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Pre-Service Teachers’ Preparation for Students’ Computer Modeling Skills Formation (on the Example of GeoGebra)

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Keywords: Modeling Skills, Skills Development Methodology, Cloud Service, GeoGebra Cloud Service, Constructive Approach, Modeling, Interesting Curves, Math Problems, Professional Training.

Abstract: Modeling as a leading method of scientific knowledge and a means of developing intellectual skills of young people. The students’ modeling skills can be successfully formed under the condition of appropriate advanced teacher training, and therefore models and methods of pre-service teachers’ preparation for students’ modeling skills formation are in demand in modern society. The model of pre-service teachers’ preparation for the formation of students’ computer modeling skills is based on the consistent achievement of three goals: 1) mastering GeoGebra computer tools; 2) formation of pre-service teachers’ skills to model (on the material of interesting curves in Analytical Geometry or word problems in secondary school); 3) formation of students’ skills to select and/or formulate author’s problems that can be solved by the modeling method in GeoGebra. The content on which the model is implemented was a special course on mastering GeoGebra and two experimental modules “Modeling interesting curves” and “Word problems modelling”. According to the sign test the developed model allows successful pre-service teachers’ preparation to develop students’ computer modeling skills.

1 INTRODUCTION

Modern science operates with various methods, among which modeling is one of the most popular. This method allows you to move away from the object’s ideal representation and use its analogue, which retains the most important characteristics that allow you to talk about the object properties after certain changes or influences on it.

The development of computer technologies has contributed not only to the revival of the modeling method, but also led to the emergence of specialized environments, where it became possible to model various objects (processes) based on a constructive approach. At the same time, the widespread use of smartphones and tablets that have access to the Internet has led to the emergence of cloud services, which also allow you to model objects of different nature. However, methods of using cloud services to develop modeling skills are just beginning to be developed and implemented, and therefore are not well established and need experimental confirmation.

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2 LITERATURE REVIEW

The authors believe that the pre-service teachers’ preparation for the formation of students’ computer modeling skills is based on the perception of a constructive approach as the leading one in the formation of modeling skills.

The importance of developing constructive skills of youth is emphasized in the findings of Laksha (Laksha, 2011), Kononenko (Kononenko, 2010), Ivanina (Ivanina, 2010), and the formation of modeling skills by individual scientists is associated with the formation of research skills (Bilousova et al., 2022). Ziatdinov and Valles (Ziatdinov and Valles,

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2022) think that "while the model is being constructed, the student can stumble upon a pathway that results in a better understanding of the connection present amidst the model world and reality". Flehantov et al. (Flehantov et al., 2022) performed a study to investigate the effectiveness of GeoGebra in gaining and cultivating knowledge on mathematical modeling. Marciuc et al. (Marciuc et al., 2016) emphasize, that use of GeoGebra offers a specific, constructivist, teaching approach that allows students to independently build their own models while offering guidance.

Analysis of the problem shows that with the advent of specialized mathematics software its solution has focused not so much on understanding the algorithms of elementary constructions, but on the ability to use computer tools and the ability to visualize the result. The latter, in particular, is emphasized in the findings of Bilousova and Zhytyenyova (Bilousova and Zhytyenyova, 2017). For example, Lenchuk and Franovskyi (Lenchuk and Franovskyi, 2016) consider it possible to expand the visual presentation of information in the field of planimetry by reproducing the real state of operation of its objects, resorting, as a priority, to visual methods of activity based on constructive modeling. Regarding the ability to use tools, it should be noted the emergence of cloud services, including specialized services.

Different aspects of educational using of cloud technologies and services are examined in the studies of (Shakeabubakor et al., 2015; Smith et al., 2014). For example, Shakeabubakor et al. (Shakeabubakor et al., 2015) explore advantages of using cloud technologies in research, such as availability of various tools and applications for analyses and collecting data, for managing and organizing references, for communication with peers and experts, the absence of constraints, the access to cloud resources from anywhere any time that has an active Internet connection, etc. (Smith et al., 2014). They offer the approach to applying of cloud services for enhancing the productivity of university research activities, increasing competitiveness and flexibility of educational institutions.

Shyshkina and Popel (Shyshkina and Popel, 2013) consider the problems of implementation of cloud technology services in the educational process, describe the current state of development and use of cloud technology services in educational institutions and analyze the content of educational and scientific components of cloud-based educational environment.

The use of specialized software for modeling mathematical objects is mentioned in (Sheng, 2014). Rubio et al. (Rubio et al., 2015) emphasize that by fusing modeling and digital technologies through simulation, there are obtained learning environments that promote the development of knowledge and skills of scientific thinking in students. The teaching of students to model is discussed in (Çekmez, 2020). Author discuss the pedagogical value of a real-world phenomenon selected for a modelling activity, followed by the implementation sequence of the activity in the classroom. Çekmez (Çekmez, 2023) believes that pre-service mathematics teachers should be familiar with the potential use of computers in mathematical modelling.

Currently, cloud versions of well-known environments with mathematical modeling capabilities are available, including SageMath. We can also add GeoGebra cloud service to this list, because it "can be considered a very creative tool for mathematical modeling" (Ziatdinov and Valles, 2022).

Experience in using GeoGebra cloud service (visualization of mathematical objects; organization of not only analytical but also empirical search for answers in determining individual characteristics of mathematical objects; organization of home computer experiment) (Drushlyak et al., 2021a; Hrybiuk, 2020; Semenikhina et al., 2019b,a) allowed us to consider GeoGebra as means for formation of students' modeling skills.

However, the analysis of scientific findings confirmed the lack of established models of pre-service teachers' preparation for the formation of students' modeling skills based on GeoGebra, which determined **the purpose of our study**: to develop and experimentally test the model of pre-service teachers' preparation for the formation of students' computer modeling skills (based on GeoGebra).

3 MATERIAL AND METHODS

Experimental base was Makarenko Sumy State Pedagogical University. The total number of respondents is 51 people (students, pre-service mathematics and computer science teachers).

The model of pre-service teachers' preparation for the formation of students' computer modeling skills is based on the consistent achievement of three goals: 1) mastering GeoGebra computer tools; 2) formation of pre-service teachers' skills to model (on the material of interesting curves in Analytical Geometry or word problems in secondary school); 3) formation of students' skills to select and/or formulate author's problems that can be solved by the modeling method in GeoGebra.

To test the effectiveness of the developed model, a pedagogical experiment was organized, which lasted 3 years (2019-2021) and was conducted among pre-service mathematics and computer science teachers.

The model was implemented using the free GeoGebra software (https://www.geogebra.org) in the study of the disciplines “Dynamic Mathematics Software” for pre-service mathematics teachers and “Computer Mathematics Systems” for pre-service computer science teachers (2nd year). Within the discipline “Methods of teaching mathematics” and “Methods of teaching computer science” (3rd year) were introduced experimental modules “Modeling of interesting curves” (10 hours – 2 lecture hours and 8 laboratory hours) to achieve the second goal; “Modeling of word problems” (6 laboratory hours) to achieve the third goal.

Testing the effectiveness of the methodology involved two tests: after mastering GeoGebra and after studying the second module.

Students were offered two typical problems for modeling the Conic sections by its geometric definition (the problems differed from each other in the initial conditions, for example, the distance between the foci was different or one of the foci was at a specific point in a given coordinate system, etc.) and motion word problem.

The solution of the problems was evaluated by the following indicators (table 1, 2).

Since the results of the tests were dependent and each time provided for the accumulation of marks, the sign test was used. The number of respondents, whose total score decreased (“–”), did not change (“0”) and increased (“+”), was fixed.

Table 1: Indicators of the formation of modeling skills (Module “Interesting Curves”).

No	Indicators	Marks
1	Ability to take into account the analytical relationship between the elements	1
2	Ability to take into account the geometric relationship between the elements	1
3	Ability to use Locus	1
4	Ability to use Trace	1
5	Ability to demonstrate the change of the curve shape when changing the input data	1
6	Ability to construct a model visually correct (location, color, size and style of geometric objects)	1
7	Ability to add dynamic text to study numerical characteristics	1
8	Ability to write an algorithm for constructing a model	1
9	Ability to reproduce the steps of the algorithm to construct the model	1
10	Ability to interpret the result of a computer experiment	1

Table 2: Indicators of the formation of modeling skills (Module “Word Problems”).

No	Indicators	Marks
1	Ability to analyze the problem	1
2	Ability to establish a relations between data and questions	1
3	Ability to use Slider	1
4	Ability to use Dynamic Text	1
5	Ability to use Button	1
6	Ability to use Check Box	1
7	Ability to use Image	1
8	Ability to construct a model visually correct (location, color, size, etc.)	1
9	Ability to write an algorithm and reproduce the steps of the algorithm to construct the model	1
10	Ability to interpret the result of a computer solution	1

In accordance with the experiment purpose and the sign test, the null hypothesis was formulated: the developed model does not provide successful pre-service teachers preparation for the formation of students’ computer modeling skills. Then the alternative hypothesis was “the author’s methodology contributes to the formation of such skills”.

The constructed hypotheses define the one-sided sign test for checking the dependent samples. According to the decision-making rule (Grabar and Krasnjanskaja, 1977) the null hypothesis of inefficiency / effectiveness of the author’s methodology was accepted or rejected.

4 CONSTRUCTIVE APPROACH

The constructive approach is characterized by the fact that acquaintance with the properties of concepts begins with constructive activities for their “discovery” and assimilation with a gradual transition to definitions and logical proofs. This, in particular, simplifies the perception of the Geometry course, makes it more accessible, while raising the scientific level through the intensification of educatees’ research activities.

The use of the constructive approach contributes to the fact that the activity is manifested in the gradual transition of actions for the construction of objects from the executive level (is characterized by external regulation), then to reproductive (is marked by internal regulation of actions in the construction of known structures), then to the applied level (using the method of construction), and, finally, the creative level (involves the construction of new objects) (figure 1) (Tukholko, 2018).

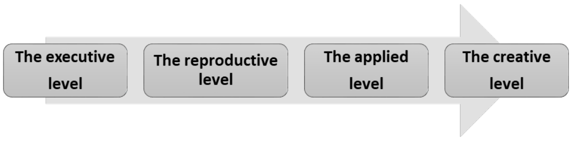


Figure 1: Constructive approach activity levels.

We consider constructive tasks to be one of the means of implementing a constructive approach. Many authors use the term "constructive tasks" in a sense identical to construction problems. However, the peculiarities of the constructive approach require the use for its implementation and other tasks, the solution of which requires the implementation of a particular constructive activity. Therefore, for example, Lisimova (Lisimova, 1997) considers constructive tasks as tasks for construction, imaging, measurement, geometric design and structural-geometric modeling. Dalinger (Dalinger, 2012) considers constructive tasks as "problems in the process of solving which reveal the material conditions of geometric figures. Their purpose is to identify the essential features of ideas that are formed through the material conditions of their origin".

Constructive tasks can be a base for establishing new properties of figures (concepts formation), for the consolidation of knowledge, for repetition, control, intensification of research activities. "The peculiarity of constructive tasks is that they can be solved both logically and figuratively or visually effective" (Dalinger, 2012).

When solving constructive tasks, there is a productive activity that motivates to think independently (methods of constructing have to be developed independently), and not reproductive activity, which is often not an independent mental process, but is a repetition of known steps (Dalinger, 2012).

Mastering the system of knowledge and skills can take place on two levels: constructive and analytical. The main feature of the constructive level of mastery of the material is its visual and constructive awareness. This is manifested:

- in the ability to recognize objects that belong and do not belong to the content of this concept, give examples, demonstrate the existence of the studied figures by construction;
- in the knowledge of their most essential properties and the ability to apply known properties in solving problems.

The constructive approach provides "points of support" for Geometry study at a higher abstract level, which is characterized by the ability to formulate definitions of concepts, statements and prove already in formal language, rather than the language of geometric images.

5 MODEL OF PRE-SERVICE TEACHERS' PREPARATION FOR STUDENTS' COMPUTER MODELING SKILLS FORMATION (BASED ON GEOGEBRA)

The model of pre-service teachers' preparation for the formation of students' computer modeling skills (based on GeoGebra) is based on the perception of a constructive approach as leading in the formation of modeling skills and requires the use of certain forms, methods and teaching purpose (figure 2). Let's dwell on them in more detail.

The purpose of implementing the developed model is pre-service teachers' preparation for students' computer modeling skills formation.

The content on which the model is implemented was a special course on mastering GeoGebra and two experimental modules.

Module "Modeling interesting curves"

Nowadays, their study in the classical course of Analytical Geometry is possible in three ways:

- analytical description and further study of curves – at first analytical (parametric, implicit, explicit) equations, usually of conics, are given and then they are investigated;
- study of curves as locus with a given property – at first the geometric definitions of curves are given, on the basis of which their analytical equations are written (as a rule, these are conics, conchoid of Nicomedes, limaçon of Pascal, strophoid, cissoid of Diocles, lemniscate of Bernoulli, Cassini oval);
- study of curves generated in the kinematic way (as the trajectory of a point), usually cycloidal curves (figure 3), folium of Descartes, witch of Agnesi, logarithmic spiral.

Module "Word problems modelling"

Among other things, the general method of solving word problems includes knowledge of the solving steps. The solving steps include: analysis of the problem text; translation of the text into the mathematics

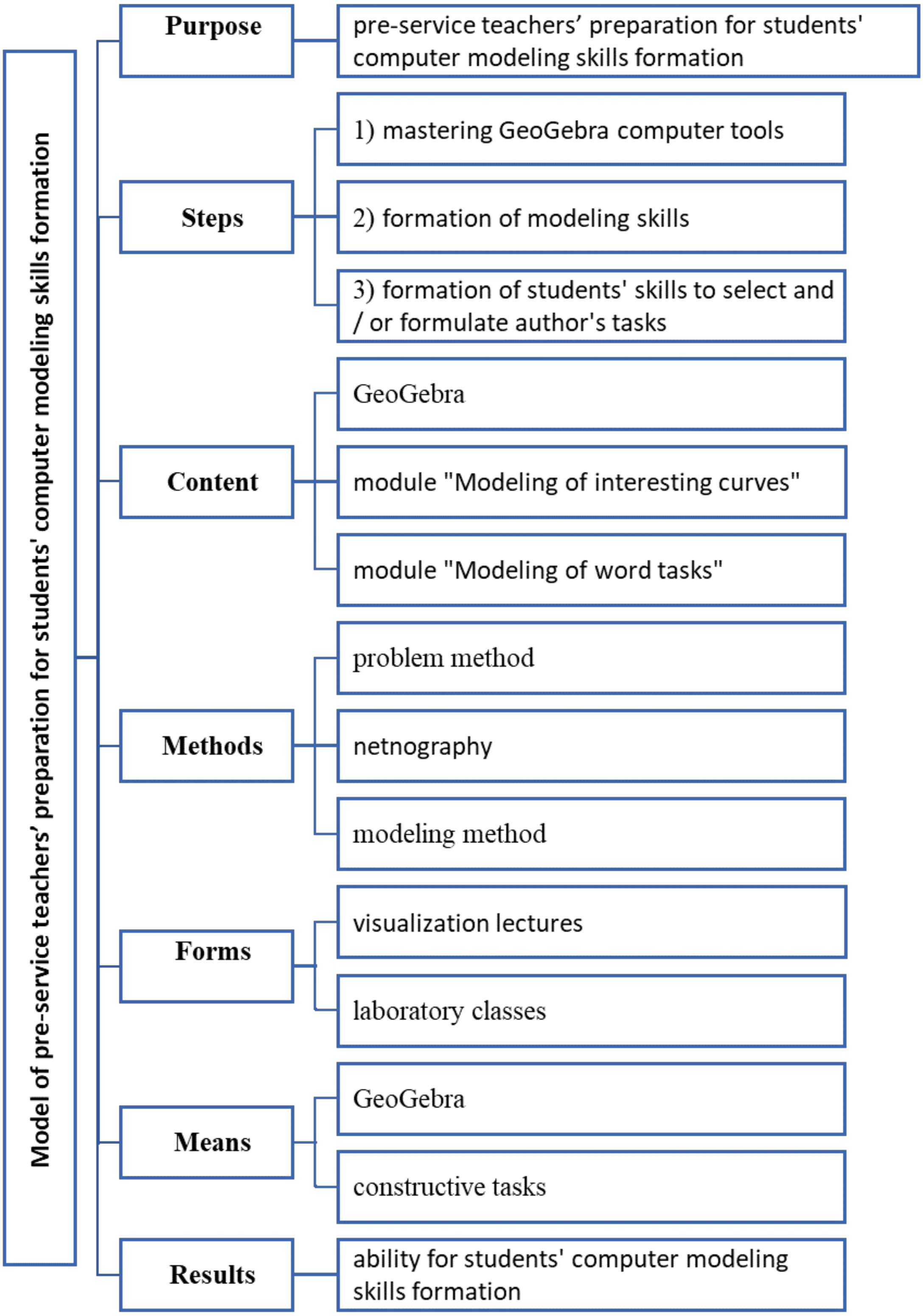


Figure 2: Model of pre-service teachers' preparation for students' computer modeling skills formation.

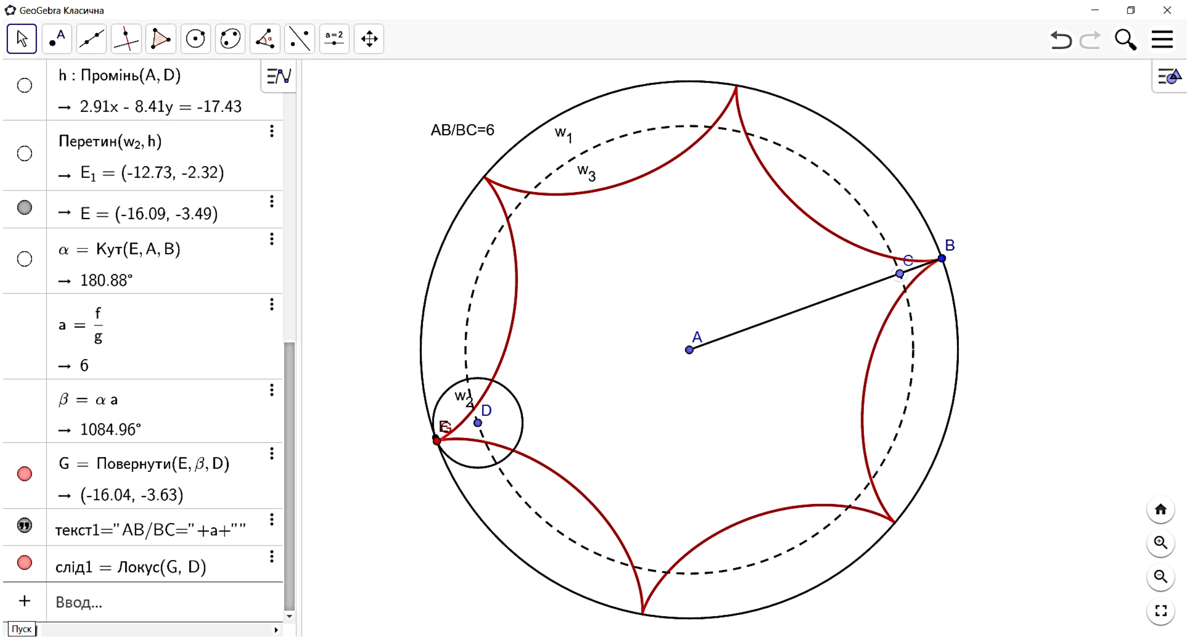


Figure 3: Construction of a hypocycloid using the Locus tool.

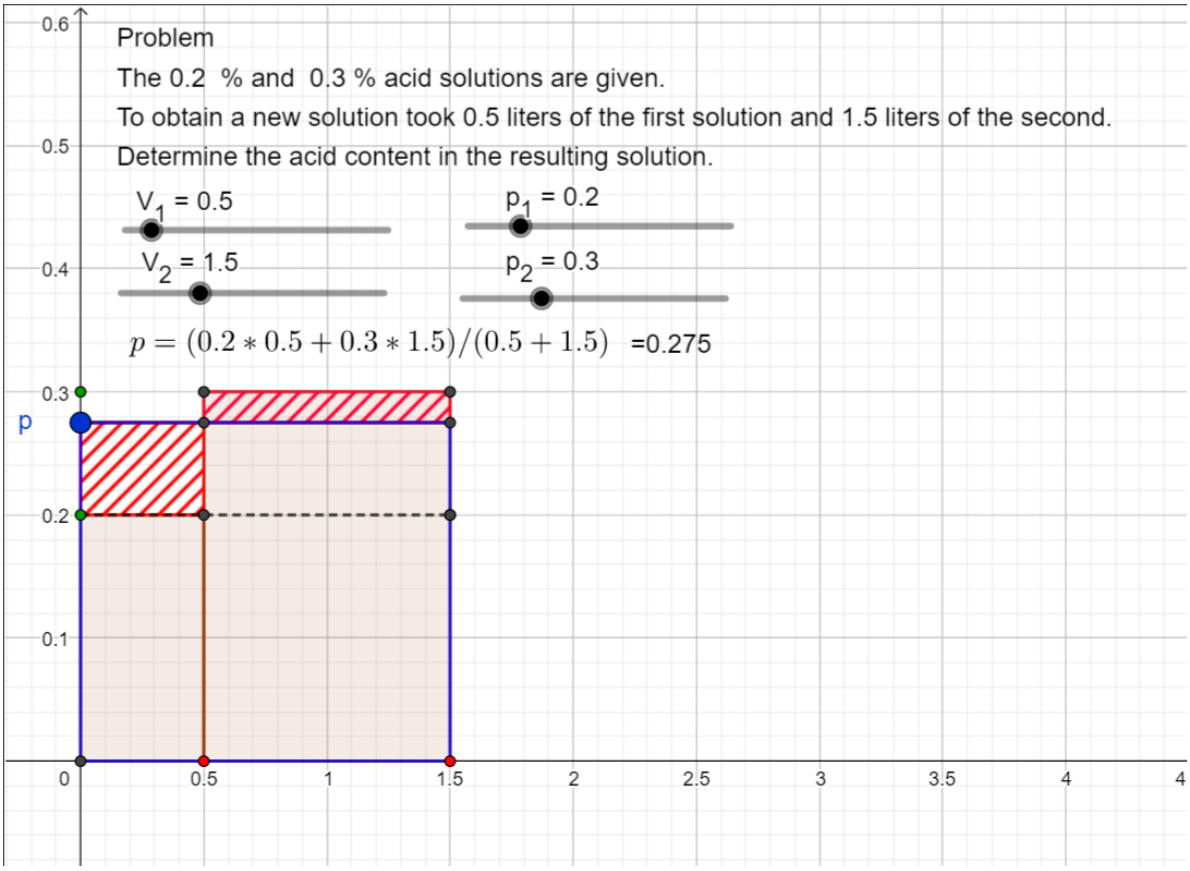


Figure 4: Word problem modelling based on GeoGebra (https://www.geogebra.org/m/fmupxx5a).

language (modeling); establishing the relationship between the input data and the problem question; drawing up a problem solution plan; implementation of the solution plan; checking and evaluating the problem solution.

The essence of the method of modeling in solving word problems is to translate the text of the problem into the language of visual models of various kinds: drawings, diagrams, graphs, tables, symbols, formulas, equations, etc. The translation of the text into the form of a visual model allows you to identify properties and relationships that are often difficult to detect when reading the text (figure 4).

Learning forms of the model are visualization lectures and laboratory classes.

Among the teaching methods used problem method, modeling method and netnography.

GeoGebra, constructive tasks and instructional materials are learning means.

The model of pre-service teachers' preparation for students' computer modeling skills formation is implemented in three stages:

1) mastering GeoGebra computer tools;
2) pre-service teachers' preparation to modele (on the material of interesting curves in Analytical Geometry or word Math problems in secondary school);
3) formation of students' skills to select and/or formulate author's problems that can be solved by the modeling method in GeoGebra.

In the first stage, GeoGebra computer tools are mastered: students get acquainted with the possibilities of using GeoGebra to solve different classes of math problems. Particular emphasis should be placed on tools of geometric constructions and sliders, thanks to which it is possible to change the constructed structure in an interactive mode.

The methodology of forming the skills to model interesting curves is as follows: the teacher on a common online platform informs about constructive approaches to the construction of various curves, which were studied in ancient times (the netnography method). He briefly tells about how such constructions were done (compass and ruler, one compass, two compasses, one or two rulers, etc.), or gives an example of practically oriented problems that are solved using interesting curves. After that, the teacher demonstrates one of the described constructions in GeoGebra cloud service, and then asks students to write an algorithm for the above construction (the problem method).

Then the teacher asks students according to the algorithm (provided to each student) to reproduce the construction and demonstrate the result, to analyze errors, and if not, to analyze possible limit cases. After that, students are offered the definition of curves generated in mechanical way together with the algorithms of their construction in the cloud service; students must model this type of curve according to the existing algorithm. Then together with students, the task of the following type is carried out: algorithms of curves construction are offered and after their construction, students need to characterize properties of the modeled curves, to give them definitions or kinematic characteristics. After completing this type of task, students are offered only the definition of the curves or their kinematic characteristics, and they must model the curve themselves.

The methodology should be briefly described as follows. Step 1 – the teacher offers an example of a curve model through the definition (the teacher step by step models the curve), and students must independently compile an algorithm for constructing the model. Step 2 – the teacher offers a description-definition of the curve and provides a ready-made algorithm according to which students model the curve independently. Step 3 – the teacher offers an algorithm for constructing a curve model, and students need to characterize the properties of the curve or give its definition based on the results. Step 4 – students are offered definitions of curves that they have to model them.

More details about the methodology in (Drushlyak et al., 2021b).

The method of the second stage described by us differs from the traditional one, as the latter usually involves only step 2 and step 4, which does not allow students to understand the algorithms involved in building a model, to develop the ability to compare step-by-step ideas and steps. There is also no practice of qualitative analysis of the algorithm (which is provided by step 3 and which is supported by the "step-by-step playback service" in GeoGebra). This is what we consider to be fundamentally important for the effective learning of modeling skills and what makes the GeoGebra service possible.

Mastering the module "Modeling of word problems" involves providing students with instructional materials with examples of solving word problems in GeoGebra. At the first lesson, students must complete tasks on modeling word problems of the school mathematics course on the model and independently. For the second lesson, students have to prepare 10 word problems, up to 5 of which provide instructional materials for solving in GeoGebra. Students must exchange developed didactic materials, solve problems and return them for testing. For the third lesson, stu-

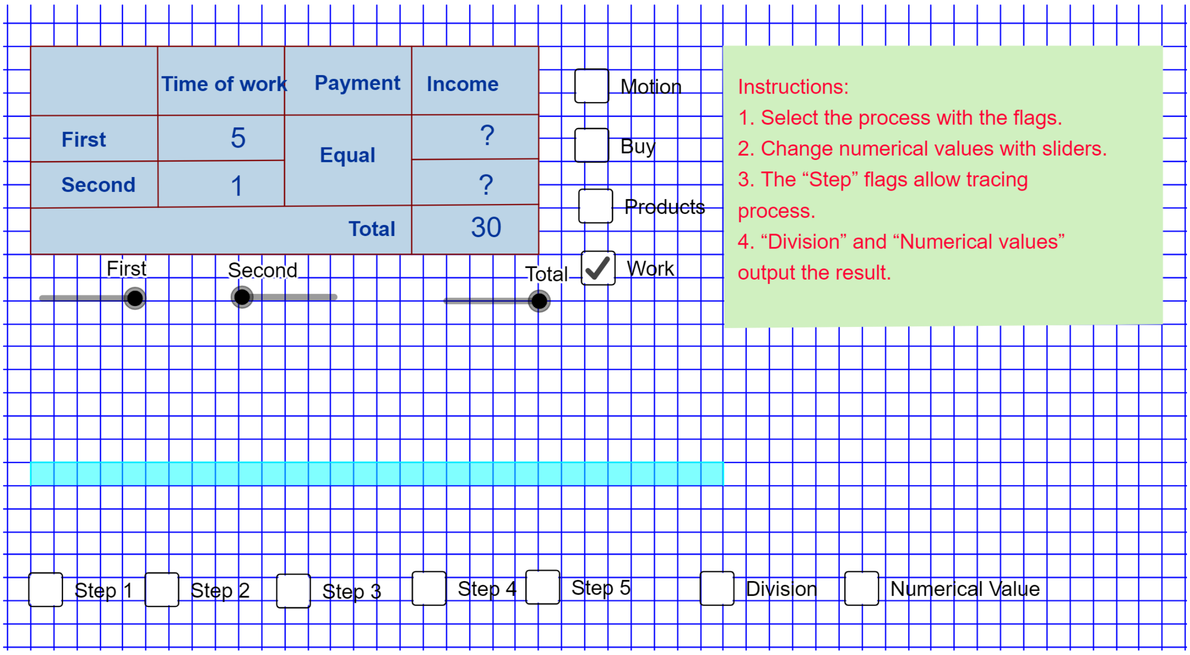
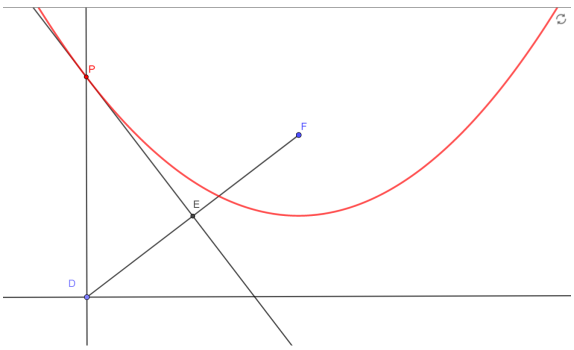
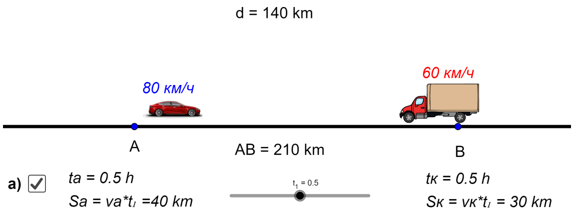


Figure 5: The problem of proportional division (author Nataliia Kishchuk, https://www.geogebra.org/m/bhw6xbcp).



(a) Construction of a parabola, Locus tool.



(b) Visual model of the motion problem.

Figure 6: Visual models.

dents should check the tasks performed by another student and analyze the errors, which should be presented to the general public for discussion.

We will describe in more detail the method of teaching this module.

The method of forming the skills to model word problems is as follows: the teacher on the cloud service https://www.geogebra.org/ introduces students with examples of visual models for word problems (the method of netnography, figure 5). This briefly dwells on how such constructions were carried out (using Slider, Text, Button, Check Box). After that he demonstrates one of the described constructions in GeoGebra cloud service (figure 4), and then asks students to prescribe the algorithm of the given construction (the problem method).

Then the teacher asks students according to the algorithm (provided to each student) to reproduce the construction and demonstrate the result, to analyze possible errors.

Briefly, the technique should be described as follows:

Step 1 – the teacher offers an example of a visual model of a word problem, and students must independently create an algorithm for a model constructing;

Step 2 – the teacher offers a ready-made algorithm by which students independently reproduce the visual model;

Step 3 – students are offered a type of word problems (motion problems, work problems, alloy mixtures problems, etc.), they select the appropriate problem and independently construct a visual model.

It should also be noted that in the conditions of distance learning, GeoGebra service allows the demonstration of shared constructions and the ability to work with models at any time from anywhere.

Table 3: The results of students' tests.

Student	Mark 1	Mark 2	Student	Mark 1	Mark 2	Student	Mark 1	Mark 2
1	10	10	18	13	12	35	17	17
2	13	11	19	11	16	36	12	13
3	12	12	20	9	10	37	11	13
4	5	9	21	8	8	38	11	13
5	14	14	22	9	11	39	9	12
6	6	7	23	9	11	40	9	13
7	9	10	24	9	9	41	9	11
8	10	12	25	9	9	42	9	11
9	12	12	26	7	16	43	7	10
10	12	11	27	15	15	44	9	12
11	11	12	28	13	14	45	7	10
12	11	15	29	14	15	46	8	9
13	6	6	30	11	11	47	13	11
14	5	9	31	11	12	48	15	14
15	7	12	32	11	12	49	16	16
16	9	9	33	12	12	50	12	13
17	9	11	34	7	9	51	12	11

6 STATISTICAL ANALYSIS OF RESULTS

The effectiveness of the developed model was tested on the basis of two tests. Students had to solve problem 1 (for example, to build a curve for which "A point and a line, the distance between which is equal to a are given. A line is drawn through an arbitrary point X of the line and the point. The points at a distance b from point X are marked. Find the locus of such points", figure 6 (a)) and problem 2 (for example, to build a visual model for the problem "From points A and B, the distance between which is 210 km, car and truck moved to meet each other. The speed of a car is 80 km/h, and a truck – 60 km/h. What will be the distance between the machines in half an hour?", figure 6 (b)) before the experiment and after the experiment.

Assessment of the solutions of problem 1 was carried out through the assessment of skills: take into account the analytical and geometric relationship between the elements; use the Locus and Trace tools; successfully visualize the model; add dynamic text to demonstrate numerical characteristics; develop an algorithm for model constructing; reproduce the steps of the algorithm for the model constructing; interpret the result of a computer experiment (in more detail in table 1). Assessment of the solutions of problem 2 was carried out through the assessment of skills: the ability to analyze the text of the problem; establish a relationship between the input data and the question; use Slider, Text, Button, Check Box, Image; successfully visualize the model; to develop an algorithm for a model constructing; reproduce commands of the model construction algorithm; check and evaluate the computer solution of the problem (more details in table 2).

The results of the tests are presented in table 3.

These marks were used to determine the number of respondents whose total score decreased ("–"), did not change ("0") and increased ("+") (table 4).

Table 4: Dynamics of scores based on the results of students' tests

Dynamics of scores	Number of respondents
Negative, "–"	6
Without changes, "0"	13
Positive, "+"	32
Number of changes, n = "–"+" + "	38

7 CONCLUSIONS

1. The development of information technology has actualized the perception of modeling as a leading method of scientific knowledge and a means of developing intellectual skills of young people. Thus for the decision of many mathematical problems the method of modeling which is realized on the basis of the constructive approach is used.

2. The students' ability to model can be successfully formed under the condition of appropriate advanced teacher training, and therefore models and methods of pre-service teachers' preparation for students' modeling skills formation are in demand in modern society.

3. The developed model of pre-service teachers' preparation for students' modeling skills formation (based on GeoGebra) is based on the perception of a constructive approach as a leader in the development of intellectual skills of young people. Its implementation is based on a special course on mastering GeoGebra and two experimental modules "Modeling curves" and "Modeling word problems", mastering which involves the use of appropriate forms (visualization lectures and laboratory classes), methods (problem, modeling and netnography) and training means (GeoGebra, constructive tasks and instructional materials).

4. The model of pre-service teachers' preparation for students' modeling skills formation is implemented in three stages: 1) mastering the GeoGebra computer tools; 2) formation of pre-service teachers' skills to model; 3) formation of students' skills to select and/or formulate author's problems that can be solved by the method of modeling in GeoGebra.

5. The developed model is focused not only on the pre-service teachers' preparation for students' modeling skills formation with GeoGebra, but also thanks to the role-playing game in the third stage of its implementation allows awareness of their own mistakes in future professional activities and typical mistakes of students.

Further scientific research is needed to implement the methodology: in the training of teachers of natural specialties (biology, chemistry, geography); in the conditions of mobile training; based on other specialized software.

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