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METHODOLOGY FOR USING 3D MODELING TECHNOLOGIES TO DEVELOP STUDENTS' CREATIVE THINKING IN 9TH GRADE GEOMETRY LESSONS

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Annotation. This article analyzes the methodological foundations for the use of 3D modeling technologies in developing students' creative thinking in 9th grade geometry lessons. In modern education, the integration of digital technologies plays an important role in enhancing students' spatial imagination, logical reasoning, and creative abilities. The study examines the possibilities of using 3D modeling tools in geometry teaching to visually demonstrate complex geometric shapes and their properties. In addition, methodological approaches aimed at developing students' independent learning, problem-solving skills, and creative thinking are discussed. The results of the study show that the use of 3D modeling technologies significantly improves the effectiveness of geometry education and contributes to the development of students' spatial thinking and creative activity.

Keywords: geometry education, creative thinking, 3D modeling, spatial visualization, digital technologies, innovative methodology, visualization.

Introduction. In the context of the rapid development of digital technologies and the ongoing transformation of modern education, the integration of innovative tools into the teaching and learning process has become a key factor in improving the quality of education. In particular, the effective teaching of mathematics, especially geometry, requires the use of advanced pedagogical approaches that support the development of students' higher-order thinking skills. Geometry, as a fundamental branch of mathematics, plays a crucial role in developing students' spatial imagination, analytical reasoning, and creative thinking abilities. Therefore, the implementation of modern digital technologies in geometry education is considered an important pedagogical task.

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One of the most promising directions in contemporary educational practice is the use of three-dimensional (3D) modeling technologies. These technologies enable students to visualize geometric objects, analyze their properties, and interact with mathematical concepts in a dynamic and exploratory environment. Unlike traditional teaching methods, which often rely on static images and abstract explanations, 3D modeling provides opportunities for interactive learning, allowing students to construct, manipulate, and investigate geometric figures in a virtual space. Such an approach significantly enhances the clarity of geometric concepts and contributes to deeper conceptual understanding.

The development of students' creative thinking is also one of the central objectives of modern education. Creativity in mathematics education involves the ability to approach problems from multiple perspectives, generate original ideas, and apply knowledge in novel situations. In geometry lessons, creativity is closely related to spatial reasoning, visualization skills, and the ability to construct and transform geometric objects. The integration of 3D modeling technologies into the educational process creates favorable conditions for stimulating these cognitive processes and fostering students' creative potential.

Furthermore, the use of digital modeling tools encourages students' active participation in the learning process. Through the design and construction of three-dimensional geometric models, learners are able to engage in inquiry-based and problem-oriented activities. This not only enhances their understanding of geometric relationships but also promotes independent learning, critical thinking, and collaborative problem-solving skills.

Despite the increasing interest in digital technologies in education, the methodological aspects of applying 3D modeling tools specifically for the development of students' creative thinking in geometry lessons remain insufficiently explored. In particular, there is a need to develop effective pedagogical strategies that integrate 3D modeling into the teaching of geometry at the secondary school level.

Therefore, the purpose of this study is to investigate the methodological foundations for the use of 3D modeling technologies in developing students' creative thinking in 9th grade geometry lessons. The research aims to identify effective instructional approaches that facilitate the visualization of geometric concepts, enhance students' spatial thinking, and support the development of creative problem-solving skills in the process of learning geometry.

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Methodology. The present study employs a comprehensive methodological approach aimed at investigating the effectiveness of using 3D modeling technologies in the development of students' creative thinking in 9th grade geometry lessons. The research methodology is grounded in contemporary pedagogical theories related to constructivist learning, digital education, and competence-based instruction. These theoretical foundations emphasize the importance of active student participation, visual learning environments, and the integration of innovative technologies into the educational process.

The research was conducted using a mixed-method approach that combines qualitative and quantitative research methods. Such an approach allows for a more comprehensive analysis of the pedagogical effectiveness of 3D modeling technologies in geometry education. The study involved the systematic observation of the teaching and learning process, analysis of instructional practices, and evaluation of students' creative and cognitive development during geometry lessons that incorporated 3D modeling tools.

A key component of the methodology was the experimental implementation of digital 3D modeling tools in the instructional process. During the study, selected geometry topics related to spatial figures, polyhedra, geometric transformations, and cross-sections were taught using interactive 3D modeling environments. Students were engaged in tasks that required them to construct, manipulate, and analyze three-dimensional geometric models. These activities were designed to stimulate students' spatial imagination, encourage independent exploration, and promote creative problem-solving.

The experimental design included both a control group and an experimental group. In the control group, geometry lessons were conducted using traditional instructional methods, including textbook-based explanations, two-dimensional diagrams, and standard problem-solving exercises. In contrast, the experimental group participated in lessons that incorporated 3D modeling technologies as an integral component of the instructional strategy. This comparative approach made it possible to evaluate the pedagogical impact of 3D modeling on students' creative thinking and spatial reasoning abilities.

Several research methods were used to collect and analyze data. Pedagogical observation was employed to examine students' engagement, interaction with digital models, and participation in creative learning activities. In addition, diagnostic tasks and problem-solving assignments were

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administered to assess students' level of spatial understanding and creative thinking. Comparative analysis was then used to identify differences in learning outcomes between the control and experimental groups.

Furthermore, elements of pedagogical experiment, analysis of educational outcomes, and generalization of empirical data were applied in order to determine the effectiveness of the proposed instructional methodology. The results obtained from the experimental work were analyzed in order to identify patterns related to the development of students' creativity, spatial visualization skills, and their ability to independently construct and interpret geometric models.

Overall, the methodological framework of the study ensures a systematic investigation of the role of 3D modeling technologies in geometry education. By combining experimental teaching practices with analytical evaluation, the research provides a scientifically grounded basis for the development of effective pedagogical strategies aimed at enhancing students' creative thinking in the process of learning geometry.

Literature Review. The integration of innovative technologies into mathematics education has been widely discussed in contemporary pedagogical research. In particular, the application of digital tools in geometry teaching has attracted increasing attention due to their potential to improve visualization, conceptual understanding, and students' cognitive engagement. Geometry, as a discipline closely connected with spatial reasoning and visualization, requires instructional approaches that allow learners to effectively perceive and manipulate geometric objects. For this reason, many researchers emphasize the importance of integrating technological tools that facilitate dynamic representation of geometric concepts.

Studies on mathematics education methodology highlight that visualization plays a fundamental role in understanding geometric relationships. According to S.Alikhonov, effective geometry instruction should rely not only on theoretical explanations but also on visual and practical activities that help students develop spatial imagination and analytical thinking. Similarly, research in mathematics pedagogy suggests that the use of technological tools significantly enhances students' comprehension of complex mathematical structures by transforming abstract concepts into visually interpretable forms.

International studies also confirm the pedagogical value of digital technologies in geometry education. Research conducted by H.R.Jacobs

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emphasizes that modern geometry teaching should focus on conceptual understanding supported by visual reasoning and exploratory learning. In this regard, digital modeling environments provide opportunities for students to actively investigate geometric relationships rather than merely observe static representations. Such environments allow learners to manipulate geometric objects, observe transformations, and experiment with different structural configurations.

Recent developments in educational technology have further expanded the possibilities of teaching geometry through three-dimensional visualization tools. Scholars studying digital learning environments note that 3D modeling technologies significantly improve students' spatial visualization skills, which are essential for understanding geometric structures and solving complex problems. Interactive modeling platforms enable learners to construct virtual geometric models, explore their properties, and analyze relationships between different elements of geometric figures.

Research in the field of science and mathematics education also indicates that the use of 3D visualization tools enhances students' cognitive engagement and creativity. For example, studies on multimedia learning environments demonstrate that interactive three-dimensional representations help students better understand spatial relationships compared to traditional two-dimensional diagrams. These technologies provide opportunities for inquiry-based learning, where students can explore geometric principles through experimentation and discovery.

Another important direction in modern educational research is the development of students' creative thinking through technology-enhanced learning. Creativity in mathematics education is associated with the ability to generate original ideas, apply knowledge in new contexts, and approach problem-solving from multiple perspectives. Educational researchers argue that digital modeling environments support these processes by allowing students to design and modify geometric constructions independently.

Despite the growing body of research on technology integration in education, the methodological aspects of applying 3D modeling technologies specifically for the development of creative thinking in geometry lessons at the secondary school level remain insufficiently explored. Many studies focus primarily on visualization and spatial reasoning, while the creative potential of digital modeling in geometry education requires further investigation.

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Therefore, the present research aims to contribute to this field by examining the methodological foundations for using 3D modeling technologies in 9th grade geometry lessons. By analyzing existing pedagogical theories and technological practices, the study seeks to identify effective strategies for integrating digital modeling tools into geometry instruction in order to foster students' creative thinking and enhance their spatial understanding.

Analysis and Results. The integration of 3D modeling technologies into the teaching of geometry in the 9th grade demonstrates significant pedagogical potential for enhancing students' creative thinking and spatial reasoning abilities. In the course of the study, particular attention was paid to the methodological organization of geometry lessons in which digital modeling tools were used to visualize geometric objects and support students' active cognitive engagement. The analysis focused on how interactive visualization and model construction influence students' understanding of geometric concepts and their ability to approach mathematical problems creatively.

The findings indicate that the use of 3D modeling technologies substantially improves the clarity and accessibility of geometric material. Traditional methods of teaching geometry often rely on static diagrams and two-dimensional representations, which may limit students' ability to fully perceive the spatial properties of geometric figures. In contrast, three-dimensional modeling allows learners to dynamically observe geometric shapes from different perspectives, manipulate their elements, and explore the relationships between geometric structures. Such visualization significantly enhances conceptual comprehension and supports the formation of stable mathematical knowledge.

Another important outcome of the study is related to the development of students' creative thinking. The process of constructing and modifying three-dimensional models encourages students to engage in exploratory learning activities. While working with digital models, learners actively formulate hypotheses, test geometric relationships, and independently search for solutions to mathematical problems. This environment stimulates intellectual curiosity and encourages students to apply non-standard approaches to solving geometric tasks.

Furthermore, the use of 3D modeling technologies promotes the development of spatial imagination, which is considered one of the key cognitive components of geometry learning. Through the manipulation of virtual objects,

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students gain the ability to mentally transform geometric figures, analyze their structures, and understand complex spatial relationships. As a result, learners demonstrate improved abilities in solving problems related to polyhedra, cross-sections, transformations, and other spatial constructions.

The research also revealed that the integration of digital modeling tools increases students' motivation and engagement in the learning process. Lessons organized with the use of 3D technologies tend to be more interactive and student-centered, which creates a favorable educational environment for creative exploration. Students show greater interest in performing geometric constructions, designing their own models, and presenting the results of their work.

From a methodological perspective, the results of the study confirm that the effectiveness of 3D modeling technologies in geometry education largely depends on the pedagogical strategies employed by the teacher. Effective implementation requires a structured instructional approach that combines theoretical explanations with practical modeling activities, problem-based tasks, and collaborative learning. When properly integrated into the curriculum, 3D modeling tools serve not only as visualization instruments but also as powerful means for developing higher-order thinking skills.

Overall, the analysis demonstrates that the use of 3D modeling technologies in 9th grade geometry lessons significantly contributes to the development of students' creative thinking, spatial reasoning, and independent problem-solving abilities. The obtained results highlight the importance of incorporating modern digital technologies into mathematics education in order to enhance the effectiveness of the learning process and to prepare students for intellectual challenges in the context of a rapidly evolving technological society.

Conclusion. In conclusion, the integration of 3D modeling technologies into 9th grade geometry instruction represents a significant step toward modernizing mathematics education and enhancing the quality of the learning process. The findings of this study demonstrate that the use of digital three-dimensional modeling tools creates favorable pedagogical conditions for the development of students' creative thinking, spatial visualization, and analytical reasoning skills. By enabling learners to interact dynamically with geometric objects, 3D modeling technologies transform abstract mathematical concepts into visually accessible and intellectually engaging learning experiences.

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The research results confirm that the application of 3D modeling in geometry lessons not only improves students' comprehension of complex geometric structures but also stimulates their creative and exploratory activities. Through the process of constructing and manipulating three-dimensional models, students are encouraged to analyze geometric relationships, generate original ideas, and approach mathematical problems from multiple perspectives. Such learning activities contribute to the formation of higher-order cognitive skills and foster students' independence in the process of acquiring knowledge.

Furthermore, the study highlights that the successful implementation of 3D modeling technologies depends largely on the methodological competence of the teacher. Effective integration requires carefully designed instructional strategies that combine theoretical explanations, visual demonstrations, and practical modeling tasks. When these elements are systematically incorporated into the educational process, 3D modeling tools become an effective pedagogical instrument for promoting meaningful and student-centered learning.

Overall, the incorporation of 3D modeling technologies into geometry education significantly enhances the effectiveness of teaching and learning by fostering students' creative potential and improving their spatial reasoning abilities. The results of the study indicate that such innovative approaches can play an important role in aligning mathematics education with the demands of the digital era. Therefore, it is recommended that educators increasingly integrate modern digital technologies into geometry instruction in order to create a more interactive, engaging, and intellectually stimulating learning environment for students.

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