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Актуальні питання формування курсу «Інженерна та комп'ютерна графіка» для здобувачів інженерних спеціальностей

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Анотація. Постановка проблеми. *Тенденції розвитку сучасної вищої школи інколи призводять до наслідків, які негативно впливають на рівень підготовки*

майбутніх фахівців. Зокрема, скорочення годин, відведених на вивчення курсу інженерної та комп'ютерної графіки, передбачене в нових освітніх програмах, значно ускладнює якісну підготовку студентів інженерних спеціальностей, зокрема в частині оволодіння пакетами систем автоматизованого проєктування. Додатковим чинником є недостатня базова математична підготовка студентів, що обмежує їхню здатність повною мірою використовувати можливості сучасних графічних пакетів та застосовувати інтегровані засоби програмування для автоматизації проєктних задач.

Мета. *Метою цієї статті є огляд існуючої практики викладання дисципліни інженерна та комп'ютерна графіка, виявлення її ключових обмежень та обґрунтування шляхів підвищення ефективності засвоєння студентами навичок геометричного моделювання у сучасних системах автоматизованого проєктування на рівні, що перевищує рівень звичайного користувача.*

Методи. *У роботі використано такі методи наукового пізнання: аналіз існуючих методик викладання дисципліни інженерна та комп'ютерна графіка, огляд сучасних наукових публікацій з проблематики інтеграції 3D-технологій та CAD-систем в інженерну освіту, а також теоретичний синтез математичних основ геометричного моделювання в середовищі САПР. У роботі визначено напрям та засоби підвищення фахової підготовки студентів і окреслено перспективи подальшого розвитку методики викладання відповідної дисципліни.*

Результати. *Встановлено, що традиційна методика викладання інженерної та комп'ютерної графіки суттєво обмежує потенціал використання студентами повного спектру можливостей сучасних CAD-пакетів. Запропоновано доповнити базовий курс елементами векторної алгебри та векторного аналізу – зокрема параметричним визначенням кривих і поверхонь, перетворенням координат у тривимірному просторі та кінематичними поверхнями – а також основами програмування для автоматизації проєктних задач засобами, інтегрованими в САПР. Обґрунтовано, що такий підхід сприяє формуванню*

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компетентностей, що виходять за межі рівня стандартного користувача, і забезпечує більш глибоке та ефективне використання сучасного графічного програмного забезпечення.

Висновки. *Подальший розвиток методики викладання інженерної та комп'ютерної графіки тісно пов'язаний з включенням до курсу основ математичного апарату дослідження плоских та просторових об'єктів. Таку підготовку слід розглядати як базову умову формування повноцінної інженерно-графічної компетентності, що дозволяє студентам самостійно налаштовувати програмне забезпечення під власні задачі та ефективно автоматизувати процеси проєктування. Перспективами подальших досліджень є розробка конкретних навчально-методичних матеріалів і практичних завдань для самостійної роботи студентів, спрямованих на опанування засобів програмування, інтегрованих у сучасні САПР-пакети.*

Ключові слова: *системи автоматизованого проєктування, геометричне моделювання, векторний аналіз, інженерна графіка, параметричне моделювання, засоби програмування, кінематичні поверхні, вища інженерна освіта.*

Current Issues in the Development of the ‘Engineering and Computer Graphic’ Course for Engineering Students

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Abstract. Objective. *Certain trends in the development of contemporary higher education have given rise to consequences that adversely affect the quality of future specialists' preparation. In particular, the reduction in instructional hours allocated to engineering and computer graphics – as stipulated in newly adopted curricula – substantially complicates the effective training of students in engineering specializations, especially regarding proficiency in CAD software packages. A further contributing factor is students' insufficient foundational mathematical preparation, which limits their ability to fully leverage the capabilities of modern graphics packages and to employ integrated programming tools for the automation of design tasks.*

Objective. This study reviews current practices in the teaching of engineering and computer graphics, identifies their key limitations, and substantiates pathways for enhancing the effectiveness of students' acquisition of geometric modeling skills in modern CAD systems at a level that exceeds standard user proficiency.

Methods. *The study employs the following research methods: analysis of existing methodological approaches to teaching engineering and computer graphics; a review of recent scholarly publications on the integration of 3D technologies and CAD*

systems into engineering education; and theoretical synthesis of the mathematical foundations underlying geometric modeling in CAD environments. The study defines the direction and means for advancing students' professional preparation and outlines prospects for the further development of the discipline's teaching methodology.

Results. *It has been established that conventional methodologies for teaching engineering and computer graphics significantly limit students' ability to utilize the full range of capabilities offered by modern CAD packages. The study proposes supplementing the foundational course with elements of vector algebra and vector analysis – including the parametric definition of curves and surfaces, coordinate transformations in three-dimensional space, and kinematic surfaces – as well as programming fundamentals for automating design tasks using CAD-integrated tools. It is argued that this approach fosters the development of competencies that extend beyond standard user proficiency, enabling deeper and more effective engagement with modern graphics software.*

Conclusions. *The further advancement of engineering and computer graphics pedagogy is closely tied to the incorporation of mathematical foundations for the study of planar and spatial objects into the course curriculum. Such preparation should be regarded as a prerequisite for the development of comprehensive engineering-graphic competence, enabling students to independently configure software for their own design needs and to effectively automate design workflows. Directions for further research include the development of targeted instructional materials and practical assignments for students' independent study, aimed at building proficiency in the programming tools integrated into contemporary CAD packages.*

Keywords: *computer-aided design, geometric modeling, vector analysis, engineering graphics, parametric modeling, programming tools, kinematic surfaces, higher engineering education.*

Statement of the Problem. Given the high professional standards expected of future engineers, the contemporary study of engineering computer graphics can no longer be confined to mastering the fundamentals of engineering graphics and the ability to operate CAD tools. The future specialist must be a well-rounded professional in modern technology. Accordingly, the content of the engineering and computer graphics discipline should be supplemented with the mathematical foundations of analytical principles of geometric modeling, along with selected elements of programming. These additions would enable the introduction of programming fundamentals into the course, with a focus on the use of CAD-integrated tools for automating specific tasks, while also providing students with the capacity to independently configure software to meet their particular needs.

Review of Recent Research and Publications. Review of Recent Research and Publications. The body of scholarly work devoted to the study of engineering disciplines is continuously enriched by the contributions of Ukrainian scholars – not only in the teaching of graphic and engineering disciplines for higher education students, but also in the investigation of the possibilities and practical implementation of 3D technologies in the educational process and in various areas of engineers' future professional activity. The professional competence of an engineer is largely determined by the specifics of the graphic preparation of students in engineering specializations, considering the close relationship between graphic activity and the professional activity of an engineering specialist, as well as the specifics of working with graphic forms of information.

The increasing demands placed on higher education students in the fields of mechanical engineering, manufacturing, and transportation are addressed by Koziar, who argues that the labor market requires graduates to rapidly adapt to working conditions, successfully complete production tasks, and engage in continuous professional development. In this context, higher education institutions are challenged to identify new approaches and improve existing teaching methods to ensure high-

quality specialist preparation. The rapid advancement of engineering and technology necessitates the application of cutting-edge technologies and modern design algorithms for creating innovative structures and high-quality products within the shortest possible timeframes – a context in which 3D modeling is playing an increasingly significant role [1, P. 143–146]. The potential of 3D modeling for the development of competencies in engineers specializing in mechanical engineering is examined in detail by Stozhok, Koziar, and Tovt [2, P. 855–877]. The theoretical and methodological foundations for the development of graphic competence and technical thinking in higher education institutions through the use of computer technologies are defined by Raikovska [3, P. 235–237; 4, P. 169–173].

The relationship between graphic preparation and the professional competence of engineers is further explored by Boiko, who demonstrates that the level of students' graphic training in engineering specializations significantly determines their overall professional readiness. The author examines approaches to the application of computer graphics software, with particular emphasis on the integrated use of AutoCAD and Fusion 360, and develops criteria, indicators, and levels of engineering-graphic preparation regarded as the outcome of implementing a substantiated teaching methodology for future mechanical engineers [5; 6, P. 40–45; 7, P. 15–20].

The integration of 3D technologies and robotics into engineering education is addressed by Strutynska, who identifies project-based activity as a key implementation pathway. In her view, robotics and 3D technologies constitute an effective method for studying key fields of science and engineering design, grounded in the active use of modern technologies in production and the high level of preparation required of specialists working in an innovation-driven economy [8, P. 96–109].

The role of independent creative activity in the professional preparation of future specialists in computer-related fields is highlighted by Kabak, who emphasizes that project-based learning enables students to produce tangible final outcomes – such as three-dimensional models, assembly units, mechanisms, or simulations of

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technological processes [9, P. 25–28]. Such activity presupposes broad, multidisciplinary knowledge and skills on the part of the student.

Graphic competence as a constituent of the engineer's broader professional competence is investigated by Dzhedzhula, who argues that this competence encompasses preparedness for the conscious application of graphic knowledge and skills, grounded in an understanding of the functional and structural characteristics of technical objects, the principles of their design, the specifics of technological processes, and practical experience in professionally oriented graphic activity – including the effective use of graphic computer technologies for production, communication, and conceptual tasks [10].

The demands that current technological development places on the preparation of engineers in technical specializations are analyzed by Karpiuk, Davidenko, and Duryshev, who maintain that the most in-demand specialists in the labor market are those with systematic, comprehensive knowledge in their professional field. Since 3D modeling is grounded in classical methods of engineering graphics, foundational elements such as projection drawing are identified as essential prerequisites for the subsequent successful use of computer models [11, P. 43–47]. The impact of mastering CAD system tools on specialist preparation and labor market competitiveness is examined by Savelieva and Pustovoi, whose findings confirm that the integration of CAD proficiency into the educational process contributes to the intensification of learning and a significant enhancement of graduates' professional competitiveness [12, P. 146–150]. Interdisciplinary connections between technical and natural science disciplines through the use of 3D modeling are explored by Feshchuk and Myslynchuk [13, P. 72–78]. The application of three-dimensional and four-dimensional modeling not only for product visualization but also for its transformation in time and space – thereby opening new possibilities for design, engineering, and modernization of technical objects – is considered by Parfeniuk [14, P. 20–23].

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Modern technologies and tools for 3D modeling and 3D printing in higher education institutions are the focus of research by Voitsekhivska and Karavaiev, who argue that the adoption of 3D printing technology in higher education contributes to increasing the accessibility and quality of education through the physical realization of objects under study, the development of working project designs, the digitization of existing parts and mechanisms, and the enhancement of the visual quality of educational and methodological materials [15].

Identification of Previously Unresolved Aspects of the Problem. For the engineering training of higher education students, one of the most important skills is proficiency in computer-aided design systems. Current methodologies do not allow future specialists to fully utilize the capabilities of graphics packages. This is due to insufficient foundational mathematical preparation and, consequently, an inability to employ programming tools for automating the construction of engineering drawings.

Formulation of the Article's Objectives (Statement of the Task). The purpose of this article is to substantiate pathways for increasing the effectiveness of students' acquisition of geometric modeling skills in modern CAD systems at a level that exceeds that of an ordinary user. This may be achieved not only through the study of the functional capabilities of a specific system, but also through mastery of foundational knowledge in the mathematical description of geometric objects and methods of their analytical modification. The proposed approach will enable students to more productively employ automated tools for creating models of various technical objects using integrated programming languages.

Presentation of the Main Research Material. The contemporary dynamic development of science and technology is inconceivable without various computer-aided design (CAD) systems. One of the key components of these systems is computer engineering graphics, which draws upon mathematical methods of geometric modeling. The importance of this field lies in the fact that the creation and

manufacturing of technical objects require precise determination of their dimensions and form.

Historically, engineering drawings were the only effective means of conveying geometric information about technical products. They enabled the representation of the spatial characteristics of objects through projections onto selected planes, providing an accurate and clear depiction of the forms and proportions required for manufacturing or structural evaluation. The advent of the first two-dimensional CAD systems marked a significant breakthrough in this field, as developers gained the ability to produce graphic documentation using computer technologies. However, this considerable technical advance did not eliminate the traditional need to represent objects in planar form. Engineering drawings, despite the introduction of new digital tools, remained an integral part of the design process, ensuring the necessary precision and compliance with established standards.

Modern automated 3D modeling systems enable developers to work effectively with three-dimensional geometric models that realistically represent the objects being designed.

Accordingly, within the framework of training future engineering specialists, the acquisition of in-depth knowledge and solid practical skills in working with CAD software packages plays a critically important role. This constitutes a key component of the educational process, as proficiency in such software enables engineers to solve complex technical problems, develop modern designs, and improve production processes.

Traditionally, the process of studying computer graphics can be divided into several stages. In the first stage, students become acquainted with the package interface and learn to configure dimensional and text styles, among other settings. Subsequently, the system's capabilities for creating graphic primitives – such as lines, polylines, splines, and polygons – are examined. The next step involves studying editing

commands (move, rotate, scale, array creation, etc.), as well as the methods and specifics of dimensioning.

A natural continuation of this topic is the application of parametric tools to the created objects. The following stage introduces students to the library of available three-dimensional graphic objects, Boolean operations, and 3D commands for moving, copying, rotating, and other manipulations. The use of section planes for generating cross-sections of parts is also studied. This stage concludes with the construction of a three-dimensional model of an object. The final stage of mastering the software package consists of composing a working drawing of the part based on the developed 3D model. However, this teaching methodology significantly limits students' ability to utilize the full range of resources offered by the software package.

There is currently a clear trend toward reducing the number of hours allocated to computer graphics instruction. Nevertheless, an important resource frequently remains underutilized – students' independent study time. To enhance the skills of effective system use, it is proposed to expand the foundational course to include the basics of analytical principles of geometric modeling. High-quality theoretical preparation of users fosters the development of deep foundational knowledge regarding the functioning of graphics packages, facilitating the rapid acquisition of new material and the subsequent productive use of modern CAD systems.

Since geometric modeling of technical objects in CAD systems is implemented using vector representation, comprehensive preparation in this area must encompass two key components: vector algebra and vector analysis. Within vector algebra, vectors – or directed line segments – are treated as constant quantities, whereas in vector analysis they are treated as variables, enabling the study of their behavior under dynamic conditions.

The key topics within vector analysis that merit particular attention include:

- the concept of the radius vector **r** (x, y, z) in a rectangular Cartesian coordinate system

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- curved lines and their parametric equations
- the concept of a tangent to a curve
- the parametric definition of surfaces and curves on a surface
- coordinate transformations in three-dimensional space, which may be regarded as the analytical foundation for the use of user coordinate systems.

Also relevant is the study of analytical methods for defining lines and surfaces in space, including:

- second-order curves in parametric form
- composite curves
- parametric surfaces.

Since the kinematic approach is widely used in CAD for shape generation, an important topic for study is kinematic surfaces – including ruled surfaces with generatrix and directrix lines, as well as translation and rotation surfaces.

Acquisition of foundational knowledge in the analytical description of geometric objects, together with command of the mathematical apparatus for translation, rotation, and scaling operations, will enable students to progress toward mastering the system's capabilities in automated construction using CAD-integrated programming tools.

Conclusions. In the context of engineering education, professional competence may be understood as an integrated system encompassing a foundation of technical knowledge, design and engineering skills, and a creative approach to solving engineering problems. Current methodologies for training specialists in the field of computer-aided design substantially limit students' ability to fully exploit the capabilities of available software packages – a shortcoming attributable to insufficient foundational mathematical preparation and the resulting inability to employ programming tools for design automation tasks.

The approach proposed in this study – supplementing the engineering and computer graphics course with the fundamentals of vector analysis, analytical

description of geometric objects, and selected elements of programming – addresses these limitations and enables the development of competencies that extend beyond the level of a standard CAD user, fostering deeper and more effective engagement with modern graphics software. Directions for further research include the development of targeted instructional materials and practical assignments for students' independent study, aimed at building proficiency in the programming tools integrated into contemporary CAD packages.

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