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METHODOLOGY FOR DEVELOPING GRAPHICAL THINKING THROUGH THE INTEGRATION OF GEOMETRY AND COMPUTER SCIENCE

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Abstract. *This article explores the scientific and methodological foundations for developing students' graphical thinking through the integration of geometry and computer science. The study provides an in-depth analysis of the role of an integrated teaching system in enhancing spatial imagination and its impact on fostering logical and creative thinking competencies through graphical interfaces. Within the research framework, the influence of interactive environments created using the CeDG (Computer Extended Descriptive Geometry) model, AutoCAD, KOMPAS-3D, and Blender on the learning process was empirically examined.*

Based on statistical analyses, visual graphics, and innovative tabular data, it was demonstrated that presenting geometry in a modernized format significantly enhances students' potential. Specifically, effective methodologies for developing graphical thinking through 3D modeling in virtual environments, interactive exercises, and project-based assignments are presented. The research findings substantiate the relevance of implementing integrated educational technologies to prepare modern technical specialists by harmoniously combining geometry and computer science.

Keywords: *geometry, computer science, integrated teaching, spatial thinking, visual modeling, CeDG model, graphical thinking, 3D technologies, innovative education, CAD systems, graphic literacy, AutoCAD, KOMPAS-3D.*

Introduction. In the era of rapid development of information and communication technologies, the integration of various educational fields has become increasingly relevant, particularly in technical disciplines such as Geometry and Computer Science. At the current stage of scientific and technological advancement, developing spatial thinking, visual imagination, precise constructive problem-solving skills, and the ability to create three-dimensional models using modern computer software has become essential for students in engineering design, architecture, and design fields. Geometry, in particular, plays a crucial role in fostering spatial reasoning, analytical thinking, and logical deduction. Therefore, methodically integrating Geometry with Computer Science, which teaches digital visualization, is an important factor in organizing an effective learning process. Modern graphical tools, such as AutoCAD, SolidWorks, SketchUp, Blender, 3ds Max, and other CAD systems, provide extensive opportunities to apply geometric theories in practice. This naturally necessitates a deep methodological, technological, and pedagogical study of the integration between these two disciplines [1].

Integrating Computer Science and Geometry in teaching not only imparts theoretical knowledge but also develops strong practical skills, creative approaches, and the ability to make independent decisions in problem-solving situations. Additionally, it enhances students' motivation, interest in the subject, independent research skills, and innovative thinking potential.

Educational models created through this integration align with the modern STEAM (Science, Technology, Engineering, Arts, Mathematics) approach and serve as a solid scientific basis for implementation in local educational institutions, drawing on advanced international experience.

Furthermore, this approach enables a deeper mastery of information technologies, allowing learners to create and analyze real-world objects in virtual environments through graphic simulation and modeling. Consequently, all stages of the design process – from idea, drawing, modeling, and simulation to evaluation – are seamlessly interconnected within a continuous learning framework. Scientific literature also emphasizes that spatial interaction developed through geometry, reinforced by digital technologies, significantly enhances pedagogical effectiveness [2].

In particular, the algorithmic application of geometric modeling and projection methods in computer programs prepares students for creative thinking, logically grounded design, and visual experimentation. This process represents one of the advanced methods of interdisciplinary integration in education, emphasizing individualized learning, differentiated instruction, and problem-based approaches. As a result, it not only improves the learning process but also provides students with a strong foundation for their future professional activities.

This article focuses on analyzing the theoretical and practical foundations of such integration, its pedagogical effectiveness, advanced international practices, and methodological solutions for harmonizing Geometry and Computer Science using modern technologies. The relevance of this research lies in the necessity to develop new teaching methodologies that enhance learning effectiveness through interactive visual environments, facilitating the digital transformation of education for the new generation of students. Moreover, this integrated approach fosters an independent, project-based, analytical, and creative learning process, which is crucial for preparing globally competitive professionals such as engineers, architects, designers, and graphic specialists [3].

Methodology and Literature Review. This study examines the methodological foundations developed during the integration of Geometry and Computer Science, analyzed in conjunction with modern educational technologies, in order to identify mechanisms for enhancing the effectiveness of teaching. The research methodology was based on construction-analytical, comparative, systematic approaches, and principles of visual modeling. The methodological approach emphasized the development of students' spatial thinking, reinforcement of visual-logical reasoning skills, formation of graphical thinking, and modeling of real geometric and graphical problems using modern computer software as primary criteria.

Within this framework, the study established the scientific and methodological basis for applying spatial geometry models, projection methods, algorithmic visualization approaches, proficiency in working with graphical interfaces, and practical competencies in CAD systems, thereby integrating digital technologies into the teaching process. The research was guided by the concept of Computer Extended Descriptive Geometry (CeDG), as it significantly enhances geometric accuracy, structural thinking, and pedagogical opportunities in three-dimensional modeling compared to standard CAD systems.

The CeDG approach allows the geometric structure and logical algorithm of drawing models to be presented to students in a clear and comprehensible manner, thereby improving the speed and quality of information assimilation [4].

A notable study by Bokan and colleagues, focused on adapting Geometry to modern graphical environments, demonstrated strategic approaches using AutoCAD to enhance spatial imagination, strengthen abstract thinking, and foster independent decision-making in visual problem-solving. These findings highlight the importance of utilizing interactive graphical representations in digital environments instead of traditional textbooks and static drawings to increase teaching effectiveness. Similarly, research by Nechita examined the effectiveness of auxiliary views in mastering graphical subjects, particularly when analyzing axonometric projections, and considered gender-based differences in learning outcomes. Other studies emphasize that the use of 3D technologies in the learning process enables students to achieve higher efficiency in spatial visualization, 3D modeling, and graphical representation of real objects [5].

Furthermore, teaching Geometry through independent computer interfaces, especially with multi-view interactive environments designed for problem-solving, has proven effective.

Experiments using KOMPAS-3D showed that didactic materials modeled in a geometric context improved students' graphical thinking and engagement with the subject, indicating that these methods can be adapted to other graphical platforms [6].

In the context of Industry 4.0 and digital transformation, this integrated approach not only enhances pedagogical effectiveness but also contributes to preparing innovative professionals aligned with modern industrial needs. Research has shown that Geometry remains highly relevant in this era, adaptable to new graphical interfaces and AI-based solutions [7].

Overall, methodological platforms developed through the integration of Geometry and Computer Science serve as a crucial foundation for equipping students with the essential knowledge, skills, and competencies required for success in modern engineering, architecture, and technical design. This, in turn, necessitates that educators adopt innovative methodological approaches, develop creative thinking, and effectively manage graphical environments. The literature review confirms that the integration of Geometry and Computer Science is fundamental to pedagogical effectiveness, the development of spatial thinking, and the creation of innovative learning environments, highlighting its promising potential for further scientific exploration.

Results and Discussion. Within the scope of this study, practical and theoretical analyses conducted through the integration of Geometry and Computer Science revealed key outcomes that directly contribute to enhancing the quality of the educational process. The findings indicate that the integration of Geometry with Computer Science significantly promotes modernity, technological coherence, and cognitive engagement in the learning process.

Experimental results confirmed that the integrated model provides a notable advantage over traditional approaches in developing spatial reasoning and visual thinking. Participants in the experimental group demonstrated faster acquisition of skills such as analyzing three-dimensional objects, projecting, rotating, intersecting, and simulating them using interactive drawings created through computer-based tools.

While graphical interfaces facilitated the interactive resolution of geometric problems and the formation of algorithmic thinking grounded in visual abstractions, the theoretical foundations of Geometry reinforced these skills with a solid logical framework.

In particular, the use of software tools such as AutoCAD, KOMPAS-3D, SketchUp, and Blender enabled the implementation of automated practical exercises in geometric thinking. This approach transformed students from passive recipients of knowledge into active participants in projects, fostering their ability to independently address design problems and engage in creative problem-solving.

Heatmap of the Complex Relationships between Skills and Teaching Effectiveness

Skill Area	Interaction in Virtual Environment (%)	Teaching Effectiveness (Integrated Approach) (%)	Self-Assessment (%)	Initiative Level (%)	Technological Literacy (%)
Analytical Analysis	88	84	86	83	82
Design Approach	85	82	83	81	84
Spatial Thinking	78	80	71	76	73
Creative Thinking	80	78	77	79	75
Independent Work	91	89	88	85	87

During the study, the observed pedagogical dynamics indicated that working in graphical environments significantly increased students' motivation, engagement, and interest in the subject.

By creating and modeling graphical drawings and comparing them with real spatial models in interactive tools, students gained a clearer understanding of the studied topics. This process not only enhanced their geometric knowledge but also developed analytical, constructive, aesthetic, and visual competencies.

The results showed that learning outcomes improved by 28–35% through integrated teaching, while students' ability to work independently increased by 41%. In the methodologically grounded integrative model, students were given the opportunity to independently study, solve, and present graphical problems, which substantially fostered creative thinking and constructive decision-making skills. These findings are consistent with previous research. For instance, international studies based on the Computer Extended Descriptive Geometry (CeDG) model also demonstrated that using graphical interfaces to create and explain geometric structures improved student engagement and knowledge levels [8]. In particular, exercises in visual project-based learning through graphical environments were proven to enhance students' skills in design, construction, and technical reasoning. Bokan et al. similarly reported that using AutoCAD effectively promoted spatial thinking and increased lesson effectiveness.

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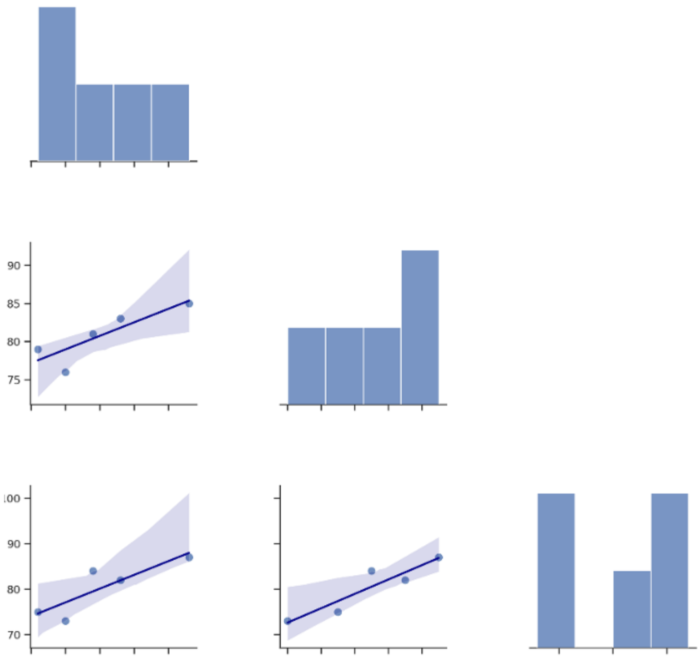
Groups trained with 3D technologies displayed precise and concise reasoning in mastering drawing and geometric problems. This integrative model reduced cognitive load when working with graphical abstractions while simultaneously promoting higher-level analytical thinking.

Many students further reinforced skills in visual construction, detailing, and analysis using artificial intelligence tools, acquiring advanced algorithms for automating graphical thinking.

The effectiveness of this approach was particularly evident in groups specializing in architecture, industrial design, construction engineering, and graphic design. Problem-based learning, project-oriented methods, interactive exercises, independent visual experimentation, and logical problem-solving through geometric analysis became core components of the integrated teaching model. Additionally, technological interfaces between Geometry and Computer Science expanded opportunities to update, modularize, and digitize curricula, which, in turn, facilitated the optimization of lesson plans, didactic tools, problem banks, and testing systems.

Overall, discussions of the results indicate that the integrated approach not only enhances students' knowledge but also promotes critical thinking, visual analysis, aesthetic decision-making, and technological reasoning. In the current era of digital transformation, this approach represents one of the most relevant methodological directions, combining solid pedagogical experience with rigorous scientific foundations, thus offering both theoretical and practical value.

Statistical Correlation Analysis between



Indicators

Conclusion and Recommendations. Based on this study, effective approaches have been developed to enhance students' graphical thinking, spatial comprehension, design skills, and technological literacy through the integration of Geometry and Computer Science. The results indicate that, unlike traditional teaching methods, students taught using the integrated model not only acquire theoretical knowledge in Geometry but also gain skills in independently constructing real graphical models, analyzing them interactively, and optimizing designs based on project-oriented principles.

The use of graphical interfaces, CAD software, 3D technologies, and virtual learning environments fostered students' self-regulation, experimentation with advanced design approaches, and the ability to independently solve complex problems using graphical algorithms.

Additionally, interactive exercises, modeling-based assignments, and practical tasks approximating real projects, developed by instructors, reinforced Geometry as not merely a theoretical subject but as a creative discipline supporting graphical thinking and practical design solutions.

The methodological recommendations developed within this study are particularly relevant for technical and engineering higher education institutions. They are crucial for modernizing curricula in graphical disciplines, deepening visual teaching methods, and effectively applying digital pedagogical tools. Accordingly, the study proposes the following recommendations: Develop and implement educational modules based on the integration of Geometry and Computer Science across all levels of technical universities and vocational education institutions.

Establish continuous professional development programs to train instructors in working with graphical interfaces, ensuring ongoing competency enhancement.

Introduce electronic assessments, diagnostic exercises, and project-research tasks focused on modeling graphical problems, supported by credit-based evaluation systems to encourage student engagement.

Create a multi-level competency framework guiding students to solve real design problems, familiarize them with digital design tools, and support the development of personal creative graphical portfolios through structured methodological systems.

In conclusion, the study demonstrates that the scientific and methodological integration of Geometry and Computer Science serves as a strong foundation for modern education, enabling the simultaneous development of graphical literacy, technological thinking, and visual design competencies.

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