusion, the conditions under which three-dimensional modeling contributes to the development of basic properties that ensure the formation of critical thinking are generalized: application together with other methods of scientific knowledge; modeling not only in a software environment for creating a 3D project, but also developing an Instruction as a model for its practical application; obtaining qualitatively new knowledge, etc.

Keywords: scientific knowledge, 3D-project, model, critical thinking, in-demand professional of the future, digital economy, project

For Reference:

Mamaeva, E. A., Isupova, N. I., Masharova, T. V., & Vekua, N. N. (2021). Modeling in the environment of three-dimensional graphics as a method of forming students' critical thinking. *Perspektivy nauki i obrazovaniya – Perspectives of Science and Education*, 50 (2), 431-446. doi: 10.32744/pse.2021.2.30

Introduction

Justifying the relevance of the presented study, we highlight the following factors:

1. The Federal State Educational Standard of Higher Education (hereunder referred to FSES HE) has defined systemic and critical thinking as an important universal competence that must be mastered by all university students, regardless of the direction of training [1]. Critical thinking, as noted by M. V. Solodikhina, A. A. Solodikhina [2], in the new conditions of digital transformation is perceived and interpreted as long-term thinking. A person who thinks long-term must be able to reason, analyze, synthesize and evaluate external information, and then use it in practice to formulate conclusions and make decisions in the face of uncertainty of the future. However, despite the requirements of the development of relevant skills and character traits, recommendations on specific methods and tools that allow them to be most effectively developed in the context of e-education are still not enough [3].

2. In science, there is a transition from the analysis of particular problems to the analysis of general ones, which leads to the universalization of the methods of cognition. This has a great impact on the development of the educational system. Modeling, as shown by E. V. Sinyavskaya [4], is just one of such universal methods of scientific cognition. R. E. Paterson argues that it is modeling as a method-action that allows you to create the basis for the correct choice of strategies for development, improvement and innovation [5].

3. The didactic capabilities of computer graphics for visualization of educational material have been substantiated and actively applied in practice. In particular, I. D. Stolbova, E. P. Aleksandrova, L. V. Kochurova, K. G. Nosov prove that spatial demonstration materials are of great help in the perception and understanding of the topic under consideration. Scientists point out that the most effective visual presentation of information is three-dimensional graphics [6]. The display of three-dimensional models ensures the greatest efficiency of students' perception of the material presented, contributes to the development of their spatial thinking [7].

From an industrial point of view, 3D models are an indispensable element in the design of modern vehicles, interiors, architectural models, etc. E. Ya. Varshavskaya, E. S. Kotyrlo emphasize that works on the potential of modeling in terms of training the demanded specialists of the future are becoming relevant [8]. Moreover, educators-innovators offer educational projects for the formation of certain types of thinking (engineering, systemic) [9].

Information modeling issues are considered in the research of many modern scientists, however, priority, as for example in the works of I. Damyanov, N. Tsankov [10], is given to three-dimensional modeling as an activity; as a means for the development of cognitive activity, perception, imagination, etc.

Therefore, the use of 3D (three-dimensional) models of real objects can not only serve as an excellent illustration when conducting reports and presentations. The three-dimensional model is an important means of conveying information that can significantly improve the effectiveness of training. The ability to build a three-dimensional model becomes an essential skill for everyone who plans to use information technology in their professional activities. And the use of modeling as a universal method of cognition determines additional potential for the formation of competencies that are in demand in a digital society.

Thus, a practical need arises:

- changes in the organization of educational activities by a teacher focused on the development of critical thinking in professionals of the future;
- active application of the modeling method in 3D graphics environments for integrating sustainable development goals into real projects, promoting them in science and industry.

By guiding students in modeling, experimenting and creativity, a digital school teacher gets additional opportunities to develop their critical thinking skills. The use of the modeling method not only supports learning, knowledge in a higher educational institution, but also prepares for successful professional activities, contributes to self-determination. In the process of multi-stage creative activity, students have to apply knowledge from various fields, interdisciplinary communication skills; the ability to predict, compare, analyze, evaluate and make decisions.

So, the purpose of the work is to study the possibilities of cognitive modeling in 3D environments for the formation of critical thinking as a universal skill of the demanded professional of the future.

Hypothesis of the research: the inclusion of students in modeling activities in 3D graphics environments will improve the quality of teaching in terms of the formation of skills and abilities that form the basis of critical thinking.

Materials and methods

The authors used the following methods: theoretical analysis and generalization of scientific literature on the formation of critical thinking; the use of three-dimensional graphics in teaching; didactic potential of computer modeling in the conditions of training professionals of the future. The provisions of the project "Digital Economy" [11], the Strategy for Developing the Information Technology Sector in the Russian Federation in 2014–2020 and until 2025"[12], the Federal State Educational Standard were studied. Based on these provisions, the importance of three-dimensional modeling skills, critical thinking in the soft skills system was substantiated as the basis for the introduction of innovations for the digital economy.

The main research method is modeling, as a scientific method for studying the phenomena of reality using the analogy between the model and the original.

A 3D model is viewed as a digital file of an object created by a software. A 3D model is used to replace the original in a thought experiment, to create ideas about the object under study, to simplify understanding of the essence of a phenomenon or process, to reflect the interpretation of an object by a specific researcher.

Within the framework of the work, the scientific position is taken as a basis that critical thinking is reflexive in nature. Under the critical thinking of a specialist trained in a digital educational environment, we mean a set of qualities and skills that determine a high level of research culture, as well as "evaluative, reflective thinking", for which knowledge is not the final, but the starting point, reasoned and logical thinking, which based on personal experience and proven facts". Thus, the assessment of critical thinking will make it possible to draw an objective conclusion about the development of reflection. Reflection cannot be formed at a level that meets the requirements of the digital economy if the student does not know how to correctly build reasoning and evidence, argue his points, make inferences,

evaluate information resources, arguments of team members, etc. In other words, evaluating the qualities and skills that form the basis of critical thinking, one can get an idea of the formation of this high-order skill as the competence of the economy of the future.

The empirical methods (observation, analysis of the results of three-dimensional modeling) were used to obtain relevant information about the formation of skills and abilities that form the basis of critical thinking of students. These methods made it possible to obtain information about real changes in reflection, motivation, involvement in a problem situation, activation of students' cognition, the formation of research skills and independent work as important skills for preparing for a successful professional activity.

The experimental study was organized on the basis of Vyatka State University within the framework of teaching the discipline "Innovative technologies and methods of electronic education". The sample consisted of 42 students in the field of study 44.04.01 Pedagogical education, profile Informatization of Education (master degree level). The average age of the respondents was 26 years (68% of girls and 32% of boys).

A software tool for organizing modeling as a method of teaching and scientific cognition is SketchUp. This computer program is designed to perform 3D graphics, interior architecture, objects and drawings in the shortest possible time. The advantage of the environment is an accessible, user-friendly interface. In this system, you can create and drawings, and sketches, and realistic renderings.

The Pearson χ^2 (chi-square) test was used as a method of statistical processing.

Literature review

The complexity and versatility of cognizable objects of reality challenges scientists to look for special ways to understand the essence of the phenomena, processes of a society under trends in automation and globalization. Therefore, studies aimed at identifying and developing tools that contribute to the development of critical thinking are of particular interest in pedagogy and informatization of education. S. D. Karakozov, N. I. Ryzhova [13] determine that the digital economy makes a request for the education system regarding the training of professionals who not only have theoretical knowledge, but also know how to apply it in the uncertain future.

After the expansion of the Internet into everyday life, the massive use of smartphones and other communication devices, as N. V. Ronzhina shows [14], critical thinking began to play a particularly important role in the training of in-demand personnel to achieve the goals of global digital transformation. It is the ability to critically assess information resources that allows people to make the right decisions in their careers, personal and public life [15].

For example, I. A. Shcheglova, Yu. N. Koreshnikova, O. A. Parshina clarify that in the digital educational space, the priority is to prepare an independent personality through the formation of high-order thinking, including critical thinking [16]. E. Ya. Varshavskaya, E. S. Kotyrlo conclude that the presence of critical thinking is one of the key requirements for candidates in employment [8].

The didactic possibilities of innovative e-learning technologies (mobile applications, interactive services, gamification resources, etc.) are multilaterally investigated and proven. The potential of a digital school for training modern specialists, supporting their cognitive activity in solving practical-oriented, professional tasks is described in the work of E. V. Soboleva, N. L. Karavaev [9].

One of the innovative educational information technologies, according to P. Jääskelä, S. Nykänen, P. Tynjälä [17], is three-dimensional modeling. The use of 3D modeling in education stimulates students' interest in acquiring knowledge, develops spatial thinking and imagination, and increases the creative potential of an individual. Consequently, the technology of three-dimensional modeling can be applied in completely different educational subject disciplines [18].

A. I. Benzer, B. Yildiz consider in detail the features of modeling as an activity in the study of graphic disciplines [19]. In the presented materials, spatial objects are projected onto a plane to create optimal geometric shapes for mechanical engineering, architecture and construction objects. Scientists believe that it is necessary to learn how to depict spatial geometric objects on a plane, and vice versa – to restore the position of a three-dimensional original in space using a given drawing. According to I. D. Stolbov, E. P. Aleksandrov, L. V. Kochurov, K. G. Nosov, showing electronic slides with three-dimensional models will also contribute to an increase in students' awareness of the display of various spatial objects on a plane [6]. M. Chugunov, I. N. Polunina agree with their conclusions that information technologies accompany almost all areas of human activity, and substantiate in this regard the importance of including the practice of using three-dimensional graphics in the training of in-demand specialists of the future [20].

H. Mykhailyshyn, O. Kondur, L. Serman emphasize the potential of 3D modeling technologies to support cognitive activity, curiosity, creativity. In addition, they believe that the use of computer graphics will contribute to the implementation of the principles of an interdisciplinary approach to learning, the formation of communication skills [21]. A. A. Salamatov, D. S. Gordeeva note that the use of modeling in a university teaching should be not only innovative, emotionally attractive for students, but also take into account the specifics of their training [22].

A. I. Benzer, B. Yildiz [19] conducted a large-scale study that proved that 3D modeling activities improve the quality of knowledge, promote cognitive motivation, support reflection, and the ability to think non-stereotypically in relation to professional activity.

That is why the skill of critical thinking is singled out by Y. Koreshnikova [23] as one of the universal skills of demanded specialists of a “new” generation, the formation of which requires special support from teachers. According to N. J. McCormick, L. M. Clark, J. M. Raines [24], the skills that form the basis of critical thinking are most effectively developed through model design and development.

Analyzing the works of foreign scientists in terms of high-quality training of in-demand specialists, we note the achievements of G. Ozogul, C. F. Miller, M. Reisslein [7], which also indicate the importance of design activities in modeling. Their research emphasizes that three-dimensional modeling has a powerful toolkit for active cognitive work during the development and research of the model using specific digital technologies.

Thus, the modern model of the digital economy forces people to think strategically and focus on the future, new norms and ethics of behavior appear, which opens up wide opportunities for planning a strategy for professional activity. In the context of digital transformation, the implementation of these requirements must be supported not only by software tools, but also by specially organized work on the part of the teacher in preparing the graduates [25]. Critical thinking should be viewed as an important universal skill that can and should be taught through modeling not only as an activity, as a way to stimulate interest, but also as a method of cognition.

As options for supporting modeling activities in the analyzed studies, it is proposed to use the development of mobile applications, cyber-physical systems, engineering prototypes, educational projects by means of innovative technologies. Modeling in 3D graphics environments is reasonably noted as one of these. It is the application of the modeling method that becomes an important condition for the formation of critical thinking in future specialists. This method is a tool for searching and processing information for making decisions, discovering patterns, analogues, independently setting problems, finding optimal solutions.

Research program

As part of the experiment, a systematic educational work in the environment of three-dimensional graphics was organized to study objects of various nature, to obtain qualitatively new knowledge. At all stages of cognitive activity (from goal-setting, the choice of means and methods of action, the implementation of the intended goal and tasks setting, to the analysis and assessment of the result obtained), the modeling method was used as a universal method of cognition. The main purpose of the experiment was to test the interdisciplinary didactic potential of the modeling method in the environment of three-dimensional graphics for the development of critical thinking, professional skills in the field of innovative e-learning technologies.

At the preparatory stage of the experiment, a list of skills was selected, which were subsequently assessed, and tasks corresponding to this set were developed. Further, entrance testing was carried out among the participants. Questions for measurement before the experiment, as in the case after, were constructed taking into account Bloom's classification [16]. According to this classification, critical thinking is formed through the development of six fundamental processes of information synthesis: memorization, understanding, application, analysis, evaluation and creation. Based on this provision, 5 types of questions were formulated (each type was included in the test twice for more precise control): a question for formulating an inference and its assessment; a question to compare two or more objects; a question to search for information necessary to resolve a problem situation; a question for a reflective assessment of the reliability and content of the source; the question of finding the main information against the background of redundant information. Thus, both versions of the test consisted of 10 tasks, each of which was rated at 2 points.

To fulfill the rules for probabilistic selection of subjects, the same instructor used the SketchUp 3D environment for modeling throughout the experiment. To assess the input conditions, we used test materials compiled in accordance with the requirements of state federal educational standards. Let us give an example of tasks for finding main information (task 1), for working with sets of objects (task 2), for evaluating information (task 3).

Task 1. Imagine that during the year you have accumulated a sufficient amount of funds for a holiday abroad. In order to spend less time traveling to your destination, you have decided to use an airplane. You have found a specific flight time and a specific plane. Determine what objects and their properties you need when choosing a place (underline the correct answers): the travel class (business or standard); the airplane wingspan; the aircraft number; the graphic representation of the plane with the indication of free and occupied seats; the name of the airline providing air passenger services; the number of

pilots; the number of seats in the plane; the time spent on the flight; the number of free seats; the number of occupied seats.

Task 2. Compare the object of the real world with its possible information models.

Object: Construction company, Cat, Saturn, Country house, Patient of the clinic, Flower, Chemical element, Kirov.

Information model: Verbal description of the plant, House plan, Review on the official website, Animal photo, Mendeleev's table, Globe, City map, Medical card

Task 3. On the model, a diagram of roads connecting cities A, B, C, D, E, F, G, H, I, J, where A is the Lepse square, and J is the railway station. On each road, you can only move in one direction, indicated by the arrow. How many different routes are there to get from Lepse square to the railway station?

When processing and interpreting test results, the level of formation of skills that form the basis of critical thinking was determined according to the following scale: the high level – if the student scored more than 18 points; the average level – if the student gains from 9 to 17 points; the low level - if the student gets less than 8 points.

The high level: the student correctly applied the terminology; independently analyzed the modeling object based on deep knowledge; knew theories, concepts, functional capabilities of the environment and gave them a critical assessment; showed elements of scientific knowledge in his work; clearly outlined the goals and objectives of modeling; logically, consistently and reasonably argued his statements and the choice of the environment functionality; competently, correctly and comprehensively answered all additional questions; did not make mistakes in the technical presentation of the results.

The average level: the student knew scientific terminology; mastered the functionality of the 3D graphics environment, but did not use it effectively in all situations; knew the main theories, concepts, but could not give them a critical assessment; in most of his work, he showed elements of scientific knowledge; adhered to the goals and objectives set by the teacher in modeling; he could not always prove his decision with arguments; demonstrated skills of creative independent thinking; competently, logically and correctly answered most of the additional questions; made one or two non-critical errors in the technical presentation of the simulation results.

The low level: the student showed an insufficient volume of concepts, knowledge from the field of computer science, cybernetics, etc .; used terminology, but could not always answer additional questions on the model; did not know how to navigate the basic theories, concepts and functionality of the environment; made meaningful mistakes in modeling; could not reason for his decisions; could build a simple inference during research, but did not cope with the tasks for building a series of inferences; when formalizing the simulation results, he made technical errors.

Thus, it was possible to select 42 undergraduates, of which the control (21 students) and experimental (21 students) groups were formed.

The second stage is devoted to determining the directions of improving the forms of support for the cognitive activity of students in modeling in the environment of three-dimensional graphics. The need was identified for the application of the modeling method as a universal method of cognition, which will contribute to the formation of critical thinking. In addition, through 3D modeling activities, the quality of vocational education in innovative technologies and e-learning methods will increase.

The third stage of the research is the organization of educational and cognitive activities of students by modeling the resources of the selected software environment.

Research results

The activity of a mentor when using the modeling method as a method of cognition in the environment of three-dimensional graphics includes the following stages (methodological component):

- 1) communication of fundamental theoretical information for the accumulation of information about the original object;
- 2) the organization of practice-oriented activities for the systematization of the data obtained in order to identify the essential information necessary for the construction of a substitute object, that is, a model;
- 3) development of a system of cognitive tasks, the solution of which requires the study of the model;
- 4) the development of a system of cognitive tasks, which means the completion of the study of the model;
- 5) organization of practice-oriented activities to check and correct the results obtained during the study of the model in the conditions of the original object.

The stages of a teacher's activity must take into account the following principles: the need to identify those characteristics of the original object that require study or improvement; selection of available methods for building a model object; predicting actions, which involves checking the information obtained on the model in the conditions of the original object, as well as the corresponding correction of the conclusions.

Next, we will describe the content of the mentor's activities to study the basic functionality of the SketchUp software environment. Here, it is important to take into account the principles and stages for applying the modeling method as a scientific method of cognition. To confirm that the modeling method is actually universal, consider some tasks from the sequence of actions for creating a 3D model from a 2D drawing.

Select and delete all unnecessary objects in the workspace. Using the Rectangle tool, create a rectangle with one of its vertices at the origin. Methodological emphasis: unnecessary - unimportant from the point of view of modeling.

Go to the main SketchUp for Web menu and click on the "Insert" button. Insert the floor plan into your workspace. Next, you need to place one end of the image at the origin, and the other - to stretch to the opposite side of the rectangle. Methodological emphasis: work with the interface, methods of action is checked.

Select the Roulette tool and use it to determine if the dimensions in the drawing match the actual dimensions in the application. If not, then after determining the second roulette knot. One knot is the middle of one wall, the second knot is the middle of another wall. Specify the dimensions shown in the drawing immediately. Methodological emphasis: work with the interface, methods of action is checked. In addition, there is a comparison of the substitute model and the original model.

Check if the dimensions have changed. If they again differ from the dimensions in the drawing, then repeat the procedure.

Group our material and rectangle. Use the Line tool to draw all walls, windows, and doors in the drawing.

After all the walls, windows and doors are drawn, select the Extrude / Extrude tool and start extruding the walls.

Add tabs at the top and bottom (sill) to one of the windows. Usually the height of the windowsill is 90 centimeters. From the ceiling to the top of the window - 40 cm. Erase the extra lines with the Eraser tool. Install doorways at a height of 210-220 centimeters. Methodological emphasis: there is a comparison, comparison of properties of objects.

Wallpaper the inside of the house using a pattern of your choice. Calculate the cost of pasting with the selected wallpaper (different rooms have different wallpapers or other materials). To do this, you need to know the cost of wallpaper and the area of pasting. Methodological emphasis: the ability to search for information is tested, its application in practice.

For example, the calculation of the cost of wallpaper in the farthest room (with gray wallpaper) is shown. To do this, it is enough to know the area of the walls for pasting, the size of one roll of wallpaper, as well as the cost of one roll.

The area of the walls for pasting is 31.53 square meters. Note that the windows and the door are not included in our selection, which means we will not spend wallpaper on them. Then we divide the total area of pasting by the area of one roll. The size of one roll is 0.53x10m.

$K=31,53/(0,53*10)=5,949056$. Round to the nearest whole (up). One roll of these wallpapers costs 1,355 rubles. Therefore, it is necessary to spend on the purchase: $6 * 1355 = 8130$ rubles. To calculate the total costs, add up the costs of the pasting in each room.

Install windows in the house. Using the Select tool, select all surfaces that are part of the window. You need to rotate the window. To change the width and height of the window separately, you must use intermediate nodes (green dots located in the middle of the sides). To change everything together, accordingly, it is necessary to select one of the vertices.

The resulting tutorial model is presented in Figure 1.

Figure 1 Tutorial model in 3D environment

Further, activities were organized that required the transfer of the acquired knowledge into a real practice-oriented environment. For example, students were asked to find the layout of an apartment of any Kirov real estate developer and reproduce a 3D model of the apartment. Methodological emphasis: application of existing knowledge in new conditions, with new initial data.

As a credit assignment, students were asked to complete a research project that includes the implementation of all the stages and principles described earlier. Sample project. "Hello, my friend! Today we will simulate an immersion in the profession "Designer - furniture designer".

Imagine that you are a furniture designer. You have received an order to create three objects of different complexity and for different rooms. The first room is the kitchen. You have found all the furniture for the kitchen. But you didn't find what to sit on. It is problematic to design a complex stool or sofa right away, since you are not familiar with the program. And you get a great thought "What if you create a simple stool for a start ?!". To make it easier for you to create it, I suggest "Instructions for creating a simple object" using a simple stool as an example.

The kitchen is now all furnished. Next, you move to the bedroom and notice that there is not enough chest of drawers. The chest of drawers is one of the main pieces of furniture in the apartment. However, the dresser differs from the stool in the complexity of creation: more details, as well as more modified objects. Therefore, the process of modeling a chest of drawers is more difficult and requires more knowledge of the program. To create a chest of drawers, use the "Instructions for creating an object of medium complexity".

Now the bedroom is ready. Only the living room remained. There is a computer desk in the living room. However, it is already old and badly worn down. The landlord instructs you to find a new computer desk. You, as a professional, decide to model it yourself. To create a table, you have to use all the knowledge that you gained when creating a stool and chest of drawers. Use the "Instructions for creating an object of increased complexity".

Thus, the directions of the teacher's activities to support the cognitive activity of students and the organization of the modeling method as a universal method of cognition in the environment of three-dimensional graphics are described.

At the fixing stage of the experiment, the repeated measurement was performed, also containing 10 test tasks, designed according to the principle described earlier. We will also give examples of some tasks.

Assignment 1. Determine the type of information model: product description in the online store, Metro lines scheme, gardener's lunar calendar, Children's riddle.

Assignment 2. Determine the adequacy of each of the given information models for the specified purpose of modeling.

Information model: A picture of a sofa from a furniture catalog with the specified dimensions and materials of manufacture, wiring layout for indoor wiring, Instructions for assembling a kitchen set, Scheme of the bus movement around the city with its stops, The formula for the reaction of sodium with water in a chemistry textbook

Purpose of the simulation: To provide the buyer with an opportunity to assess whether the sofa fits the interior and the size of his living room, Find out whether the electrical network will withstand the use of a heat gun indoors, Assemble a kitchen set, Select the public transport stop of the bus route that is the closest to home, Describe the nature of the interaction of sodium with water (vigorously, slowly, etc.)

Assignment 3. For a team competition at a computer science lesson, the game master transformed a raster graphic image.

As a result, the number of colors decreased from 65,536 to 16. How many times has the information volume of the image decreased? The measurement results before and after the experiment are presented in Table 1.

Table 1**Results of the level of formation of critical thinking**

Level	Groups			
	Experimental group (21 undergraduate)		Control group (21 undergraduate)	
	Before the experiment	After the experiment	Before the experiment	After the experiment
High	2	7	2	2
Average	9	12	10	11
Low	10	2	9	8

To apply the statistical criterion to assess the level of critical thinking, the following hypotheses were accepted: H_0 : the level of formation of skills and qualities of the experimental group is statistically equal to the level of the control group; hypothesis H_1 : the level of the experimental group is higher than the level of the control group. In the course of automated calculations using the online resource <http://medstatistic.ru/calculators/calchit.html> we calculate the value of the criterion statistics before ($\chi^2_{\text{emp.1}}$) and after ($\chi^2_{\text{emp.2}}$) the experiment. Let's choose the significance level $\alpha = 0.05$. In this case, $c = 3$, which means that the number of degrees of freedom $v = c - 1 = 2$. According to the distribution tables χ^2 for $v = 2$ and $\alpha = 0.05$, the critical value of the statistics is 5.99. Thus, we obtain: $\chi^2_{\text{emp.1}} < \chi^2_{\text{crit}}$ ($0.11 < 5.99$), and $\chi^2_{\text{emp.2}} > \chi^2_{\text{crit}}$ ($6.42 > 5.99$). Hence, it can be argued that the hypothesis leans towards the alternative hypothesis H_1 , i.e. the shift towards an increase in the level of formation of the skills and abilities that form the basis of critical thinking can be considered not accidental.

Discussion

Thus, a variant of the application of the modeling method as a method of scientific knowledge for the formation of students' critical thinking is described. An obligatory element is the completion of a research assignment. The project assumes from students not only independent implementation in the environment of three-dimensional graphics, but also writing Instructions of various levels of complexity. Despite the fact that the experiment was implemented for the level of training in the pedagogical field, such Instructions, as information models, can be developed and applied for any level of professional training.

It is this kind of synthesis of engineering and technical practice and the didactic component that maximizes the development of critical thinking. When describing the work of a teacher, we have identified specific methodological recommendations, the implementation of which contributes to the development of the required personality traits.

Indeed, the student should investigate the initial object of cognition (receive information, process it, present it in a certain way for further study), reach a new level of cognition and evaluate the result from the standpoint of its application in qualitatively different conditions. The main functions of modeling are as follows: deepening knowledge of the essential and meaningful characteristics of known systems, objects, phenomena; determination of essential / insignificant characteristics, directions for further improvement; conducting a comparative analysis of the original and the resulting model; identification of new qualitative properties for the formation of new knowledge about a system, object, phenomenon.

The method of modeling is the basis for obtaining scientific knowledge both about the possibilities of 3D graphics and the application of innovative technologies for e-learning. The

significance of three-dimensional modeling is determined by its wide range of applications: the study of both macro- and micro-objects, in carrying out various studies of processes, phenomena that often do not have any points of contact. In the presented approach, the micro-level is implemented both in the SketchUp software tool and in filling the Instructions. The macro-level involves modeling the learning process according to the Instruction.

Thus, a model is at the origins of epistemological processes regardless of the level, goals, methods and means of cognition. It, which has received development, enriched with information, presented in material or symbolic form, is its result.

Performing a quantitative analysis of the above results, we can conclude that after the completion of the experiment, 33% of the master's students in the experimental group had a high level of qualities and skills that form the basis of critical thinking (7 students out of 21), while initially this percentage was 10 % (2 participants out of 21). The indicator for the level of formation "low" has significantly decreased from 48% to 10%. This indicates a qualitative improvement in the learning indicators of the subjects in the group. Moreover, the most significant changes occurred during the transition from "low" to "average" and "high".

The level dynamics in the control group is also present, but it is less significant. After completing the experiment, 52% of the master's students in the control group had an average level of qualities and skills that form the basis of critical thinking (11 students out of 21), while initially this percentage was 48% (10 participants out of 21). The indicator of the level of formation "low" decreased from 43% to 38%. There were no changes in the "high" level.

In general, the pedagogical experiment allows us to conclude that modeling in three-dimensional graphics environments can improve the quality of education in terms of the formation of skills that constitute the basis of critical thinking.

Conclusion

The skill of "thinking critically" is highlighted in many educational systems as one of the main learning outcomes. Every year there are more and more innovative technologies for the development of critical thinking (educational robotics, programming, augmented and virtual reality, STEM technology, smart cards, etc.).

In the context of global transformation, society's requirements for the quality of digital school graduates are changing. Modeling, working with 3D objects, the use of software and hardware has become an essential element of social, pedagogical and methodological research. In addition, modeling is an activity and a universal method of scientific knowledge. This led to the objective need for additional research on the capabilities of the modeling method for the development of critical thinking.

Modeling in research is used together with other methods of scientific knowledge (experiment, comparison, classification, etc.). When modeling in a 3D graphics environment, students applied the skills and abilities that form the basis of critical thinking as follows:

- for memorization (concepts, theoretical facts, tools of the software environment, methods of manipulation and functionality);
- for understanding (at the scientific-theoretical, practical, methodological level);
- for use (when working in the environment of three-dimensional graphics and designing future work with the Instruction);

- for analysis (the results of own activities and the work of other users with the developed Instruction);
- to assess information, sources of information, software tools, the possibilities of using the obtained software, hardware and pedagogical results;
- to create/obtain new knowledge in order to apply it in practice, in professional activity.

When working in three-dimensional graphics environments, 4 directions of interaction of the modeling participants are implemented: "subject" – the initiator of the modeling and / or the user of its results; "Original object" is the subject of modeling, that is, the system that the "subject" wants to create and / or use in the future; "Model" – image, display; "Environment" in which all participants are located and interact with.

For the successful implementation of the proposed areas of modeling in three-dimensional graphics environments for the development of critical thinking, the formation of professional skills in the use of innovative technologies of electronic education, it is recommended to adhere to a set of organizational and pedagogical conditions, which includes: obtaining theoretical information about the original object; organization of practice-oriented activities on modeling in the environment of three-dimensional graphics (creation of a substitute model); development of a system of cognitive tasks for research; organization of reflection, verification and correction of the results obtained during the study of the model in the conditions of the original object; formulation of qualitatively new knowledge.

Within the framework of the designation of relevance, it was noted that critical thinking is reflexive in nature. Therefore, the most essential are metasubject/regulatory learning outcomes: to be aware of the meaning and motive of learning; generate the need for self-expression through active participation in modeling; to establish a connection between the goal of the activity and its result; work according to plan, instructions; make your assumption based on the available scientific knowledge; assess the process and results of activities; implement self-control; master the forms of speech in accordance with the norms of the native language and express their thoughts; own information culture.

The effectiveness of the proposed approach was tested during the pedagogical experiment.

The results of the study confirm the conclusions of A. I. Benzer, B. Yildiz that computer 3D modeling, as one of the innovative technologies, can provide great opportunities for the formation of in-demand skills of graduates [19].

In addition, the results of the work complement the conclusions of E. V. Sinyavskaya [4] about the potential of the modeling method for the development of critical thinking in the conditions of the formation of a digital school.

The research materials can be used to improve the quality of education due to specially organized areas of support for students' activities in modeling, focused on their intellectual development and preparation for future professional activities.

REFERENCES

1. Order of the Ministry of Education and Science of the Russian Federation of 21 November 2014 no. 1505 «On Approval of Federal State Educational Standard of Higher Education in the Field of Training 44.04.01 Pedagogical Education (master degree level). Portal of Federal State Educational Standards for Higher Education. Available at: <http://fgosvo.ru/uploadfiles/fgosvom/440401.pdf> (accessed 10 January 2021).

2. Solodikhina M. V., Solodikhina A. A. Development of Critical Thinking of Master's Degree Students Using STEM Cases. *The Education and Science Journal*, 2019, vol. 21, no. 3, pp. 125–153. DOI: 10.17853/1994-5639-2019-3-125-153.
3. Kuzminov Ya., Sorokin P., Froumin I. Generic and Specific Skills as Components of Human Capital: New Challenges for Education Theory and Practice. *Foresight and STI Governance*, 2019, vol. 13, no. 2, pp. 19–41, DOI: 10.17323/2500-2597.2019.2.19.41
4. Sinyavskaya E. V. Modelling as a Method of Scientific Knowledge. *The Surgut State Pedagogical University Bulletin*, 2013, no. 3 (24), pp. 192–196.
5. Paterson R. E. Intuitive cognition and models of human–automaton interaction. *Human Factors: The Journal of the Human Factors and Ergonomics Society*, 2017, vol. 59, no. 1, pp. 101–115. DOI: 10.1177/0018720816659796
6. Stolbova I. D., Aleksandrova E. P., Kochurova L. V., Nosov K. G. Profile Aspects of Graphic Education at Polytechnic University. *Higher Education in Russia*, 2019, vol. 28, no. 3, pp. 155–166. DOI: 10.31992/0869-3617-2019-28-3-
7. Ozogul G., Miller C. F., Reisslein M. School Fieldtrip to Engineering Workshop: Pre-, Post-, and Delayed-Post Effects on Student Perceptions by Age, Gender, and Ethnicity. *European Journal of Engineering Education*, 2019, vol. 44, Issue 5, pp. 745–768. DOI: 10.1080/03043797.2018.1518408
8. Varshavskaya E., Kotyrlo E. Engineering and Economics Graduates: Between Demand and Supply. *Educational Studies Moscow*, 2019, no. 2, pp. 98–128. DOI: 10.17323/1814-9545-2019-2-98-128
9. Soboleva E. V., Karavaev N. L. Characteristics of the Project-Based Teamwork in the Case of Developing a Smart Application in a Digital Educational Environment. *European Journal of Contemporary Education*, 2020, vol. 9, Issue 2, pp. 417–433. DOI: 10.13187/ejced.2020.2.417
10. Damyanov I., Tsankov N. The Role of Infographics for the Development of Skills for Cognitive Modeling in Education. *International Journal of Emerging Technologies in Learning (IJET)*, 2018, vol. 13(01), P. 82. DOI: 10.3991/ijet.v13i01.7541
11. Strategy for Developing the Information Technology Sector in the Russian Federation in 2014–2020 and until 2025 (2013). Available at L: http://minsvyaz.ru/common/upload/Strategiya_razvitiya_otrasli_IT_2014-2020_2025.pdf (accessed 5 December 2020).
12. Passport of the National Program “Digital Economy of the Russian Federation”, approved by the Presidium of the Council of the President of the Russian Federation on Strategic Development and National Projects, Protocol of 24 December 2018, no. 16. Available at: <http://government.ru/info/35568/> (accessed 10 January 2021)
13. Karakozov S. D., Ryzhova N. I. Information and Education Systems in the Context of Digitalization of Education. *Journal of Siberian Federal University. Humanities & Social Sciences*, 2019, 12(9), pp. 1635–1647, DOI: 10.17516/1997–1370–0485.
14. Ronzhina N. V. Role of Universal Competency “Systemic and Critical Thinking” in Forming Professional Thinking. *Vocational Education and Labor Market*, 2020, no. 2, pp. 116–121, DOI: 10.24411/2307-4264-2020-10235.
15. Volkov E. N. Learning Scientific (Critical) Thinking Skills and Visual Objectivization of Knowledge: Content, Practices, Tools. *Vestnik of Lobachevsky State University of Nizhni Novgorod. Series: Social Sciences*, 2016, no. 2 (42), pp. 199–203.
16. Shcheglova I., Koreshnikova Y., Parshina O. The Role of Engagement in the Development of Critical Thinking in Undergraduates. *Educational Studies Moscow*, 2019, no. 1, pp. 264–289. DOI: 10.17323/1814-9545-2019-1-264-289.
17. Jääskelä P., Nykänen S., Tynjälä P. Models for the Development of Generic Skills in Finnish Higher Education. *Journal of Further and Higher Education*, 2018, vol. 42, no. 1, pp. 130–142. DOI: 10.1080/0309877X.2016.1206858.
18. Anderson T., Shattuck J. Design-Based Research: A Decade of Progress in Education Research? *Educational Researcher*, 2012, vol. 41, no. 1, pp. 16–25. DOI: 10.3102/0013189X11428813
19. Benzer A. I., Yildiz B. The Effect of Computer-Aided 3D Modeling Activities on Pre-Service Teachers' Spatial Abilities and Attitudes Towards 3d Modeling. *Journal of Baltic Science Education*, 2019, vol. 18, no. 3, pp. 335–348. DOI: 10.33225/jbse/19.18.335
20. Chugunov M. V., Polunina I. N. Interdisciplinary Modelling of Robots Using CAD/CAE Technology. *Mordovia University Bulletin*, 2018, vol. 28, no. 2, pp. 181–190. DOI: 10.15507/0236-2910.028.201802.
21. Mykhailishyn H., Kondur O., Serman L. Innovation of Education and Educational Innovations in Conditions of Modern Higher Education Institution. *Journal of Vasyl Stefanyk Precarpathian National University*, 2018, vol. 5, no. 1, pp. 9–16. DOI: 10.15330/jpnu.5.1.9-16.
22. Salamatov A. A., Gordeeva D. S. The Model of Ontological Reflection of Ecological and Economic Value Orientations Formation in the Process of Vocational Education. *The Education and Science Journal*, 2020, vol. 22, no. 2, pp. 53–77. DOI: 10.17853/1994-5639-2020-2-53-77.
23. Koreshnikova Y. N. Critical Thinking in Modern Society: What Do Universities Provide? *Monitoring of Public Opinion: Economic and Social Changes*, 2019, no. 6, pp. 91–110. DOI: 10.14515/monitoring.2019.6.06.
24. McCormick N. J., Clark L. M., Raines J. M. Engaging Students in Critical Thinking and Problem Solving: A Brief Review of the Literature. *Journal of Studies in Education*, 2015, vol. 5, no. 4, pp. 100–113. DOI: 10.5296/jse.v5i4.8249.
25. Soboleva E. V., Isupova N. I., Karaulova L. V., Nimatulaev M. M. Development of Environmental Thinking and Lean Manufacturing Skills in the Course of Mobile Robotics. *Science for Education Today*, 2020, vol. 10, no. 1, pp. 149–173. DOI: 10.15293/2658-6762.2001.09.

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