The use of modeling in the teaching of geometry and graphic disciplines at the University

Ekaterina A Vanshina¹, Olga N Shevchenko², Olga N Malikova³, Oksana L Staselko⁴ and Irina V Shusharina⁵

¹ associate Professor of Department of descriptive geometry, engineering and computer graphics FSBEI "Orenburg state University", 13, Pobedy Ave., Orenburg, 460018, Russia
² head of the Department of descriptive geometry, engineering and computer graphics, FSBEI "Orenburg state University", 13, Pobedy Ave., Orenburg, 460018, Russia
³ associate Professor of Department of descriptive geometry, and graphics FSBEIHE "Industrial University of Tyumen", 2, UL. Lunacharskogo, Tyumen, 625001, Russia
⁴ senior lecturer of the Department of descriptive geometry and graphics FSBEIHE "Industrial University of Tyumen", 2, UL. Lunacharskogo, Tyumen, 625001, Russia
⁵ senior lecturer of the Department of descriptive geometry and graphics FSBEIHE "Industrial University of Tyumen", 2, UL. Lunacharskogo, Tyumen, 625001, Russia

E-mail: reptyf@mail.ru

Abstract. 1. Introduction: In connection with the introduction of new Federal state educational standards of higher education (FSES) to teachers of geometry graphic departments there was a problem with the revision of the contents and methodology of teaching disciplines "descriptive geometry", "Engineering and computer graphics", foundations of engineering education aimed at formation of basic knowledge for studying of the subsequent disciplines used graphic representation of information. The analysis of special literature has indicated that, despite the significant number of scientific publications on the research topic, the use of modeling in teaching geometric-graphic disciplines requires separate research. 2. Materials and methods: Study and analysis of scientific, educational and special literature on the research topic, comparison, systematization, synthesis, generalization. 3. Results: To implement modern teaching methods in the educational process in the geometric-graphic disciplines, the author applied the functionality of the system KOMPAS-3D and developed by: electronic slides based on the modeling included in the evaluation funds for engineering and computer graphics; set a clear three-dimensional (3D) models of twenty-assemblies products intended for assignments on practical and laboratory lessons on the computer in the system KOMPAS-3D to create an Assembly and working drawings; set of individual tasks designed to practical assignments on the computer in this system to create 2D-models of assemblies (Assembly drawings) and 2D models details (working drawings), associated with their three-dimensional models. 4. Discussion and Conclusions: Design and creation of didactic materials based on three-dimensional and flat modeling tools, methods and algorithms of computer graphics in the system KOMPAS-3D, their use in teaching geometric-graphic disciplines, the inclusion in the evaluation funds on descriptive geometry, engineering and computer graphics, contributes to the introduction of active learning methods to optimize the educational process of teaching of geometry and graphic disciplines.
1. Introduction

Creating high-quality products in modern conditions of industrial development implies the use of high-tech complexes and systems requiring qualified maintenance. Accordingly, special requirements are imposed on training of the engineering and technical staff. They should be capable to perform effective work in their specialty, to make high-quality decisions based on operational information, communicative and responsible.

The developed teaching aids, that are required for an effective educational process aimed at new computer technology development, should include modern software and technical means for industrial use [2].

The adoption of the new FSES, that has been driven by natural changes in industry, education system, and public life, requires updating of the educational process and introducing new special disciplines. There is a need to adjust the allocation of time for the educational process due to a decrease in classroom study hours and, accordingly, an increase in hours for independent study of the material by students. In this context, it is impossible, without the use of information technology, to train a highly qualified specialist who can work independently and apply the acquired skills.

Thus, the demand for a detailed development of the scientific methods for teaching geometric-graphic disciplines, focused on the development of the student’s personality and on the modern production needs, was disclosed in [28].

The analysis of scientific and pedagogical publications on the topic of our study suggests that, despite a great number of studies on the development of methods, didactic materials, techniques for teaching graphic disciplines, it is important to sever the use of modeling in teaching as an independent area of scientific research.

The use of computer-aided design systems in the educational process is a prerequisite for implementing the educational standards for the geometric-graphic disciplines, mastering of which requires spatial thinking and the ability to understand and to reproduce graphic information [12].

In descriptive geometry, drawing up images is based on the projection method, which allows displaying volumetric elements on a plane. Images on a plane are usually called projections used to solve spatial engineering and geometric problems. A comprehensive perception of the original object and its projections is the main difficulty for students who need a lot of effort, ability, and time to overcome it.

Undeniable is the need to develop spatial thinking as the main characteristic of the engineer’s technical intelligence [29]. The use of volumetric computer graphics, animation, and electronic slides for teaching geometric-graphic disciplines greatly simplifies the task of visual representation of geometric objects. In our opinion, the development of spatial imagination is facilitated by the use of modeling-based didactic materials.

The purpose of this study is to develop didactic materials based on modeling and to test them in the university’s educational process.

The objectives of the study are:

- developing and creating didactic materials (electronic slides, sets of problems) in geometric-graphic disciplines using the volumetric and plane modeling principles;
- testing the didactic materials in the university’s educational process;
- applying the didactic materials in the evaluation funds in geometric-graphic disciplines.

The scientific novelty of the study lies in the development of modeling-based didactic materials (electronic slides, sets of tasks for practical exercises) and their implementation in the educational process, educational publications, and evaluation funds in geometric-graphic disciplines.

The reliability and scientific validity of the results obtained are provided through a comprehensive use of modern research methods, the comparison of research results with the studies and conclusions of domestic and foreign authors, an analysis and generalization of scientific publications on the didactic aspects of teaching geometric-graphic disciplines, and the latest domestic and international
research on the problem under consideration. In addition, we reviewed publications on the development and implementation of computer graphics in the educational process, the use of innovative technology based on 3D modeling in teaching geometric-graphic disciplines.

2. Materials and methods
The paper analyzes the service functions and capabilities of KOMPAS-3D, a modern system of 3D solid-state modeling (ASCON, CJSC, http://www.ascon.ru) in the development of didactic materials for geometric-graphic disciplines based on volumetric and plane modeling.

3. Results
Modern CAD systems, including KOMPAS-3D, actively use methods of volumetric and plane modeling to create geometric models of designed objects.

Computer graphics makes it possible to automate the design document management, the tasks of which include presentation, preparation for visualization, creation, and implementation of actions with an image.

Today, many software programs are systems for interactive computer graphics, where the user can control the object properties.

CAD uses wireframe, polygonal, and volumetric models, which are the main types of mathematical models of geometric objects.

It is known that structural elements of a wireframe model are a face and a point. This model is used to describe engineering objects with flat approximating surfaces. Geometric objects on a plane can be represented using wireframe models. Such images are ambiguous and do not allow for automating the processes of removing invisible lines and obtaining sections.

Complex curved faces of engineering objects can be described using polygonal models. To build such a model, you have to involve the algorithm for creating an object by performing logical operations of intersecting or touching surfaces.

When creating a polygonal model, any surface is approximated by a polyhedron; all its faces are the simplest flat polygons; this process also uses quadrics and curved surfaces, allowing to carry out complex calculations and to work interactively with the model (examples are the Koons and Bezier surfaces).

An advantage of replacing complex surfaces with flat faces is the simplicity of mathematical methods when working with such models. A drawback of the method is an increased number of in-machine calculations and the memory used upon complicating the object shape or increasing the design object size through increasing the number of its faces.

Volumetric models allow rendering complex engineering objects with a high accuracy. The structural elements of such a model are a point, a contour element, and a surface. Structural elements form nodes of a network structure in the process of synthesizing a volumetric model. Using such a model, points can be divided into internal and external ones in relation to a real object at any time.

Requirements for high-level geometric modeling (Y. Gardan, M. Lucas) are: model regularity; ability to comprehensively create a complex object; ability to calculate engineering and geometric parameters. A model must be uniform, finite, rigid, compact, and open.

When modeling complex solid-state objects, the generatrices of which are curved lines, it is most expedient to use the basic types of mathematical models for geometric objects. This makes the algorithm for solving engineering-geometric problems of computer-aided design extremely simple.

Modeling is an essential element of any applied research or engineering development.

According to the Big Soviet Encyclopedia, modeling is "a study of real objects of knowledge on their models; creating and studying models of objects and phenomena (living and inanimate systems, engineering structures...) and constructed objects (to determine, identify their parameters, to rationalize their creation methods...)".
Computer geometric modeling associated with computer graphics includes methods and algorithms for the internal representation and transformation of geometric models on a computer. Models in computer graphics can be 2D: two-dimensional or flat or 3D: three-dimensional or volumetric. The use of applied software for the development and execution of design technical documents implies the use of flat 2D vector modeling in two ways:

- the user sequentially sets the primitive to be created, and a list of relations and primitives where these relations are defined;
- first, the object to be converted is created; then, the conversion command is executed, which is followed by analytical calculations and operations with a vector mathematical model.

The versatile computer technology includes **volumetric computer geometric modeling**, which is divided into the following types of modeling, depending on how the geometric body is described: wireframe modeling (set of vertices and edges); surface modeling (set of limiting surfaces); solid-state modeling (it consists of many simple volumetric elements using Boolean operations).

There are two main engineering tasks of computer modeling for volumetric bodies: creating a computer model of an existing product or its mathematical model; synthesis of the shape of a designed product that never existed (even in the form of material models).

Modern CAD systems deal with all types of geometric models and can even create combined models that include various element types. The geometric modeling of products uses a limited set of basic elements – objects or primitives: 2D objects, surfaces, and volumetric primitives. When performing logical operations of "intersection", "combination", and "subtraction" with simple volumetric elements using a certain algorithm, you can create a complex 3D solid-state model. To create a volumetric element in space, it is enough to shift a plane form (known as a sketch in the KOMPAS-3D system), relative to itself using the "Movement" operation. A sketch is created using 2D graphics tools and can consist of one or several contours; it can be situated on one of the projection planes or on some auxiliary surface or on a plane face of the existing element.

Volumetric elements in the KOMPAS-3D system are created using basic operations:

- Extrusion: the sketch moves perpendicular to its own plane.
- Rotation: a sketch drawn by the base line rotates around its axis (an axial line segment). In this case, it is important for both elements to be in the same plane and for the sketch to be located only on one side of the axial line.
- Kinematic modeling: the sketch as a generatrix is moved along a guide line created.
- Lofted modeling: several different sketches act as guide lines.

To modify a model by adding or removing some elements, there are combination and subtraction operations. Such an operation includes additional options for changing or refining the rules for creating a volumetric element. Multiple cyclical repetitions of logical operations allow you to create a volumetric model of any shape and complexity.

The use of modeling in teaching geometric-graphic disciplines is as follows:

*Development of electronic slides.* Didactic material means a kind of teaching visual aids for training sessions. As you know, pictures, tables, and maps, that are handed out to students in classroom lessons and for independent work; the materials developed on the basis of computer technology or demonstrated by the teacher in the classroom during the learning process contribute to:

- developing the cognitive independence;
- enhancing the cognitive activity of students;
- enhancing their creativity;
- reflection;
• developing visual-figurative, theoretical, and logical thinking;
• structuring the training;
• activating both hemispheres of the brain;
• reducing the time for presenting new material to students;
• improving the motivational component of education;
• developing the ability for cultural self-realization [4].

Based on the KOMPAS-3D computer modeling system, the authors have developed teaching aids and added them to the evaluation funds for the following disciplines: Engineering and Computer Graphics, Computer Graphics, and Computer Modeling for students in engineering specialties. Figures 1–2 show examples of slides with a frame-by-frame breakdown of the educational material of the topic "Images: Views, Profiles, Sections" in engineering graphics.

**Figure 1.** Slide "Local Cuts".

**Figure 2.** Slide "Section".

The basic conceptual idea for developing the structure and content of classes in university geometric-graphic disciplines was creating visual electronic slides that break down educational material by elements. The use of volumetric and plane modeling, as an active tool for solving various engineering and graphic problems, provides for the development of professional competencies of a future engineer. In the process of training, it becomes clear to students that a volumetric model describes the geometry of all surfaces of complex shapes and contains all the necessary information about the configuration, shape, and dimensions of the product. Geometric modeling applications are usually Windows-based systems. They provide for volumetric parametric modeling, execution of various design documents in accordance with modern requirements of the standards set by the Unified System for Design Documents; extensive libraries of standard products are integrated into their shells.
The KOMPAS-3D system is actively used for training students in engineering specialties at the Orenburg State University, the Tyumen Industrial University, and other Russian high schools. This a versatile system for development and designing engineering design and process documents in many areas of the Russian industry, allowing to create volumetric models of parts and their combinations at different complexity levels, as well as associatively related drawings – plane models.

Teachers of departments of graphic disciplines develop and create electronic slides in the KOMPAS-3D system based on the volumetric solid-state geometric modeling technology. Volumetric models of parts featuring complex geometric shapes shown on slides are created through a step-by-step execution of Boolean operations of mathematical logic on volumetric elements.

In addition, these slides are used as part of evaluation funds in geometric-graphic disciplines. A clear structure, integrity, and interdisciplinarity of the educational material contribute to its high-quality perception. It is important that the educational material for lectures and practical classes should be developed taking into account the effective visual perception of information. At their lectures, teachers demonstrate visual computer slides and other visual aids that contribute to the development of student’s geometric-graphic competencies.

Developing the set of tasks "3D models of Parts and Assembly Drawings of Products" intended to perform the task "Creation of Assembly Drawings and Working Drawings of Parts" in engineering and computer graphics in the KOMPAS-3D graphic editor [1, 3].

"Assembly" is an electronic document (*.a3d extension) to create assembly units from solid parts in perspective view; "part" is electronic document for creating solid-state models (a file with *.m3d extension).

In the graphic KOMPAS-3D system, the authors have developed a package of 3D models (20 sets) of products, where each part, including standard products, is implemented in its own color scheme. The procedure for creating a 3D "Assembly" model includes the following steps, corresponding to the product specification: creating volumetric models of parts; 3D models of assembly units (if any); 3D models of standard products and other elements. The last step is to build a 3D model of the entire product – "Assembly". In general, solid-state modeling means creating objects using Boolean operations (addition, subtraction, and conjunction. The shape of the designed volumetric element is defined according to the rule of descriptive geometry – by moving a flat figure along a guide line. Each "Assembly" in the proposed task is a solid-state model, which includes volumetric models of all parts, as well as assembly units and standard products. In addition, the system contains information about the relative position of components and relations between the parameters of their elements. Models of individual parts are independent files, whereas the assembly file contains only links to them and a description of the relative position or creation of parametric links between their elements (edges, faces, and surfaces). Removing or adding new parts defines the "Assembly" composition.

For more clarity, the tasks are executed with a quarter profile by cutting off with planes.

A flow chart for creating a 3D model of an assembly using the example of the Roller product is shown in figure 3; examples of some 3D models of product assemblies are shown in figure 4.

Thus, the use of teaching aids, that include a set of 3D models of product assemblies created in the KOMPAS-3D system based on volumetric modeling, helps optimize the educational process in geometric-graphic disciplines and allows creating a set of design documents based on the same: working drawings of parts, assembly drawings, and specifications.

The commands for creating associative views are in the menu "Insert" – "View from the Model" and "Insert" – "Auxiliary View". The "Views" panel contains command buttons. In the standard mode, KOMPAS-3D generates projection views, local views, arrow views, profiles, sections, detail elements, and local profiles. When creating an associative drawing, an associative relationship with the model is preserved: if any changes are made to the model, its associative projections are automatically changed too. An associative relationship between views and the model can be also deleted, if necessary. It is also possible to disable rendering of the elements that do not need to be shown in the drawing, if required.
In one drawing, there may be several different associative views of different models. When creating a profile or a section, you can select "uncut" elements of the product. The "drawing tree" is used to manage the views.

To create arrow views, profile, sections, or detail elements, commands are used that are enabled automatically, after the image of the corresponding elements is shown in the drawing. These commands can be also activated manually. Designations and inscriptions in a drawing of views, profile, sections, and detail elements are automatically enabled and match each other. In the "Materials and Assortment" reference book, you can assign attributes with information about the model and material weights; they are automatically assigned also to the drawing with associative views.

The procedure for creating associative drawings of 2D models of product assemblies and 2D models of parts included in the relevant product is described below:

**Figure 3.** The scheme of eating a 3D model of the product Assembly "Roller".
Open or create a model; using the "Hide" command, disable rendering the model elements that should not be shown in the drawing; add dimensions and designations, if you need to transfer them from the model; define the standard model orientation, for the front view to be fully shown; a custom orientation can be added, if necessary.

The commands for creating an arbitrary view in the KOMPAS-3D system are used to create assembly drawings and drawings of complex parts. Using the command for generating standard views, you can create a drawing of a simple model with all necessary projections.

Create projection images based on standard and arbitrary views created in the drawing.

In associative views, you need to perform image editing; to do so, customize the display settings in the views of objects and design elements available in the model; select "uncut" elements; disable the display of elements that should not be shown in the drawing.

Before generating the drawing: apply the required dimensions; add designations and inscriptions; you need to enable associability and parameterization in order to associate the constructed objects with the model and to track its changes. A profile or section line, the direction of the gaze arrow, and the designation of the detail element are marked automatically and have an associative relationship. Drawing elements with the same functional significance are recommended to be performed in separate layers for the convenience of generating and editing the drawing.

Disable the projection link between the views, if necessary, and compose the drawing on the sheet.

The set of individual tasks link contains technical descriptions of the product designs.

4. Discussion and Conclusions
The use in the educational process of educational and methodological publications, including a set of 2D models of product assemblies (assembly drawings) and their 2D models of parts (working drawings), that are associatively related to their 3D models created in the KOMPAS-3D system based on plane modeling, allows to significantly improve the quality of the educational process in the study of geometric-graphic disciplines.

The use of volumetric and plane modeling in teaching geometric-graphic disciplines contributes to the visual perception of a complex geometric object by students, interiorization, and "objectification" of a virtual model. The ability to analyze a complex drawing, to select simple geometric components from an object of complex geometric shape allows them to learn how to pass from volumetric models to their flat counterparts (associative drawings), which greatly simplifies the drawing editing process.

Therefore, the development and creating of didactic materials (visual electronic slides with a frame-by-frame breakdown of the educational material from the section "Images: Views, Profiles, Sections", set of individual tasks "3D Models of Parts and Product Assemblies" and "Assembly
Drawing. Detailing”) based on volumetric (3D) and plane (2D) modeling using modern tools, methods, and algorithms of computer graphics in the KOMPAS-3D system, their application in teaching geometric-graphic disciplines, and including them in the evaluation funds of geometric-graphic disciplines allow to implement active teaching methods to improve the quality of the educational process in geometric-graphic disciplines.

The scientific and practical significance of this study is due to the topic relevance and the research novelty. Its results can be used by university teachers during the training in descriptive geometry, engineering, and computer graphics. Our materials and findings can also be a basis for further developments in the application of volumetric and plane modeling in teaching general professional and special disciplines.

References

[1] Vanshina E A 2013 3D-modeling of assemblies in CAD systems. Technical science – from theory to practice: proceedings of the XXI international correspondence scientific-practical conference Novosibirsk: Izd "Sibak" 7-11

[2] Vanshina E A 2014 Slide-technology based on 3D modeling in the teaching of graphic-geometrical disciplines. Vestnik of the Orenburg state University 2(163) 24-28

[3] Vanshina E A and Vanshin V V 2015 Construction of 3D and 2D models of parts and assemblies products for the development of professional competences of students. Scientific almanac (Tambov: OOO "Consulting company Ucom") 684-687

[4] Vanshina E A and Gunkov V V 2015 Use of a unified didactic material for undergraduate physics and engineering graphics (on the example of Orenburg state University). Vestnik of the Orenburg state University 2(177) 10-16

[5] Vanshina E A and Vanshin V V 2017 Technology for creating associative drawings engineering graphics based on three-dimensional modelling. Intelligence Innovation Investment 2 59-63

[6] Fedotova N 2011 V three-Dimensional modelling in teaching graphical subjects. Fundamental research 12-1 68-70

[7] Yakunin V I, Guznenkov V N and Jurbenko P A 2017 Prospects for geometric-graphic disciplines in technical University. Almanac of modern science and education 2(116) 108-110

[8] Amirjanov I Yu and Vitkalov V G 2015 The current state of development of geometric-graphic culture and competence of future specialists. Vector science of Togliatti state University 2(32-2) 26-31

[9] Seydametov S, Mevlut S I, Ametov R F, Ablyakimov A N and Ametov A D 2017 Active learning methods in higher education. ICT in the economy, education and social services 2(16) 102-108

[10] Cheremanov A A and Nosov N V 2009 Computer technology, modelling and automated systems in engineering: proc for stud otech proc institutions (Volgograd: Publishing House "Inf-Folio") 640

[11] Demidov S G 2015 Computer modeling in the graphic training of students of technical University. Russian scientific journal 1(44) 143-145

[12] Jurbenko P A and Guznenkov V N 2015 Designing in CAD systems the Future engineering of Russia: collection of papers of the Eighth all-Russian conference of young scientists and specialists (M: Izd-vo MGTU im N E Bauman) 1060-1062

[13] Chemodanov T V 2004 Educational and methodical complex engineering graphic preparation based on the CAD. CAD and graphics 10

[14] Borisenko I G 2011 Innovative technologies in teaching descriptive geometry in the formation of professional competence. Vestnik of Irkutsk state technical University 12(59) 355-357

[15] Guznenkov V N, Seregin I V and Zhurbenko P A 2015 Academic discipline "Computer graphics". International research journal 6-4(37) 16-18

[16] Agoston M K 2005 Computer Graphics and Geometric Modelling (Mathematics Springer) 959
[17] Gayazov A S, G F Zamaletdinova, Amirov F A, Kostryukov A V and Tikhomirova E I 2016 Modern teaching tendencies of forming of critical thinking of university students. *International Review of Management and Marketing* **6**(2) 358-363

[18] Dongbo Zhang, Xiaochao Wanga, Jianping Hua and Hong Qind 2017 Interactive modeling of complex geometric details based on empirical mode decomposition for multi-scale 3D shapes. *Computer-Aided Design* **87** 1-10

[19] Jorge D Camba, Manuel Contero and Pedro Company 2016 Parametric CAD modeling: An analysis of strategies for design reusability. *Computer-Aided Design* **74** 18-31

[20] Prakhar Jaiswal, Jinniao Huang and Rahul Rai 2016 Assembly-based 3D conceptual modeling with unlabeled components using probabilistic factor graph. *Computer-Aided Design* **74** 45-54

[21] Benjamin Schleich and Sandro Wartzack 2015 Assembly Aproaches for the modeling of skin model shapes. *Computer-Aided Design* **65** 18-33

[22] Fatikhova L F and Sayfutdiyarova E F 2017 Improvement of methodology of teaching natural science for students with intellectual disabilities by means of 3D-graphics. *European Journal of contemporary education* **6**(2) 229-239

[23] Khasanova J S 2017 Kenesh of the System of engineering education in conditions of social modernization. *European Journal of humanities and social sciences* **2** 49-52

[24] Lototsky V L 2016 Spatial information modeling. *European Journal of computer science* **1**(2) 38-46

[25] Salova T L and Pavluchenko V S 2016 Features of modeling in 3D style. *European Journal of computer science* **1**(2) 47-52

[26] Zelensky A S and Lysenko V S 2017 The Experience of studying 3D graphics in educational process. *New computer technology* **1**(15) 154-159

[27] Teplitsky I O 2016 Modelyuvannya Yak method panana. *New computer technology* **1**(14) 7-8

[28] Basta E T, Djourik E V, Izumenko T V, Djourik N A and Ponomareva L A 2013 Methodological aspects of teaching of graphic disciplines in computer specialities of technical universities. *New computer technology* **1**(11) 8-10

[29] Pokidyshev G S, Sinelnikov V P and Dan'ko N A 2003 Psychological and pedagogical features of teaching of graphic disciplines with extra-mural form of training. *Theory and methods of learning fundamental disciplines in high school* **1**(1) 144-146

[30] Usanov G A 2003 Modeling of the training subject area, or subject a student model. *Theory and methods of learning fundamental disciplines in high school* **1**(1) 28-51