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A set of electronic graphic tasks on descriptive geometry adapted for automated assessment systems

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Abstract: The paper raises the problem of quality control of graphic training of technical university students using an automated assessment system. Despite wide access to digital educational resources, the acceptance and checking of drawings and calculation and graphic works in technical universities is still performed manually by teachers. The authors propose replacing the usual forms of graphic tasks on descriptive geometry with electronic metric and positional tasks of a new type. The result of solving such problems is expressed as a number or a short answer and can be compared with the standard using any standard testing system, for example, LMS Moodle. The work presents 20 examples of electronic practical tasks on descriptive geometry, the solution of which can be performed in any graphic editor, and the answer is checked using an automated assessment system. The set of electronic assessment tools developed by the authors contains more than 600 variants of graphic tasks and is designed to check theoretical knowledge and practical skills related to the content of the Descriptive Geometry and Computer Graphics course. The correctness of the tasks is checked automatically by means of the tools of the LMS Moodle electronic learning environment without the participation of the teacher. Pre-designed sets of control parameters, such as area, length, distance, volume, quantity, condition, and type are used for assessment. The system is successfully used for current monitoring of knowledge, skills and abilities of first-year students at the Siberian Transport University. The data from monitoring the learning outcomes indicate the effectiveness of the use of automated diagnostics of the level of development of students' graphic skills.

Keywords: set of electronic graphic tasks; Descriptive Geometry and Computer Graphics; automated assessment system; electronic assessment tools; digital educational resources; automatic checking.

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INTRODUCTION

The problem of assessing the quality of training has always been and remains one of the most discussed in the pedagogical environment. Diagnostic activities allow the teacher to obtain information on how successfully the student masters the educational material, to check the fact of the student's mastery of certain competencies, to identify the dynamics and trends in changing learning performance indicators. Providing external feedback and activating internal control are the most important functions of pedagogical diagnostics [1–3]. At the present stage, one of the priority areas in pedagogical research is the development of automated systems for assessing knowledge, skills and abilities, the development of electronic assessment tools, the use of digital educational resources, and the introduction of test forms of control [4–6].

The choice of the assessment procedure largely depends on the purpose of the assessment activities, as well as on how the assessment results are planned to be used in the future [7]. In the system of engineering and graphic disciplines, calculation and graphic works, graphic tasks and electronic models are used to assess the results of educational activities. Tasks in descriptive geometry, engineering and computer graphics and the results of their implementation are drawings. In modern realities, drawings are made mainly using CAD systems. Checking the graphic work by the teacher includes: loading the drawing file to the teacher's workstation; opening the file in a certain CAD system; analyzing the solution's compliance with the condition; critically understanding the course of action chosen by the student when solving the problem; identifying errors and shortcomings; assigning a grade; publishing a grade and review of the work. Considering the above, checking graphic tasks is a very labor-intensive operation, so there is an objective need to introduce automated systems for monitoring the level of development of graphic skills into the educational process [8–10].

There are several options for solving this problem: developing applications for automatic analysis of individual machine-readable parameters of an engineering drawing [9], using systems for automated comparison of drawings with certain standards of the correct solution [8; 10; 11], using the artificial intelligence capabilities [12], developing graphic applications with built-in drawing checking tools [8; 13; 14], and using electronic testing systems [15–17].

Processing a bitmap image obtained from a visual image of a drawing is one of the common ideas for automatic assessment. For example, the Virtual Teaching Assistant (ViTA) system is able to assess student works exported from various engineering graphic editors and recognize the most common types of errors, such as incorrect contour or scale, incorrect thickness or type of lines, irregularities in the arrangement of images, irregularities in the composition of images [9]. The assessment of a student work is performed based on comparison with a standard sample previously loaded by the user. Virtual Teaching Assistant (ViTA) has shown good results when checking educational technical drawings containing two-dimensional images of drafting views, sections and cuts (engineering graphics). However, the limitations of the program make it difficult to check works related to the Descriptive Geometry section, since the solutions to most metric and positional problems contain many auxiliary elements, the arrangement of construction lines is variable, the geometric composition of the solution depends on the sequence of actions chosen by the students and can have many visual differences with an unambiguously correct solution to the problem.

Another idea of automating the assessment of graphic work is related to the use of systems of visual comparison with a solution standard [10]. A special program searches for missing or faulty elements in the solution based on a comparison of visual clones of the checked drawing and the standard sample. An undoubted advantage of this method is the possibility of batch comparison. A disadvantage is the lack of intelligence of the human evaluator. The use of this method is justified if the correct solution to the graphic problem contains one constant set of graphic primitives, a certain combination of which creates an unchangeable graphic image of the drawing. If the correct solution to the graphic task can be obtained in several variable ways, with different sets of geometric primitives and their combinations, then the use of this method seems somewhat difficult.

An interesting idea of automating the assessment of graphic works is the use of non-text databases containing arrays of reference images and images containing errors. The procedure of checking is implemented using an element-by-element comparison of the bitmap of the checked work with reference images and with erroneous images [11]. The assessment criteria are compositional patterns such as proportions, center, symmetry, and contrast. The degree of accuracy depends on how great the diversity of samples is. Therefore, a necessary condition for the correct operation of the system is the presence of a large number of structured and labeled graphic images. A limitation of the approach is the impossibility of using a clear true/false criterion parameter, which complicates the use of this method for automatic assessment of work completed by students during the study of engineering disciplines.

One more approach to automating the checking of graphic works is associated with the development of special extension programs for standard CAD systems. A rather successful example is an application designed to work in the AutoCAD software product [14]. The application is written in AutoLISP, allows the user to initiate automatic construction of a set of graphic primitives, which are the initial data of the graphic task, gives the student access to the use of built-in AutoCAD drawing tools, checks the correctness of the drawing, and displays the assessment and feedback on the screen. Significant limitations of this technology are narrow specialization – the program works only with the AutoCAD program; a narrow range of topics in descriptive geometry for which tasks have been implemented; lack of access to the program for a wide range of users.

Another way to automate the procedures for checking graphic tasks is associated with the development of electronic testing systems [6; 16–18]. Tests are one of the most productive means of optimizing pedagogical work. The main difficulty related to the use of test forms of control in Descriptive Geometry and Computer Graphics is caused by the fact that the result of solving a problem is always a set of lines and points, and publicly available electronic educational systems are not designed to process data presented in the form of graphic elements. Therefore, the use of automated systems for assessing graphic works requires the transformation of the tasks themselves, the development of new formulations of problems in which the result of solving the problem is a drawing containing a certain control parameter. A new approach to the formation of graphic tasks will reduce the teacher's time costs by eliminating routine operations associated with downloading drawing files, opening them, and checking them against the solution standard.

The purpose of the study is to develop a set of electronic graphic tasks adapted for use together with publicly available automated assessment systems.

METHODS

Research Materials

The material for this study was the funds of assessment tools used to control the level of development of graphic skills of first-year students studying in 23.05.04 Transportation Process Management training program [19].

Stages of the Research

The research methodology included:

– analysis of assessment tools in descriptive geometry, their systematization;

– development of technology for monitoring of practical skills of students;

– selection of learning performance indicators;

– selection of tasks, their adaptation for the electronic testing system, selection of the form for presenting tasks;

– development of a sufficient number of versions of each task;

– creation of a database, placement of tasks in the electronic educational environment, setup of the electronic testing system;

– conducting training sessions with students on the use of a new system for assessment of graphic skills, conducting control activities, analyzing intermediate results;

– identification and correction of unsuccessful tasks;

– general analysis of the results of applying the developed technology.

Performance Indicators

When developing the set of electronic graphic tasks, the authors took into account that the performance indicators of training descriptive geometry are the student's ability to find projections of points and lines belonging to a plane or surface; the ability to construct intersection lines or points of contact of two or three objects located in space; the ability to determine the visibility of elements on an orthogonal drawing; the ability to perform additional constructions necessary to determine the distances between objects or their sizes.

The assessment scales are designed using a standard system based on four levels of mastering the educational material: unsatisfactory – satisfactory – good – excellent. The unsatisfactory grade was used if the student could not confirm the ability to solve typical tasks in all tests. The satisfactory grade was given to a student who demonstrated the ability to solve typical graphic tasks. If the student demonstrated the ability to solve combined-type tasks (including many elements of typical tasks), he was assigned the good grade. If a student is able to synthesize new problem-solving techniques based on their previous experience, the level of mastery was interpreted as excellent.

A high level of task variability was ensured by the previously developed system of automatic generation of task variants using sets of parametric templates [20].

Testing of a Set of Electronic Graphic Tasks

The proposed technology for automated assessment of students' practical skills was tested in 2023 at Siberian Transport University. First-year students (124 people) participated in the testing. During the semester, students completed 20 graphic tasks packed in test forms. All tasks were posted in the e-learning system. The KOMPAS CAD system was used to develop and solve the tasks. The grade was assigned automatically. Each task was assessed individually (separately, regardless of the others).

The tasks were completed by students in the classroom in the presence of a teacher. The time limit was one class (90 minutes). The number of attempts was not specified. The maximum score for completing the task was 100 points. The final grade depended not only on whether the correct result was obtained, but also on how many attempts it took the student to get the right solution. The maximum grade of 100 points was given to a student who completed the graphic task without errors the first time. If the student completed the task correctly, but not immediately, after one or more corrections, then the number of points awarded for the task was reduced proportionally to the number of attempts. The task was considered passed if the student managed to score 70 points or more (i. e. the correct answer was obtained at least on the third attempt).

The result was assessed automatically, without the teacher's involvement.

RESULTS

Composition of the Developed Materials

The authors developed a set of electronic graphic tasks, including 20 tasks covering all sections of the Descriptive Geometry and Computer Graphics course. 30 options are offered for each task. All tasks are formulated in such a way that the answer is expressed as a number or a simple phrase (selected from the proposed list). Automatic checking of tasks by one or several control parameters has been configured. Table 1 provides a specification of tasks, describes the general content of the task, presents a sample of the graphic part of the condition, and indicates the control parameter and its type. The content of the tasks fully corresponds to the structure of the calculation and graphic work performed during the semester. One should note that the specific content of the task in each of the 30 options is different. Table 1 provides only general information about the tasks. Examples of specific electronic tasks are shown in Figs. 1–3.

To organize automatic control, standard test forms available in most e-learning systems were used: task with a numerical answer, selection of missing words and nested answers.

Task with a numerical answer contains a field for entering an answer, the answer must be a number. The task condition can be presented as text or be added to the question as an attached file. Fig. 1 shows an example of a graphic task of this type.

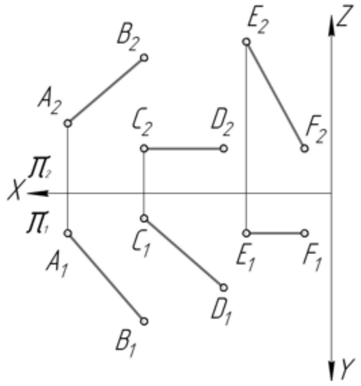
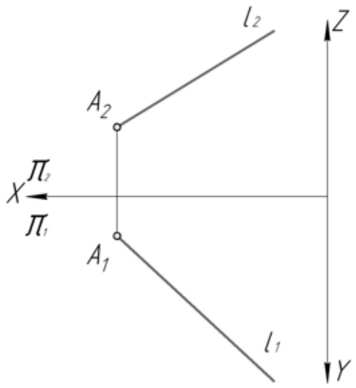
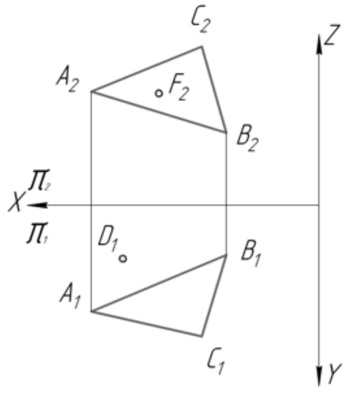
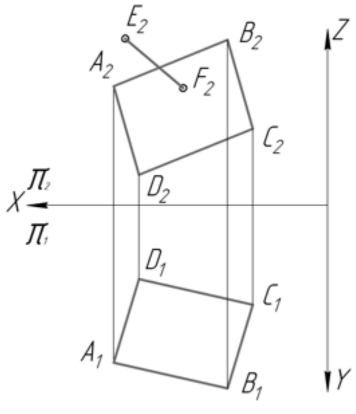
Selection of missing words is a closed-type task; the student selects an answer from a drop-down list containing a list of answer options. This type of assignment is convenient to use in graphic tasks on determining the visibility or relative position of objects. An example of using drop-down lists to issue a graphic task is shown in Fig. 2.

The third form of an electronic graphic task is nested answers. Allowed field types are Numerical Answer and Choice from List. The Numerical Answer type field requires entering an answer from the keyboard, the Choice from List type field allows the student to choose among the proposed answer options. An unlimited number of fields can be added to each task. An example of a graphic task created using the nested answers form is shown in Fig. 3.

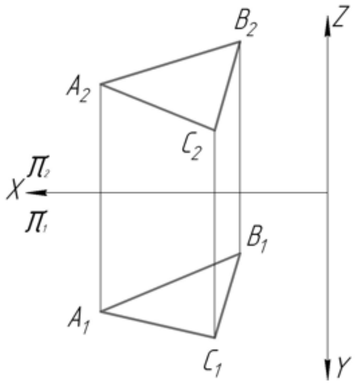
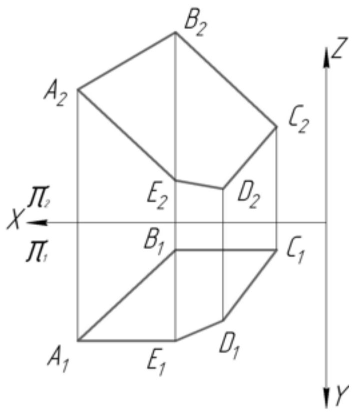
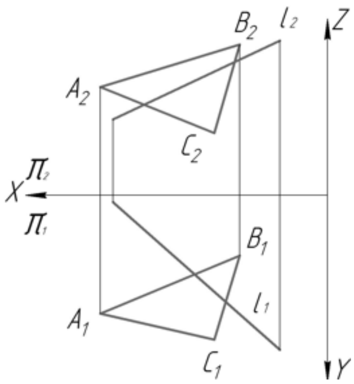
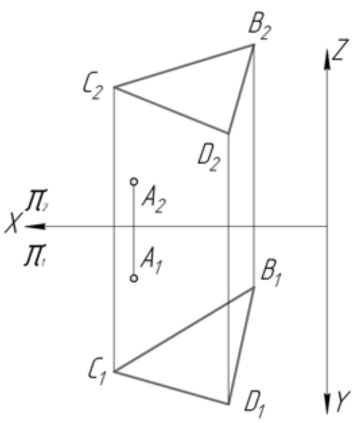
Test Results of the Approbation

Table 2 presents sample data on the execution of tasks by Student 1 (a "fairly good" student, has a high performance score in all subjects, average performance is 86 %), Student 2 (an "average" student, average performance in all subjects is 62 %), and Student 3 (a "fairly poor" student,

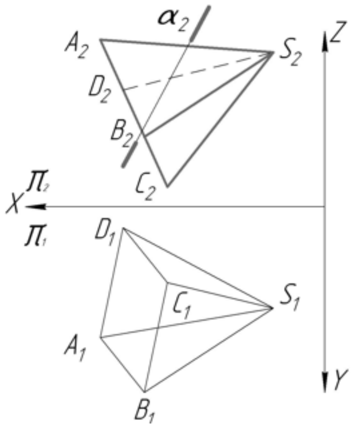
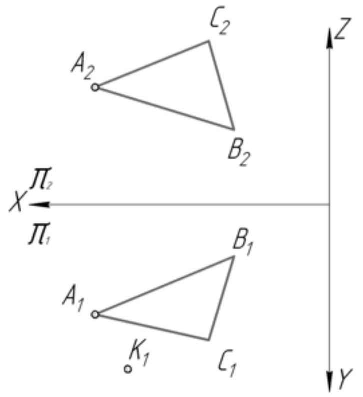
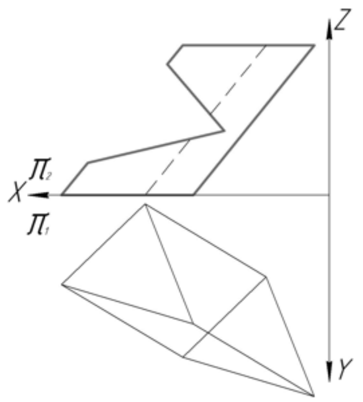
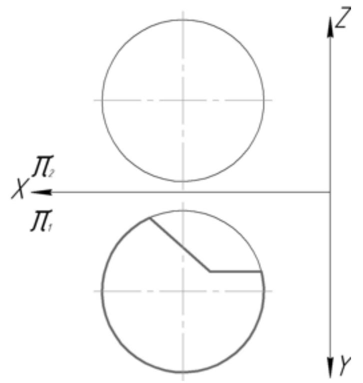
Table 1. *A set of electronic graphic tasks*
Таблица 1. *Комплекс электронных графических заданий*

Task, No.	Condition of a problem, text part	Condition of a problem, graphical part, example of one of the options	Control parameter (*parameter type*)
1	Find the actual sizes of the segments *AB*, *CD* and *EF*. Indicate the position of each of the segments in space		Actual size of the segment (*numerical*) Position in space (*choice:* contour line, general position line)
2	Plot along a general position line a segment *AB* of a given value (the specific value is indicated in the task option)		Point *B* coordinates (*numerical*)
3	Construct the projections of points *D* and *F* belonging to the plane specified in the drawing. What are the coordinates of the points obtained?		Point *D* coordinates (*numerical*). Point *F* coordinates (*numerical*)
4	Construct the projections of segment *EF* belonging to the given plane. What is the actual size of segment *EF*?		The length of segment *EF* (*numerical*)

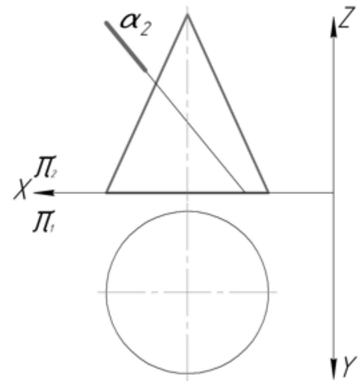
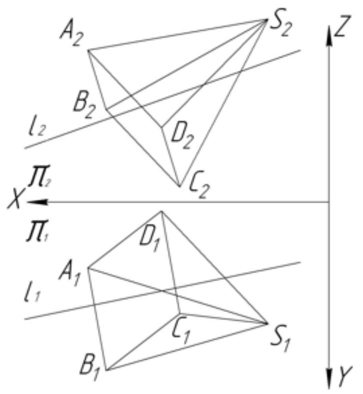
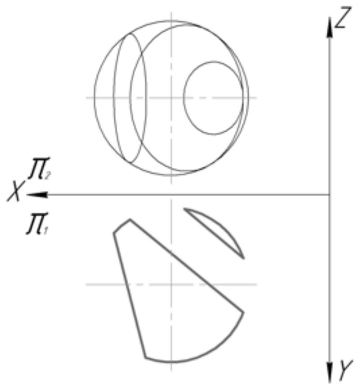
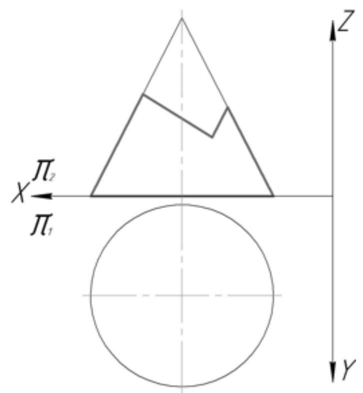
Continue of the Table 1

Task, No.	Condition of a problem, text part	Condition of a problem, graphical part, example of one of the options	Control parameter (parameter type)
5	The projections of plane *ABC* is given. It is required to construct a segment *AK* perpendicular to it (particular length of the segment is specified in the task option)		Point *K* coordinates (*numerical*)
6	Find the actual size of the flat polygon *ABCDE*		Area of the figure (*numerical*)
7	Find the point of intersection of the line *l* with the plane *ABC*		Intersection point coordinates (*numerical*)
8	Find the distance from point *A* to plane *BCD*		Distance (*numerical*)

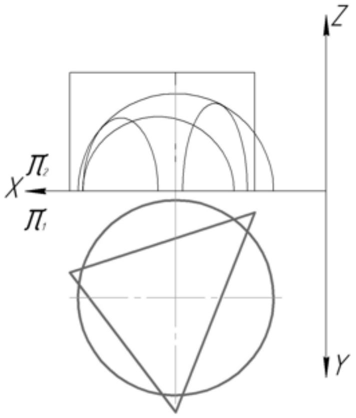
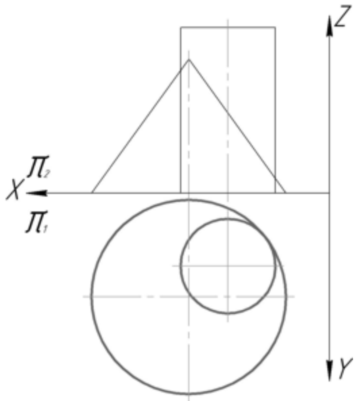
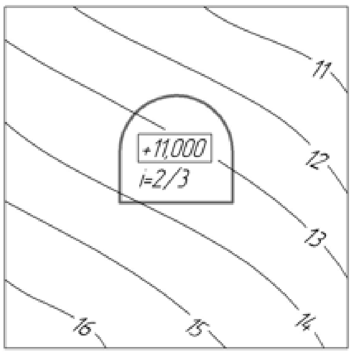
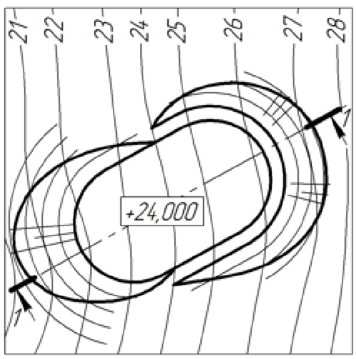
Continue of the Table 1

Task, No.	Condition of a problem, text part	Condition of a problem, graphical part, example of one of the options	Control parameter (parameter type)
9	Construct a section of the pyramid *SABCD* by plane α. What is the actual size of the section?		Area of the section (*numerical*)
10	Construct the projections of the pyramid *SABC*. The base of the pyramid is the triangle *ABC*. The height of the pyramid is the edge *AS*. *AS*=*BC*. Determine the visibility of all edges of the pyramid. Construct the missing projection of the point *K* belonging to the visible face of the pyramid		Apex *S* coordinates (*numerical*). Visibility *SA, SB, SC, AB, BC, AC* (*choice:* visible, invisible). Point *K* coordinates (*numerical*)
11	Construct the projections of a through flat cutout on the surface of a polyhedron. Find the actual size of the flat cutout (the area of one of the flat sections (any) or the total area of the entire cutout)		Area of the section (*numerical*)
12	Construct the projections of a through flat cutout on the surface of a sphere. Find the actual size of the section (the area of one of the flat sections (any) or the total area of the entire cutout)		Area of the section (*numerical*)

Continue of the Table 1

Task, No.	**Condition of a problem, text part**	**Condition of a problem, graphical part, example of one of the options**	**Control parameter (*parameter type*)**
13	Construct the line of intersection of the plane α and a cone. Determine the type of a curve. Construct the actual size of the section		Curve type (*choice:* parabola, hyperbola, ellipse, circle, line). Intersection line length (*numerical*)
14	The drawing shows projections of the polyhedron. It is shown without regard to the visibility of elements. Determine the visibility of the edges of the polyhedron. Find the points of contact of the line *l* and the polyhedron *SABCD*		Visibility of edges (*choice*: visible, invisible). Coordinates of points of contact of the line with the surface *SABCD* (*numerical*)
15	Two projections of a sphere truncated by planes are given. Determine the visibility of elements of the truncated sphere on plane Π_2		Visibility of lines (*choice*: visible, invisible)
16	The cone is truncated by two planes. Plot the missing lines on the horizontal projection. What is the shape of the flat sections? Find the actual size of the section (the area of one of the flat sections (any) or the total area)		Curve type (*choice:* parabola, hyperbola, ellipse, circle, line). Area of the section (*numerical*)

Continue of the Table 1

Task, No.	**Condition of a problem, text part**	**Condition of a problem, graphical part, example of one of the options**	**Control parameter (parameter type)**
17	Projections of two intersecting bodies are given in the drawing. It is necessary to determine the visibility of all elements of the drawing		Visibility of lines (*choice*: visible, invisible)
18	Construct the line of intersection of two quadratic surfaces		The length of the intersection line (*numerical*)
19	The design parameters of the site (elevation mark, dimensions, and slope grades) and the topographic surface contour lines are given. It is necessary to construct the boundaries of earthworks. What is the area of the building on the plan plot?		Area of the building on the plan plot (*numerical*)
20	A drawing of an engineering structure is given. It is required to construct a profile along the line 1–1. What is the area of the fill and the cut on the profile?		Sectional area of the fill on the profile (*numerical*). Sectional area of the cut on the profile (*numerical*)

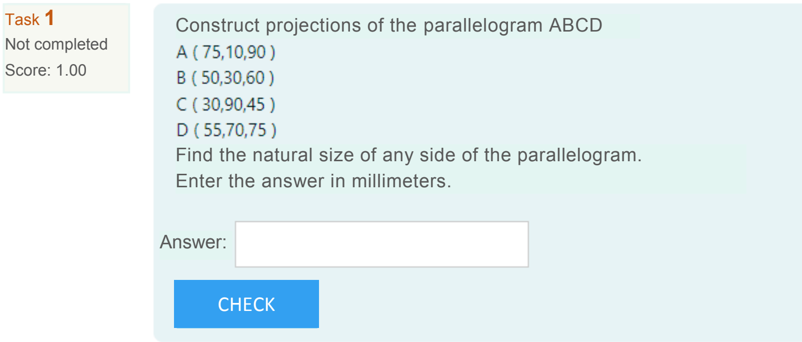


Fig. 1. Graphic task with a numerical answer
Рис. 1. Графическая задача с числовым ответом

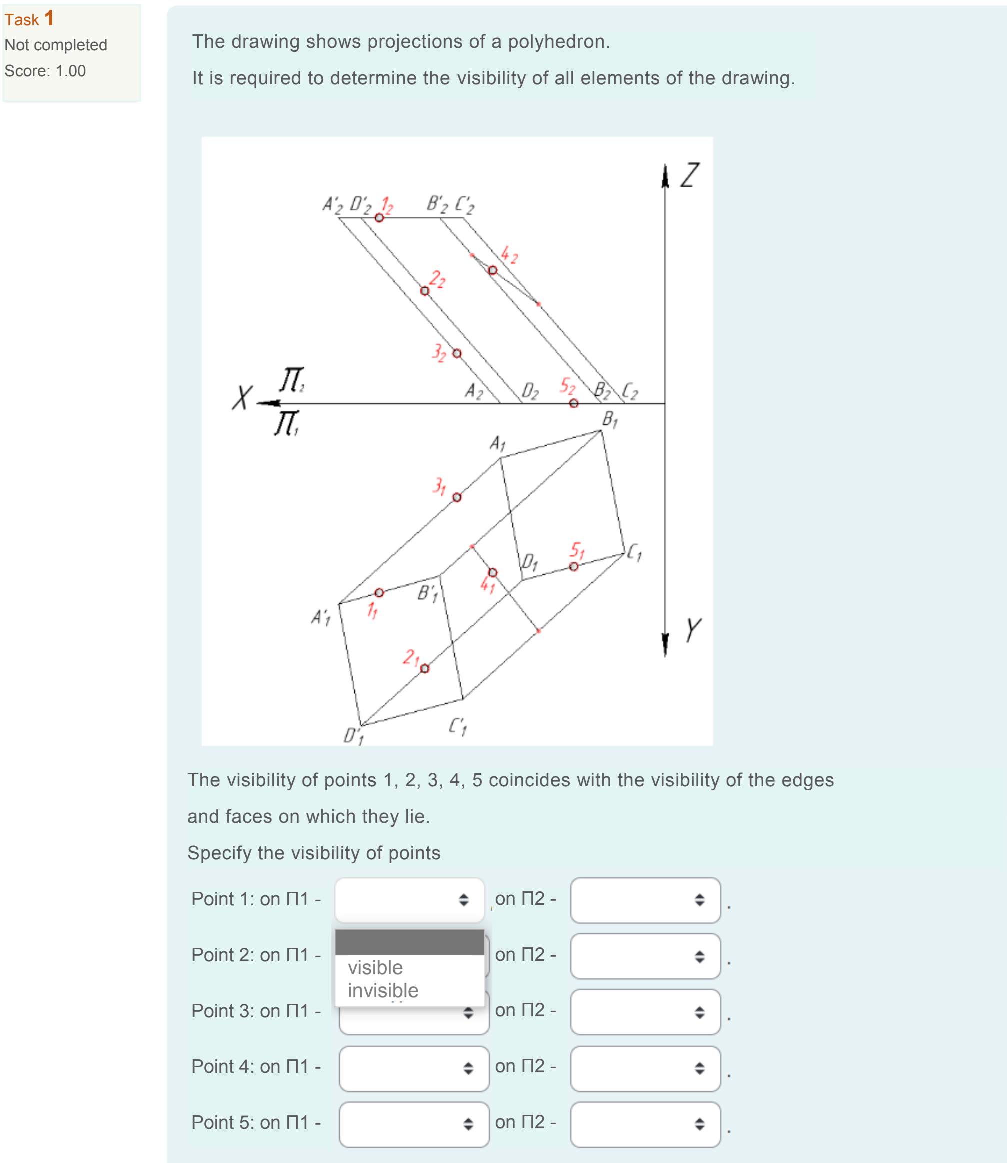


Fig. 2. Graphic task with choosing words from a list of answers
Рис. 2. Графическая задача с выбором слов из списка ответов

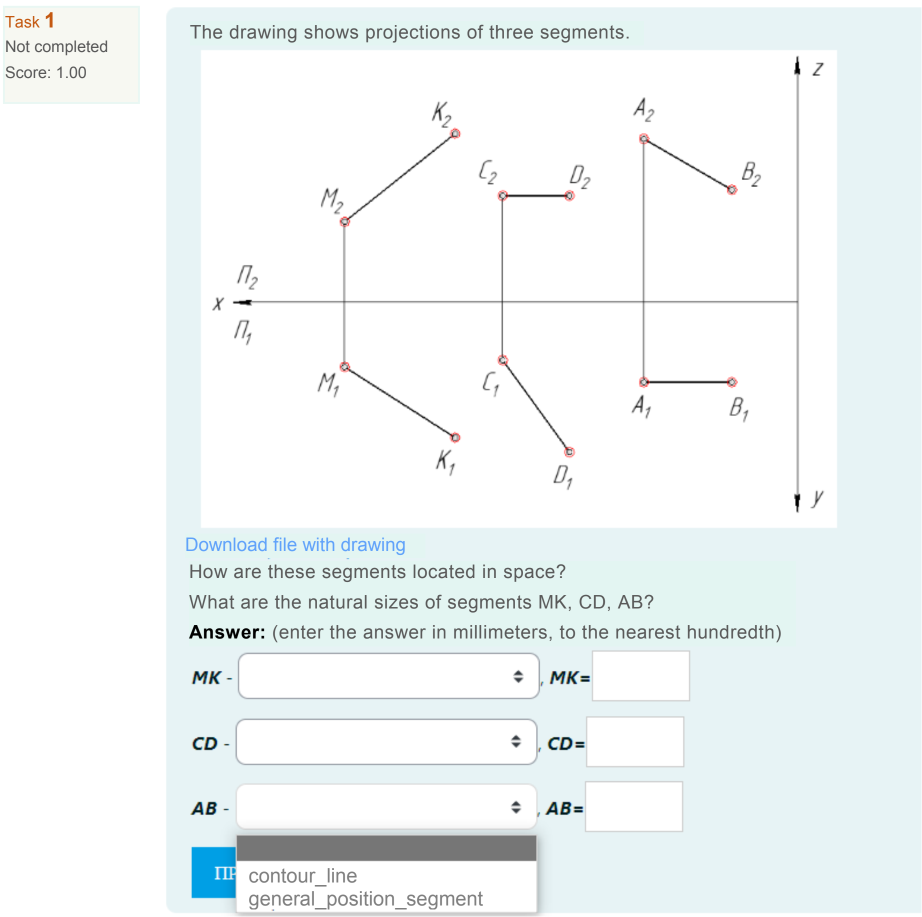


Fig. 3. Graphic task with nested answers
Рис. 3. Графическая задача с вложенными ответами

Table 2. Sample data for three students
Таблица 2. Выборочные данные по трем студентам

Student	Attempt, No.	Task, points																			
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
"Good"	1	100	100	80	100	100	100	100	20	100	80	40	80	100	100	100	100	100	100	100	100
	2			100					100			100									
"Average"	1	100	40	0	40	100	0	100	100	60	100	40	100	100	0	100	20	100	100	100	90
	2		60	50	100		100			100		100			100		60				
	3		100	100													100				
"Poor"	1	100	0	50	0	80	20	0	100	0	0	100	0	0	0	40	90	0	100	0	0
	2		40	100	0		20	60		0	20		0	60	0	20		50		20	0
	3		80		60		60	100		20	100		20	80	100	50		100		80	0
	4				80		60			60			60			90					60
	5						80			100			80								80

average performance in all subjects is less than 41 %). The data provided is actual. The names of students are not provided for ethical reasons.

The task numbers in Tables 1 and 2 coincide. The rows of Table 2 show the scores for each attempt. If a cell is empty, the attempt was not made by this student. Within one attempt, the student completed one of the task versions and could correct his answer as many times as he wanted (adaptive mode). In subsequent attempts, the student was automatically given a new version of the same task. The value “0” indicates that the student was unable to get the correct answer within the allotted time (one class, 90 minutes), i. e. the task was not completed. 100 points mean that the student completed the task correctly the first time; 90 points mean that the student corrected his answer once; 80 points – the student redid the solution twice, etc. The values of 10, 20, 30, 40, 50, 60, 70, 80, 90 points indicate that the student got the correct answer when completing the graphic task, but was unable to do it on the first try.

As one can see from the data given in Table 2, the “good” student coped with most of the tasks on the first attempt (scores greater than “0”). The “average” student had difficulties when completing several tasks. The “poor” student was able to get the correct answer to 9 out of 20 proposed tasks on the first attempt. At the same time, when completing tasks No. 3, 6 and 15, the “poor” student was unable to overcome the 70-point mark (pass grade) in the first approach and was forced to train until an acceptable result was obtained.

Fig. 4 shows the average data for the entire cohort of students (124 people).

DISCUSSION

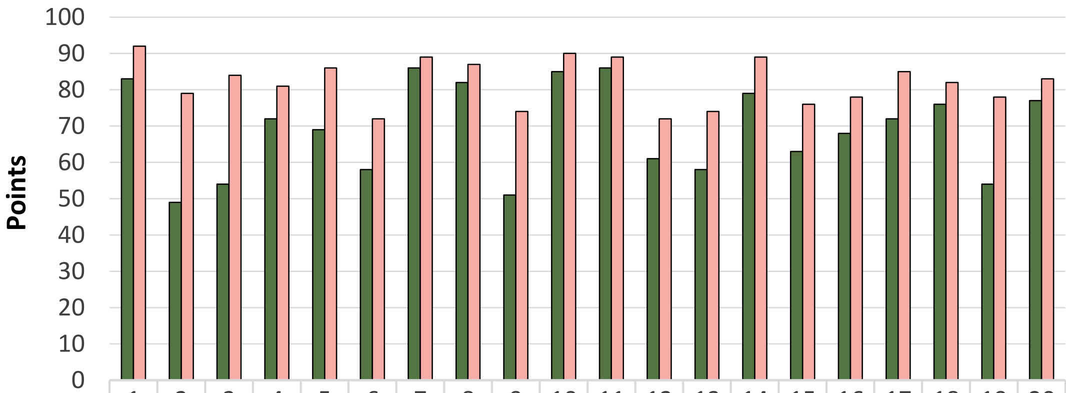
The obtained data indicate that the set of electronic graphic tasks successfully fulfills its function, allows checking the formedness of knowledge, skills and abilities related to the content of the Descriptive Geometry and Computer Graphics course. The proposed control method is a convenient tool for pedagogical diagnostics, allows relieving the teacher from performing many routine operations. Due to the introduction of the automated assessment system into the educational process, the structure of the Descriptive Geometry and Computer Graphics course has been optimized, losses of classroom time associated with delays in reviewing and checking drawings have been eliminated.

During testing, it was found that electronic tasks in descriptive geometry, packed in test forms, could be used both as an assessment tool and as a training resource (electronic simulator). Students actively use the opportunity to take training tests, independently sharpening their skills in solving graphic tasks. This is facilitated by the ability to immediately receive a grade for the task, the ability to make corrections to the solution and re-check the answer, as well as a large number of options developed for each task.

Compared with technologies based on computer vision and with technologies that involve comparing the visual image of a graphic work with a reference solution [9–11], the proposed technology for automatic assessment of graphic tasks has a number of advantages:

– reliability (the assessment does not depend on how similar or different the drawing made by the student is to the reference; if the solution is correct, the correct answer is received, then the attempt is counted regardless of the composition of graphic primitives in the drawing, their placement and positioning);

– independence from third-party developers (the assessment technology does not provide for the use of special applications, databases or comparison algorithms; the whole idea is built on the use of the standard functionality of the electronic testing system). In spite of the fact that automated drawing checking technologies that include the use of specially developed programs and applications [13; 14] may probably have a more interesting range of functions, the system proposed by the authors may be of interest to a larger number of fellow practitioners, since it is based on the familiar electronic testing and requires from



Task number	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
First attempt	83	49	54	72	69	58	86	82	51	85	86	61	58	79	63	68	72	76	54	77
Last attempt	92	79	84	81	86	72	89	87	74	90	89	72	74	89	76	78	85	82	78	83

Fig. 4. *Average results of completing tasks*
Рис. 4. *Усредненные результаты выполнения заданий*

the teacher only creative thinking and the ability to create electronic tests. To implement the proposed automation technology, no additional applications, programs or databases are required. The system can be adapted to almost any course structure and software used.

Obviously, the proposed idea of automating the assessment of graphic works has a number of limitations:

– to increase the degree of reliability of the assessment, each task should have many variations, otherwise the correct answers expressed by a number or a short review become known to the student very quickly, and the tasks no longer perform their control function;

– there are a number of tasks for which the authors were not able to find an adequate version of the test task (for example, tasks included in the Method of Perspective Projections unit of descriptive geometry and tasks related to the implementation of projection drawings of parts and assembly units (engineering graphics)).

From a practical point of view, the developed system turned out to be quite effective. Teachers note the ease of use, reliability, high degree of variability of tasks, and assessment adequacy. Students consider this method of presenting graphic assignments to be quite comfortable, and the grading system to be fair (the grade is not affected by such factors as the student's previous achievements, his reputation, and the teacher's mood at the time of the assessment, etc.).

CONCLUSIONS

The authors formulated and implemented an idea according to which graphic tasks on descriptive geometry, packed into test forms, can be assessed automatically if a certain control parameter expressed as a number or a short answer is assigned to each task.

A database of graphic tasks consisting of 20 sets of tasks has been developed. Each set includes 30 task options. A total 600 variations of electronic graphic tasks with automatic checking have been prepared, which ensures a certain level of individualization of control measures.

The system is an original development and can be used in any educational institutions with the same or similar training programs in the Descriptive Geometry discipline.

As a result of testing, it was found that graphic tasks in electronic format effectively perform two main functions – control and training.

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Комплекс электронных графических заданий по начертательной геометрии, адаптированных для автоматизированных систем оценивания

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Аннотация: Поднимается проблема контроля качества графической подготовки студентов технического университета с помощью автоматизированной системы оценивания. Несмотря на широкий доступ к цифровым образовательным ресурсам, прием и проверка чертежей и расчетно-графических работ в технических университетах до сих пор выполняются вручную преподавателями. Авторы предлагают заменить привычные формы графических заданий по начертательной геометрии электронными метрическими и позиционными задачами нового типа. Результат решения таких задач выражен числом или коротким ответом и может быть сличен с эталоном с помощью любой стандартной системы тестирования, например LMS Moodle. В работе представлено 20 примеров электронных практических заданий по начертательной геометрии, решение которых может быть выполнено в любом графическом редакторе, а ответ проверяется с помощью автоматизированной системы оценивания. Разработанный авторами комплекс электронных оценочных средств содержит более 600 вариантов графических задач и предназначен для проверки теоретических знаний и практических навыков, связанных с содержанием курса «Начертательная геометрия и компьютерная графика». Проверка правильности выполнения заданий производится автоматически посредством инструментов электронной обучающей среды LMS Moodle без участия преподавателя. Для оценивания используются заранее спроектированные наборы контрольных параметров, такие как площадь, длина, расстояние, объем, количество, состояние, вид. Система успешно применяется для текущего контроля знаний, умений и навыков первокурсников в Сибирском государственном университете путей сообщения. Данные мониторинга результатов обучения свидетельствуют об эффективности применения автоматизированных средств диагностики уровня сформированности графических навыков студентов.

Ключевые слова: комплекс электронных графических заданий; начертательная геометрия и компьютерная графика; автоматизированная система оценивания; электронные оценочные средства; цифровые образовательные ресурсы; автоматическая проверка.

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