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Implementation of the STEM project "modeling of spatial images of stellated Poyhedra" in the professional training of future vocational education teachers

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Abstract: In the context of rapid development of digital technologies and their integration into the educational process, the implementation of the STEM approach in teaching technical and natural sciences becomes particularly relevant. The combination of Science, Technology, Engineering, and Mathematics creates a powerful toolkit for developing practical skills and spatial thinking in future professional education teachers. Three-dimensional modeling of geometric figures is a prime example of an interdisciplinary approach, where mathematical concepts are implemented in a digital environment using modern technologies. For future professional education teachers, such an approach is particularly important as it allows them to develop technical skills and methodological competencies simultaneously. The article examines the theoretical foundations and practical aspects of implementing the STEM approach in the process of learning 3D modeling using the graphic editor AutoCad, as well as investigates the impact of this approach on the development of professional competencies of future specialists.

Keywords: *3D modeling, Digitization of education, STEM education, STEM projects, STEM technologies, Vocational education teachers.*

1. Introduction

According to research [1] there is an anticipated growth in demand for specialists in the fields of information technology, artificial intelligence, biotechnology, and engineering. However, there is a certain shortage of qualified personnel in these areas. This demand arises from rapid technological transformation in all aspects of life, including manufacturing, medicine, transportation, information technology, etc. In the context of the need to develop competencies in students necessary for addressing global challenges of the modern era (such as climate change, issues of international security, etc.), the prioritization of implementing a STEM-oriented approach to education becomes essential. This approach facilitates the integration of natural sciences, technology, engineering, and mathematics into the educational process. This underscores the need for the integration of STEM technologies into the higher education system. The integration of STEM technologies into university curricula is an important element of modern education strategy and meets the challenges of contemporary society, fosters innovative development, and ensures the preparation of a competitive generation. The knowledge and skills acquired through such education will be key to the success of future generations in various areas of life [2-6].

In the context of the current pedagogical paradigm, dynamic transformations of the sociocultural and technological environment highlight the necessity of developing an integrative system of competencies

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for future specialists in engineering fields and professional training. This system encompasses both professional and metasubjective competencies, including cognitive flexibility, the ability to engage in lifelong learning, critical and systemic thinking, digital literacy encompassing programming, tolerance for uncertainty, creative potential, the ability to engage in transdisciplinary communication, intercultural competence, and multilingualism with an emphasis on English as a means of international communication [7, 8].

According to modern educational trends, the priority directions for the development of higher education have been identified as the implementation of an interdisciplinary (multidisciplinary) approach in educational and scientific programs and ensuring academic autonomy for students through the personalization of educational trajectories [9-12].

A multidisciplinary approach in the professional training of future vocational education teachers involves the integration of knowledge and skills from various fields to develop comprehensive competencies. Such an educational approach not only ensures a deeper mastery of professional disciplines but also creates a foundation for the development of transdisciplinary thinking through the assimilation of methodological tools from related fields of knowledge.

A vivid example of the practical implementation of multidisciplinarity is the integration of psychological-pedagogical competencies in the teaching of technical disciplines, coupled with the application of economic tools to optimize production processes. This approach contributes to the formation of a comprehensive professional competence in future professional education teachers.

The essence of the multidisciplinary approach is to enable future professionals to solve complex problems by applying a broad spectrum of knowledge and skills. This approach fosters the development of critical thinking, creative problem-solving, and the ability to work in interdisciplinary teams.

2. Literature Review

In the context of rapid technological advancement and transformation of the educational paradigm, the effective integration of scientific knowledge into the practical aspect of professional training becomes particularly relevant. Modeling within STEM education serves as a powerful tool for such integration, ensuring synergy between theoretical knowledge and practical skills.

The use of modeling within STEM education is based on the principles of interdisciplinary integration and practice-oriented learning. This approach involves the synthesis of scientific knowledge, technology, engineering, and mathematics through a system of practical, project-oriented tasks aimed at solving real professional problems. Pedagogical research shows that such integration fosters a comprehensive understanding of professional processes and the development of complex competencies [13].

Analyzing the use of modeling in STEM education during the training of future professional education teachers, several advantages can be highlighted. These include enhancing innovative potential (developing the ability to generate new ideas, forming skills for creative problem-solving, and stimulating innovative thinking); adaptability to changes (enhancing cognitive flexibility, developing the ability to learn quickly, and preparing for professional mobility); solving complex problems (developing systemic thinking, forming skills for comprehensive analysis, and improving design abilities); enhancing critical thinking (developing analytical skills, forming abilities for assessment and verification, and refining logical thinking); and developing personal and professional skills (forming communicative competencies, enhancing teamwork skills, and improving professional expertise) [14].

The theoretical foundation of this study is based on a series of scholarly works related to the possibilities of STEM technologies in the educational process [15-17] as well as the methods of implementing STEM technologies in the process of professional training of future professional education teachers [14, 18, 19].

An important direction of STEM education for future professional education teachers is the comprehensive application of educational data mining methods in professional activities. A large body of work is dedicated to the use of EDM methods in the educational process. Key research areas include:

predicting student educational achievements using machine learning [20, 21] and artificial neural networks [22, 23] clustering of educational data [24-26]; methods of digital image processing [27-29] and segmentation [30, 31] image recognition methods and fuzzy logic [5, 32-34] computer modeling [35-40] three-dimensional graphics [41] augmented [42] and extended reality [43].

The effectiveness of using modeling in STEM education is ensured through a systemic approach to organizing the educational process, integrating theoretical and practical components, applying innovative pedagogical technologies, ensuring interdisciplinary connections, and focusing on practical outcomes.

The use of modeling within STEM education is an effective tool for developing creative thinking and forming the professional competencies of future professional education teachers. A comprehensive approach to organizing the educational process ensures the formation of necessary skills and readiness for professional activity in the conditions of the modern labor market.

One of the key aspects of this approach is engaging students in the study of geometric models, which allows them not only to master complex concepts but also to develop spatial thinking and analytical abilities.

In particular, modeling regular stellated polyhedra opens up the world of exact science to students, where they can explore the properties of shapes, their symmetry, and proportions. This approach not only enhances understanding of mathematical and geometric concepts but also fosters a deep interest in technical disciplines, which is key for a successful career in engineering and scientific fields. During the project work, future professional education teachers learn to use 3D modeling software, an important competency in many modern professions.

The implementation of the STEM project "Modeling Spatial Images of Stellated Polyhedra" is demonstrated using a stellated octahedron and includes the following stages: reviewing the fundamentals of polyhedron theory; analyzing the functional properties of commands for constructing polyhedra; step-by-step construction of a three-dimensional model of the octahedron using the appropriate commands; and printing the three-dimensional model of the octahedron on a 3D printer.

The deployment of the project involves planning each stage and using methods that ensure the development and enhancement of relevant skills. In the process of modeling polyhedra in an educational environment, the graphic editor AutoCad is actively used, which serves as a powerful tool for visualization and study of geometric objects. This software allows not only the construction of precise 3D models but also the analysis of complex geometric figures, facilitating the development of spatial thinking and the ability to work with engineering graphics [44].

One of the tasks set for students within the framework of project activities is the construction of 3D models of polyhedra, exemplified by the model of a dodecahedron. This task is complex and combines both theoretical and practical aspects, which facilitates a deeper understanding of geometry. Completing the project requires students to apply knowledge about symmetry, proportions, and properties of polyhedra, making the learning process more engaging and interactive.

Thus, in the process of implementing STEM projects, it is essential to begin with design and planning. A mandatory condition of a STEM project is the research work of students, which involves searching for relevant information, followed by processing and presenting the results of their activities. The final outcome of a STEM project is a product created by the project group participants while solving the given task. At the final stage of the STEM project implementation, there should be a presentation of this product.

3. Experimental Consideration

The methodology for teaching the basics of 3D modeling using AutoCAD for students specializing in "Professional Education (Mechanical Engineering)" is designed to ensure that students not only acquire practical skills in using AutoCAD but also develop methodological competencies for further teaching the fundamentals of 3D modeling to students. The training covers the process of creating basic

3D models, includes methods for developing spatial thinking, preparing models for 3D printing, and familiarizing with the methodology of printing three-dimensional graphics.

This approach is aimed at preparing future teachers who not only master the technical aspects of 3D modeling but also acquire the methodological skills necessary for effectively teaching this subject in the future.

The aim of the study is to theoretically substantiate the implementation of STEM technologies in the educational process of higher education as a means of developing the pedagogical skills of future professional education teachers. Additionally, the research aims to assess the level of knowledge about STEM education among future specialists and their readiness for effective integration of STEM projects into their professional practice.

The goals of constructing 3D models using AutoCAD are:

1. Formation of technical skills in 3D modeling: teach students how to create and edit simple and complex three-dimensional objects in AutoCAD.

2. Development of methodological competencies: teach students how to plan and implement lessons on the basics of 3D modeling for students, using principles of didactics and psychology of learning.

3. Reinforcement of knowledge from related disciplines: integrate knowledge from geometry, mathematics, and computer science in the process of creating 3D models.

4. Learning the basics of 3D printing: ensure students understand the technological aspects of preparing models for printing, the basics of setting up a 3D printer, and the importance of 3D printing in the modern educational process.

Let's consider the main stages of building a 3D model using the example of constructing a regular stellated octahedron.

The methodology for constructing a regular stellated octahedron is divided into five main stages, which include both practical and theoretical aspects, as well as methodological preparation.

Stage 1: Familiarization with AutoCAD capabilities.

- In the first stage, the instructor explains the basic functions of AutoCAD, introduces students to the program interface, and the main tools for working in three-dimensional space. During the lesson, students gain basic knowledge such as:
- Creating simple objects: working with tools to create basic shapes like points, lines, circles, rectangles.
- Basics of navigation in 3D space: includes camera rotation, scaling, and viewing from different angles.

Toolbars for Setting and Editing 3D Objects: Students learn how to adjust and modify three-dimensional objects using various toolbars.

This stage also includes discussions on methods to introduce students to the software environment and recommendations on teaching the program interface to beginners. This foundational knowledge is crucial for ensuring students are comfortable and proficient with AutoCAD before moving on to more complex 3D modeling tasks.

Stage 2: Methodology for Explaining the Theoretical Foundations of 3D Modeling.

In this stage, students are introduced to the theoretical foundations of 3D modeling, which include:

- Basic Concepts: Understanding the geometric properties of three-dimensional objects and the principles of their construction. This helps students grasp how shapes form and interact in 3D space.
- Mathematical Aspects of Modeling: Discussing proportions, angles, and distances between objects. This involves calculations and understanding spatial relationships critical for accurate 3D modeling.
- Didactic Approaches for Teaching: Analyzing educational techniques to explain these topics to students. This may include the use of real-world objects and analogies to simplify the understanding of three-dimensional space.

Stage 3: Practical Modeling and Step-by-Step Construction of 3D Objects.

This stage is dedicated to practical work in AutoCAD. Under the guidance of an instructor, students create a model of a simple three-dimensional object by performing the following actions:

- Building basic elements: creating and adjusting simple three-dimensional primitives.
- Editing and transforming objects: moving, rotating, scaling, and combining objects.
- Preparing the model for printing: students learn to edit the model so that it is suitable for 3D printing.

Now, let's look at constructing the basic elements of a regular stellated octahedron (Figure 1).

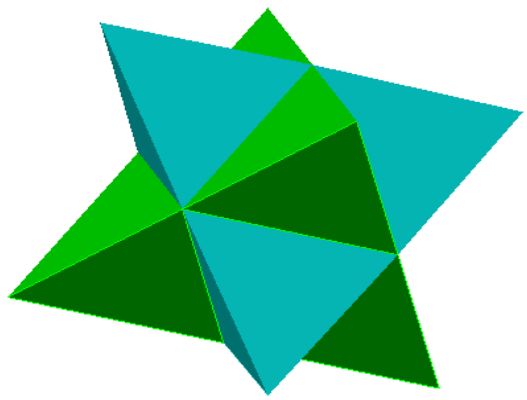

Figure 1.
Star octahedron.

1. Mathematical Calculation of the Parameters for Constructing a Stellated Octahedron The initial data for the construction of a stellated octahedron in AutoCad are:

1) An equilateral triangle inscribed in a circle with a radius of 50 mm (Figure 2a);

2) The angle of rotation of the lateral plane is 109.4712⁰;

3) The extrusion angle of the rays is 19.47⁰, and the extrusion height of the rays is 70.74 mm (Fig. 2b).

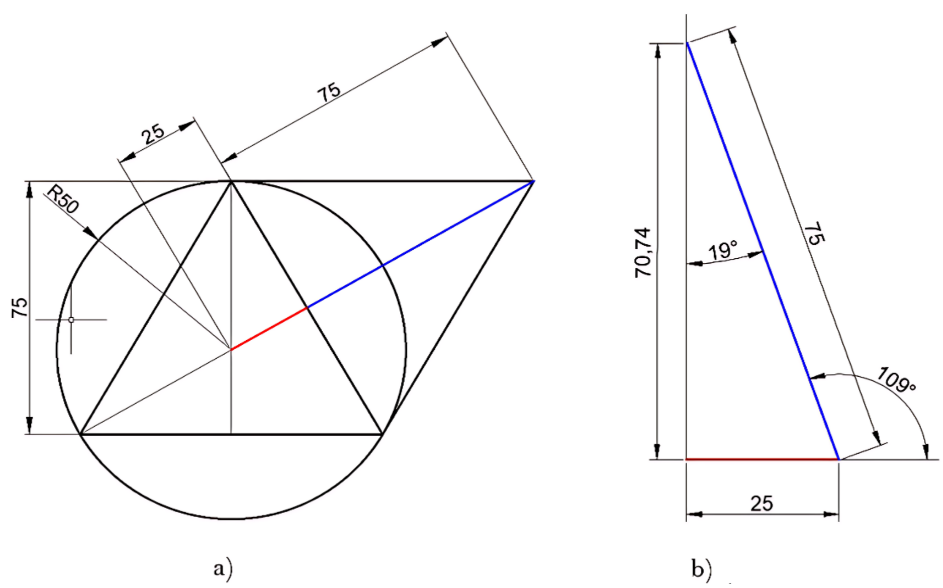

Figure 2.
Graphs of the mathematical calculation of the star octahedron.

2. Step-by-step creation of a 3D model of a star octahedron

An inner triangle is constructed using line segments (Figure 3a) and its sides are converted into a polyline (Figure 3b). The presence of polylines indicates the transformation of the shape formed by the polyline into a surface.

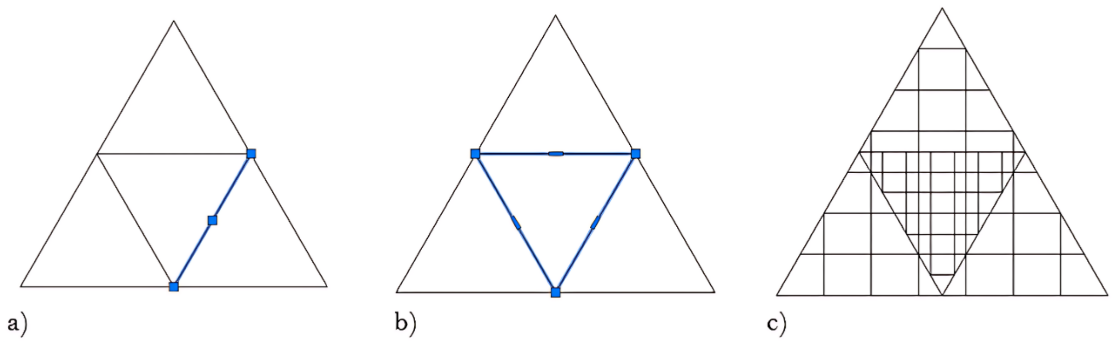

Figure 3.
Preparatory process of graphic construction.

The next step will be the process of copying the figure from Figure 2b.

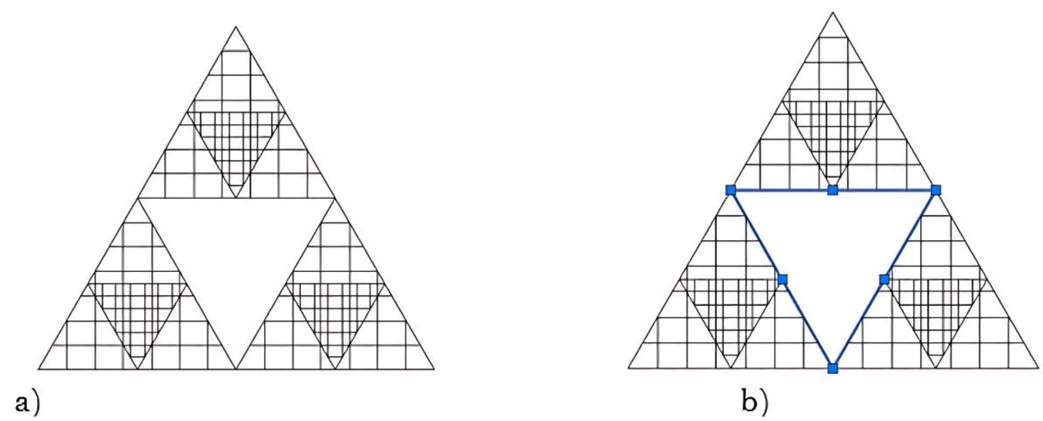

Figure 4.
Copying the created model.

The transformation of the central part of the model into a surface is verified (Figure 4a). Similarly, the central triangle is formed (Fig. 5b) and transformed into a plane (Figure 5c).

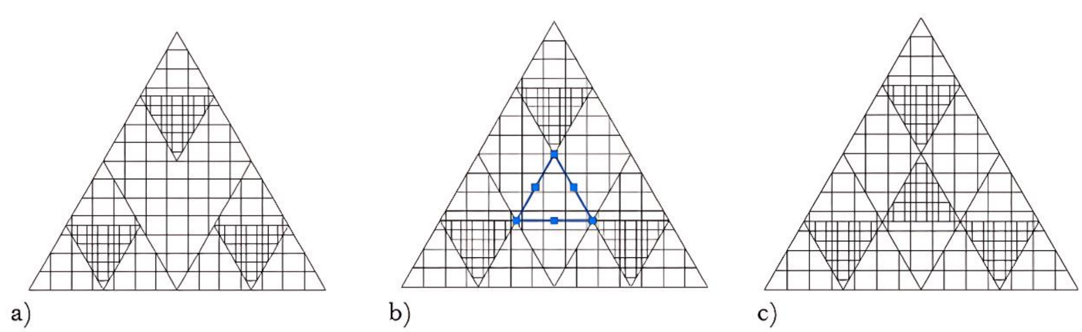

Figure 5.
Preparatory process of graphic construction.

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The next action is to rotate the sides of the future stellated octahedron relative to its base by an angle (109.4712^0). The rotation operation is performed according to previous calculations.

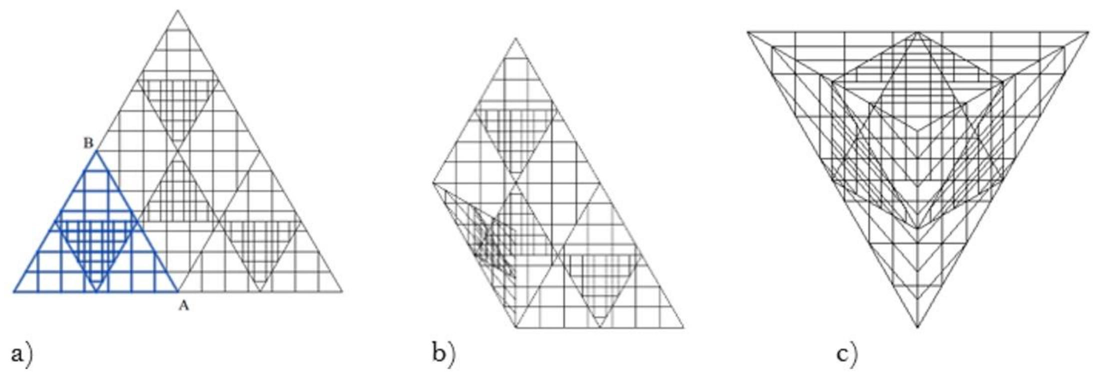

Figure 6.
Steps for turning the sides of a star octahedron.

Similar actions are taken with the remaining sides of the stellated octahedron (Figure 6, c). The next step is the extrusion of small triangles that will form the rays of the stellated octahedron at an angle of 20^0 and a height of 75 mm.

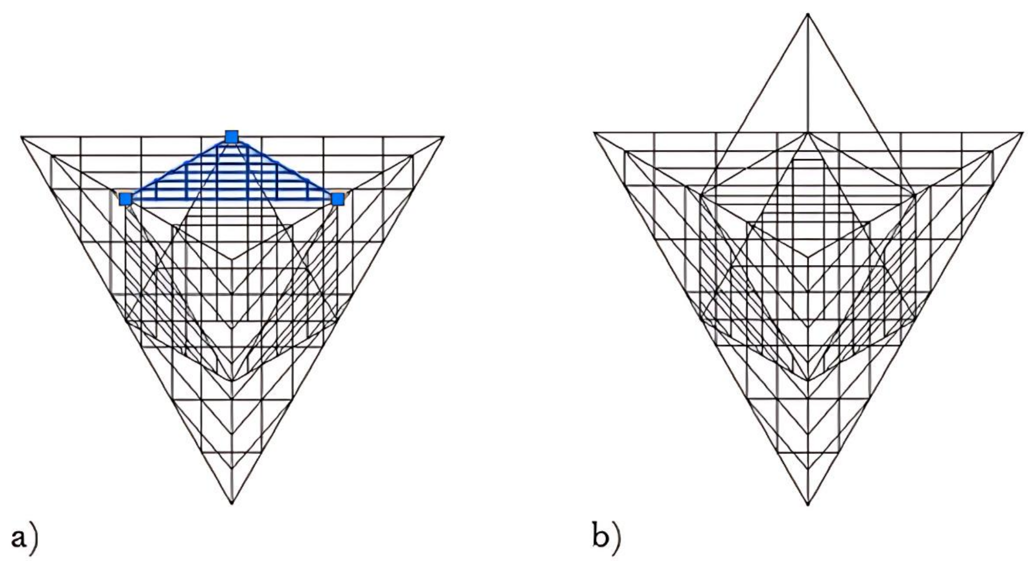

Figure 7.
Extrusion operation.

The process is repeated several times (Figure 8a-b).

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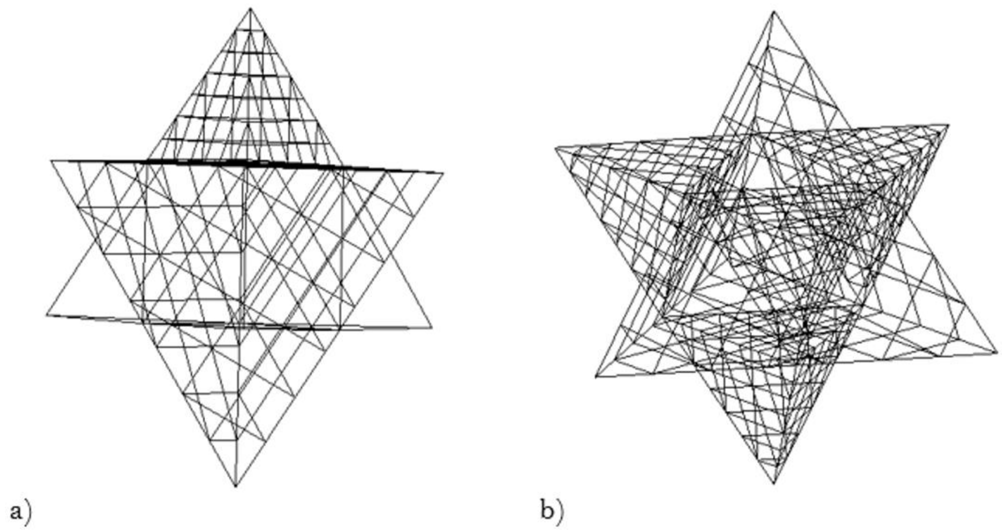

Figure 8.
The step of completing the formation of the rays of the star octahedron.

The final part of the construction is changing the color of the model and its toning

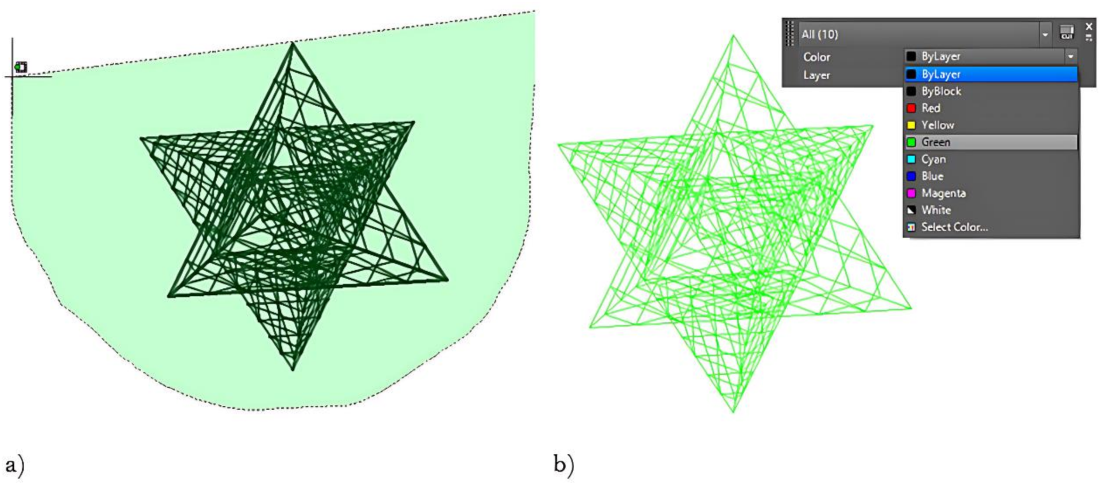

Figure 9.
The step of converting a model into an object.

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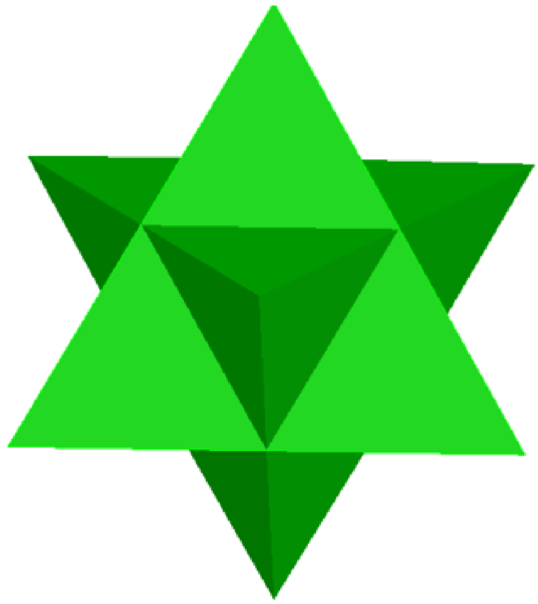


Figure 10.
The final image of the star octahedron.

Stage 4: Preparation and printing of 3D models' students learn the fundamentals of preparing models for 3D printing.

The main actions include:

- File conversion: exporting the model to STL format and checking compatibility with the 3D printer.
- Familiarization with printing software: using software like Cura or its equivalents to set print parameters.
- Printing practice: setting print parameters such as material, layer thickness, print speed, etc.

During this step, students study the basics of working with a 3D printer, gain skills in setting print parameters, and learn to monitor the process.

The 3D printing process involves modeling and preparing for printing, the actual printing of the object, and, if necessary, mechanical post-processing [45, 46].

The previously designed model is exported in formats (.stl, .obj) for further slicing into layers in the appropriate software package.

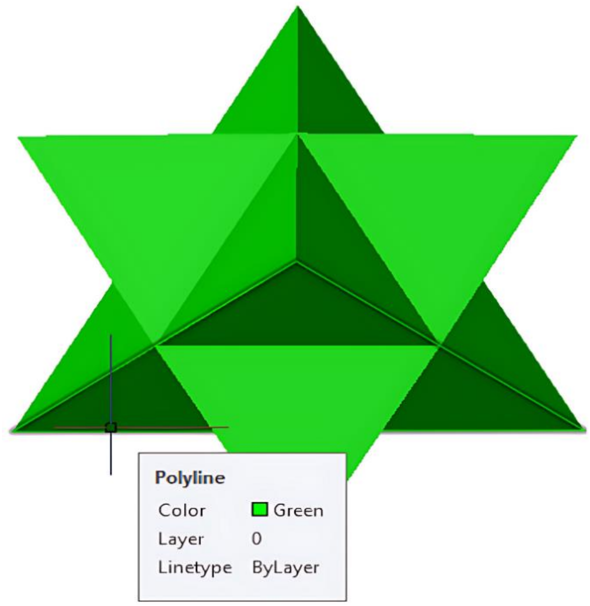
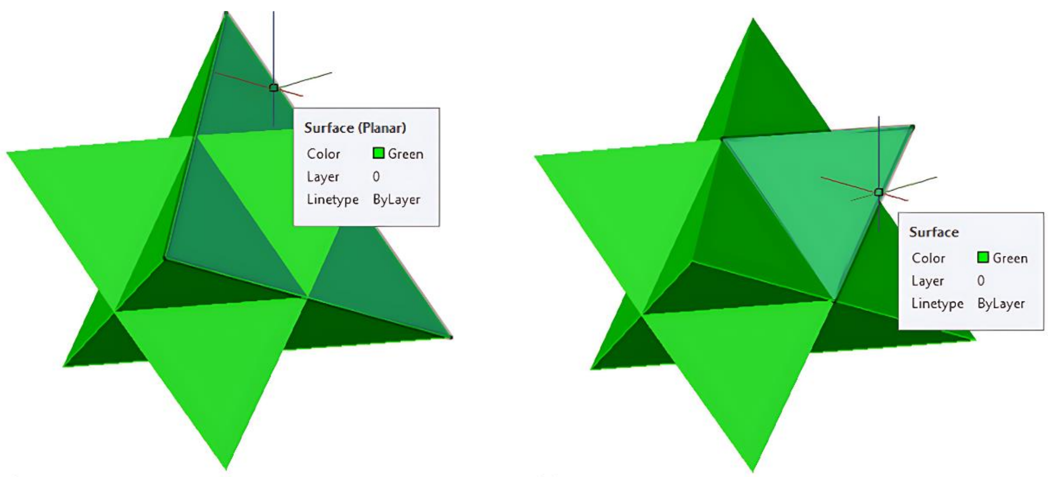


Figure 11.
The process of preparation for importing the model into STL format.

In a similar way, the fact of creation of all planes and surfaces is checked (Figure 12). The next step is to select the object (Figure 13). Upon completion, the formed 3D solid is checked (Figure 14).



a) b)

Figure 12.
Checking the planes and surfaces we created.

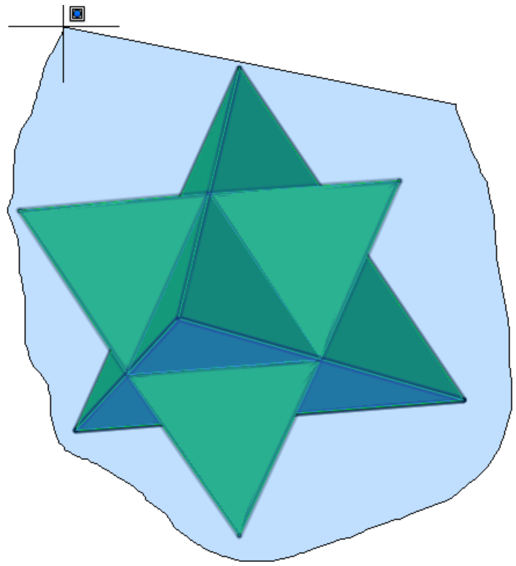


Figure 13.
Built model selection mode.

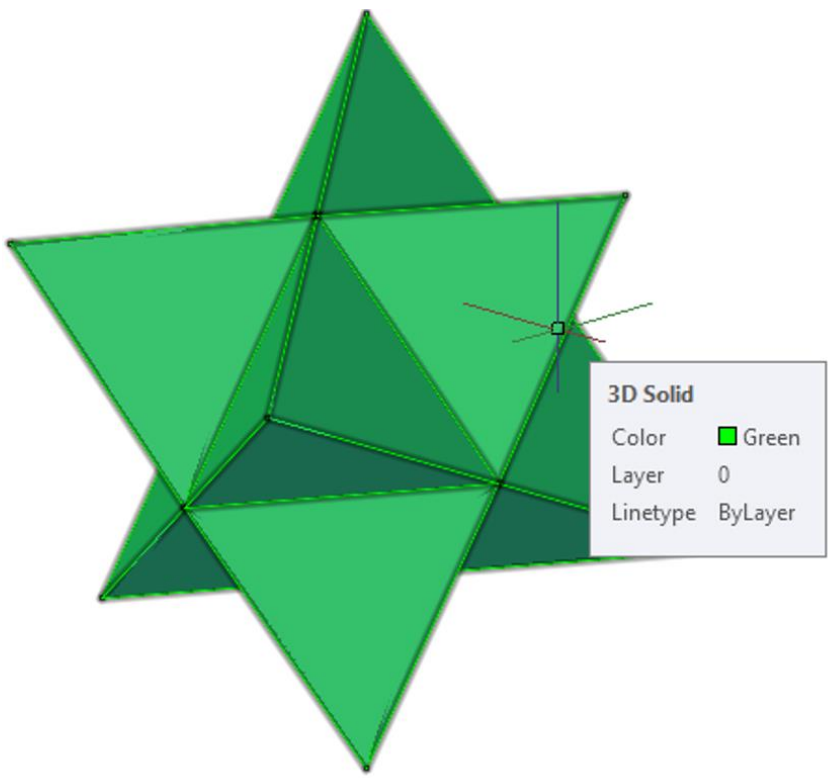


Figure 14.
Transition of constructions to a 3D solid.

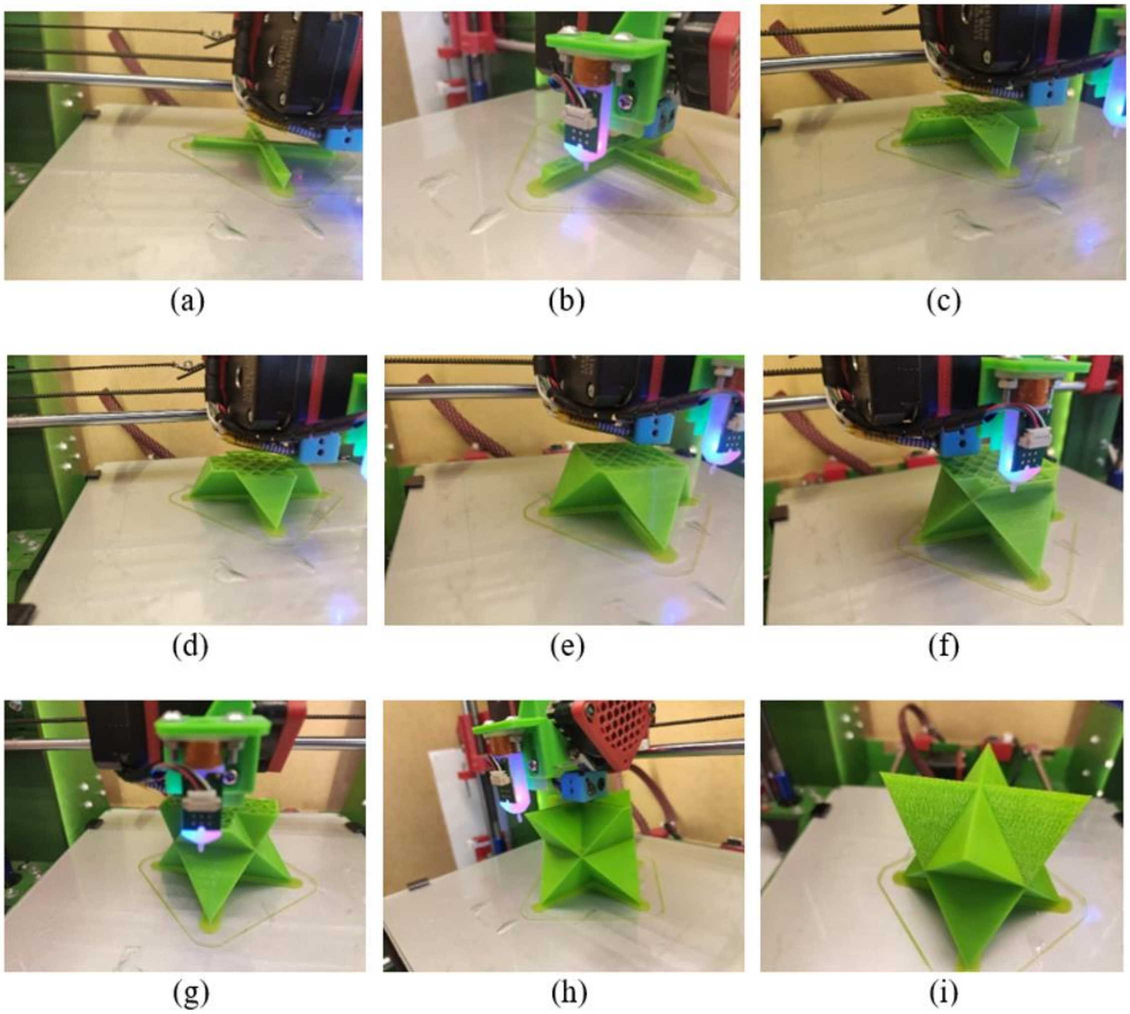


Figure 15.
The process of printing a star octahedron.

Stage 5: Analysis of results and discussion of methodological aspects.

After completing the work, students conduct an analysis of the created model, assessing the accuracy of the print, the model's conformity to the initial project, and identifying potential errors. This is followed by a methodological discussion:

- Model quality assessment: analyzing the finished product, evaluating accuracy, symmetry, and print quality.
- Discussion of methodological approaches: discussing how the teaching of the 3D modeling topic could be improved, considering the experience gained from the task.
- Feedback: students provide their feedback on the process, suggest improvements to the methodology, explore potential problems that other students may encounter, and develop methodological recommendations.

Methods of assessing results the evaluation includes various approaches that take into account both the practical and methodological preparation of students:

Practical outcomes: assessing the quality of the created 3D models, considering the accuracy of the model, the quality of the print, and conformity to the initial requirements.

Methodological evaluation: checking the developed methodological lesson plans, analyzing didactic techniques proposed by students for future teaching.

Self-assessment and reflection: students independently assess their progress, analyze successful and problematic aspects of learning, and identify their strengths and weaknesses.

4. Results and Discussion

To assess the effectiveness of the STEM project, an evaluation of the educational achievements of a group of 12 students (specializing in "Professional Education (Mechanical Engineering)") was conducted before the start of the project and after the completion of the project. The assessment of educational achievements was carried out by administering 5 tests, with the maximum possible score for each test being 100. The topics of the test tasks corresponded to the themes of the stages of the STEM project. The test questions were both theoretical and practical in nature.

The test results of the learners were analyzed for all topics, and for each test, the average score of the group (Mean) and the standard deviation (Std-Dev) of the students' scores relative to the average were calculated [47] (Figure 16, Table 1).

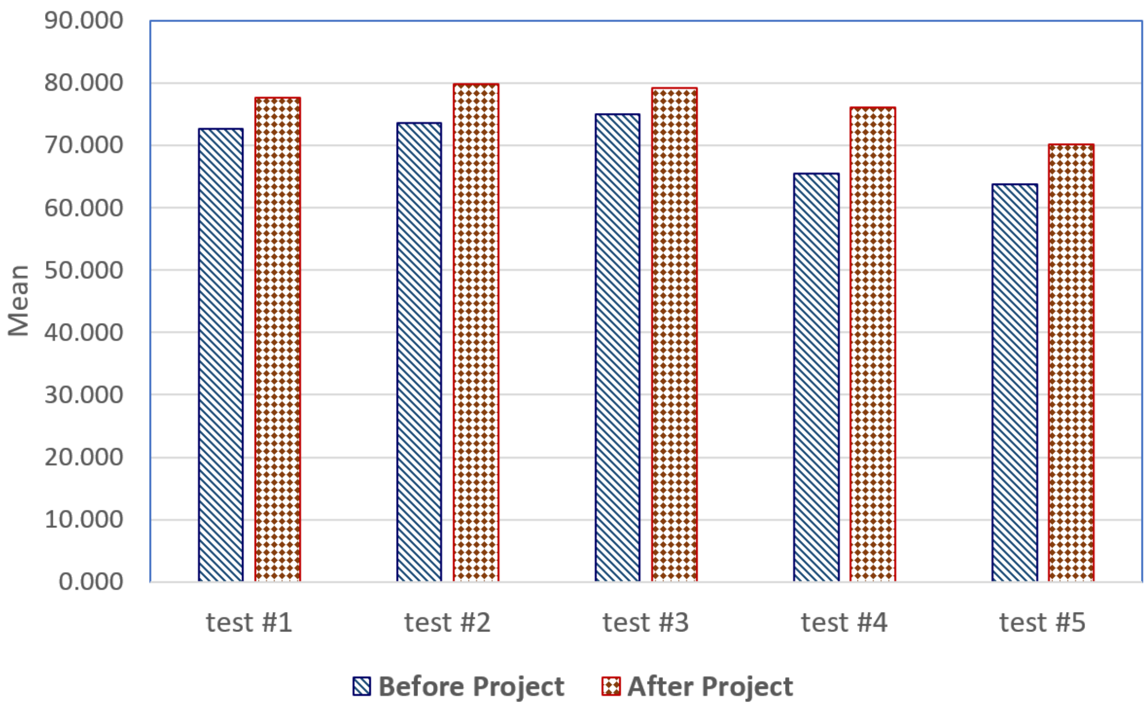


Figure 16.
Average values of student test results.

For tests #1-#5, the average score of the group after completing the STEM project increased by 4.917, 6.250, 4.167, 2.833, and 6.333 points respectively (Table 1). The standard deviation of the students' scores after completing the project slightly decreased (11.828 for all tests).

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Table 1.
Results of student testing.

Tests	Mean		Standard deviation	
	Before project	**After project**	**Before project**	**After project**
test #1	72.667	77.583	12.153	11.966
test #2	73.583	79.833	12.810	12.037
test #3	75.000	79.167	12.828	11.831
test #4	65.417	68.250	10.431	9.938
test #5	63.750	70.083	11.128	10.352

As a result of the project, students' educational achievements improved the most for Test 2, which corresponds to the theme of Stage #2 of the project "Methodology for Explaining the Theoretical Foundations of 3D Modeling" and Stage #5, "Analysis of Results and Discussion of Methodological Aspects". This improvement can be attributed to the fact that the questions about noise removal in images, enhancing contrast, and edge detection are relatively easy to understand and implement programmatically. The improvement in Test #5 results can be explained by the implementation of a structured approach to analysis and active engagement of learners in the discussion of project outcomes.

Average improvements in educational achievements were also noted for Test #1 (Stage #1 "Familiarization with AutoCAD Capabilities") and Test #3 (Stage #3 "Practical Modeling and Step-by-Step Construction of 3D Objects"). The smallest improvement in student learning outcomes was noted for Test #4 (Stage #4 "Preparation and Printing of 3D Models"), which is explained by certain difficulties in mastering the principles of fuzzy logic. However, improvements in educational outcomes were observed for all stages of the project, indicating that the project implementation was successful.

5. Conclusion

The implementation of the STEM project "Modeling Spatial Images of Stellated Polyhedra" in the professional training of future professional education teachers confirmed the effectiveness of using an integrated approach to learning. During the project, students not only acquired in-depth knowledge of geometry and spatial modeling but also developed practical skills in working with modern engineering software, specifically AutoCAD. These skills are essential for successful professional activity in today's labor market, where competencies in STEM fields are increasingly valued.

The project demonstrated that building complex three-dimensional models, such as stellated polyhedra, fosters the development of spatial and critical thinking, design skills, and teamwork abilities. Thanks to the use of interactive technologies and practical activities, students mastered the techniques of creating geometric models, allowing them to integrate theoretical knowledge with practical application.

Special attention should be paid to the potential of using a project-based approach in the professional training of vocational education teachers. The implementation of such STEM projects allows future vocational education teachers not only to master modern teaching methods but also to adapt them to various educational situations, motivating higher education students to engage in independent research and experimentation. This, in turn, contributes to enhancing the quality of professional education and preparing qualified personnel for technical fields.

Thus, the STEM project "Modeling Spatial Images of Stellated Polyhedra" has proven its effectiveness as an educational tool for the professional training of future vocational education teachers. It not only provides comprehensive development for students but also helps them acquire competencies that meet the demands of the modern technological environment, preparing them for the challenges of professional activity in a rapidly changing world. The implementation of similar projects is a promising direction for further development of STEM education and the improvement of professional training for students.

Transparency:

The authors confirm that the manuscript is an honest, accurate, and transparent account of the study; that no vital features of the study have been omitted; and that any discrepancies from the study as planned have been explained. This study followed all ethical practices during writing.

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