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Cognitive Tasks Design by Applying Computer Modeling System for Forming Competences in Mathematics

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Abstract. The article defines the basic concepts of "cognition", "cognitive activity", "cognitive task", "cognitive competence", "system of computer modeling"; types of computer models; it determines the components and structure of pupils' competence formation in mathematics on the basis of solving cognitive tasks using computer simulation systems; specifies levels and types of cognitive tasks; singles out features, basic components and levels of pupils' cognitive activity of general secondary education institutions. It was found out that different types of cognitive tasks (emotional-figurative, evaluation-educational, practical-educational, theoretically oriented, information-oriented) consistent with their levels of complexity (learning-reproductive, analytical, theoretical, applied, research, creative) form a system for the development of cognitive abilities of a high school pupil. It is determined that assessment of cognitive abilities of pupils can be carried out according to the following criteria: cognitive bases, cognitive processes, cognitive activity and cognitive qualities. It is established that the use of cognitive tasks using computer modeling systems will facilitate the formation of pupils' competences in mathematics. It is substantiated that the use of computer modeling systems will provide variability of tasks, complexity, universal access, organization of individual and team work.

Keywords. cognition; cognitive activity; cognitive task; structure; cognitive abilities; system of development; computer modeling system, services, CMODS, establishment of general secondary education (EGSE).

Key Terms. Teaching Methodology, Teaching Process, Knowledge Management Methodology, Quality Assurance Methodology, Standardization Process, ICT.

1 Introduction

Problem statement. Within the framework of implementing the New Ukrainian

School Concept, the modernization of the content of education, the intensive development of information and communication technologies, unlimited access to information resources, the child-centered approach still remains fundamental along with the development of cognitive abilities and learning capacities, the formation of compulsory pupils' learning outcomes (in terms of competences) at establishments of general secondary education.

Therefore, one of the key competences mentioned in the New Ukrainian School Concept is the natural sciences competence, namely: scientific understanding of nature, ability to utilize it in practice; apply scientific methods, observe, analyze, formulate hypotheses, collect data, conduct experiments, analyze results, and use modern technologies [1, p.13].

Modernization of the curricula contents, in particular the course of mathematics, prompts the teacher to widely apply new methods of training, based on: cooperation, game and design technologies, solving cognitive and research tasks, organizing and conducting educational experiments, team work, etc. These processes are the basis for the formation of key competences of the XXI century pupils.

Such transformational educational processes require new approaches to using digital and organizational solutions to form pupils' competences in mathematics, natural sciences and technologies, in particular, in the development of cognitive abilities and cognitive activity of pupils.

At the same time, the process of information perception by the pupils, formed in the conditions of traditional education, and the continuous, chaotic development of the Internet, saturation with an infinite number of social objects (video materials, photographs, texts, etc.) and electronic educational resources, makes it impossible to quickly search and select data; this may be achieved in the process of pupils' cognition and formation of mathematical competence.

Scientists and teachers of educational establishments state that the problem of using the latest information and communication technologies, computer modeling of natural processes and phenomena, the development of new technologies and models of education, development of a system of cognitive tasks that would ensure the continuous development of cognitive abilities of pupils and activation of their cognitive activity requires additional research.

2 Literature Review

Analysis of latest research and publications. Peculiarities of the use of Internet technologies for the investigation of natural phenomena are broached by scientists Yu. O. Zhuk, O. M. Sokoliuk, N. P. Dementievska, O. V. Slobodianyk. Scientists have identified the peculiarities of the use of Internet-oriented pedagogical technologies in the school experiment, in particular, when studying the course of physics in institutions of general secondary education.

The general aspects of the concepts formation and different methods of the

pupils' research work are revealed by: V. I. Andreyev, M. A. Akhmetov, B. A. Vikol, A. G. Iodko, V. V. Uspenskyi, L. M. Fedoriak, I. V. Kharytonova, M. V. Shabanova, T. A. Yarkov. The scientists' research results determine the need to use research tasks to improve the quality of assimilating material by pupils while studying school subjects.

The foundations of the didactic system of the activity-based teaching method are grounded in the works of L. G. Peterson, O. S. Anisimova and others. Educators-practitioners generalize the experience of constructing pedagogical systems on the basis of the system-activity approach, describe the system of didactic principles and the technology of the active method of teaching pupils in the classroom.

The use of the system of competence tasks as a means of forming pupils' IC competences is disclosed in the works of N. V. Morse, O. G. Kuzminska and others [21].

Unresolved aspects of the problem. The intensive development of Internet technologies and the expansion of educational mobility possibilities of both teachers and pupils, actualizes the problem of improving the method of using cognitive tasks for the development of cognitive abilities of pupils in general secondary education (EGSE) and elaboration of computer models for experimental and empirical research.

Currently there are a large number of on-line virtual laboratories in physics, chemistry, biology (for example, http://www.virtulab.net). However, they are mostly used for "classical" experiments (in compliance with the curriculum). Thus, the pupils' interest is formed through experiments visualization, while the combination of interesting tasks formulations with online tools would allow pupils to develop research qualities, curiosity, decision-making skills, constructing hypotheses, and others.

The purpose of the article is to summarize the main provisions and substantiate the theoretical foundations of designing cognitive tasks using computer modeling systems for building competences in mathematics and the development of pupils' cognitive abilities in the establishments of general secondary education.

3 Research Methods

This study was carried out within the framework of the research work entitled "The system of cognitive tasks computer modeling with the aim of developing pupils' competences in natural and mathematical subjects". Methods, used in the course of research, are: the method of theoretical sources analysis, the study of the advanced pedagogical experience of foreign and domestic teachers on the problem of the cognitive tasks formation and application for teaching pupils; synthesis, generalization and conceptualization for the formulation of the main provisions of the study; design and modeling of cognitive tasks and the formation of pupils' competences in mathematics; generalization and evaluation of the results.

4 Research Results

4.1. Theoretical Foundations

At the core of the child-centered approach lies not only the direction of the educational process on the development of the pupil's personality, inborn talents, but also his/her cognitive activity, which is the fundamental factor in the development of his/her cognitive abilities.

At the philosophical level, cognition is the reproduction in the mind (individual and collective) of the characteristics of objective reality. As it is noted by V.V. Lazarchuk, cognition is socially and culturally mediated, historical in nature and in most cases involves awareness of means and methods of cognitive activity [9, p. 103]. A cognitive interest is formed in the process of cognition that has a search character and focuses an individual on objects and phenomena, which provide a holistic view of the world.

Cognition does not exist in itself; this process is inextricably linked with the activity of the pupil, the development of his/her cognitive abilities, in particular, the formation of mathematical competences on the basis of solving cognitive tasks (Fig. 1).

Thus, N.F. Talyzina points to the inextricable connection of the pupil's psyche with his/her activity. Activity is the process of subject's interaction with the surrounding world, the process of solving vital tasks. Thus, in the activity approach, the psyche is understood "as a form of life of the subject", which provides solution for certain problems in the process of interaction with the world. The subject acts as a source of activity, not as a simple set of his/her mental characteristics [2, p.6].

According to S.L. Rubinstein, "person's activity is characterized by the following main features:

- objectivity;
- sociality, that is, socio-historical nature;
- individuality, that is, an individual-evolutionary nature;
- indirectness;
- social motivation and individual orientation;
- productivity, creativity" [3, p.41-45].

In addition, activities are classified according to the relative role of other processes in them, namely: sensory, visual, auditory, and others.

The system of pupil's activity in the process of cognition can be presented in the form of the following basic components:

- motivational (stimulating);
- informational (orientation);
- goal-generating (programming);
- resultative (productive);
- affirmative (emotionally sensual) [4, p.29].

The transformative, cognitive and communicative activities are distinguished in

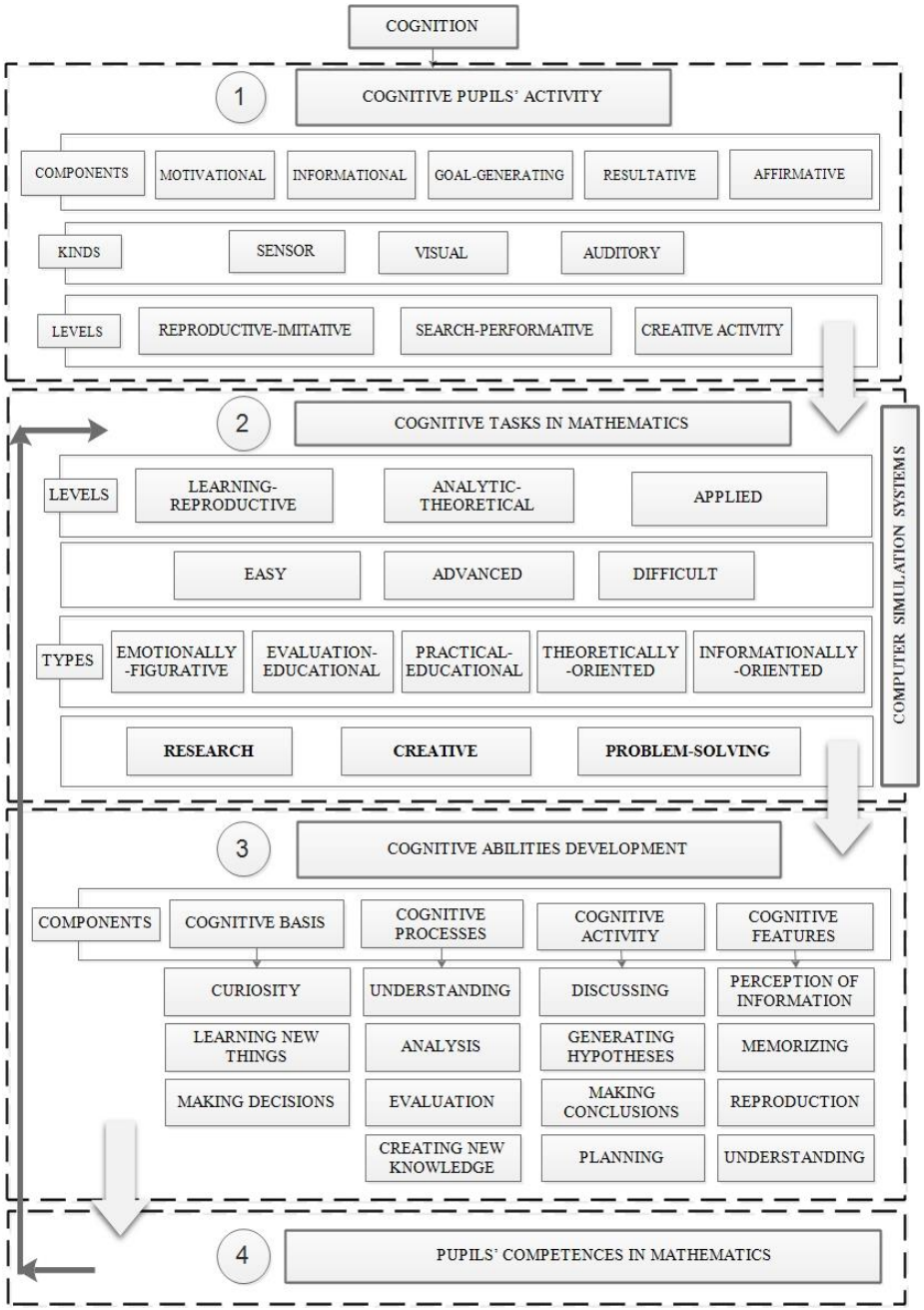

Fig. 1. Pupils' competences formation in mathematics on the basis of solving cognitive tasks using computer modeling systems

the activity system, which underlies the formation of pupils' competences.

Researchers approach the consideration of the essence of "cognitive activity" concept from different perspectives. With all the multidimensional approaches, we single out two points of view:

- cognitive activity as activity;
- cognitive activity as a personality trait.

We will consider cognitive activity as an activity of an individual aiming to acquire the cognitive, substantive and key competences.

Modern psychologists distinguish three levels of schoolchildren's cognitive activity:

Reproductive-imitative level: activity as a way of mastering the experience of another person (reproduction);

Search-executive level: an activity, in which it is necessary to get a task and to find the way for its fulfillment (interpretation);

Level of creative activity: activity, in the process of which the task is set by the pupils themselves and is solved in a new, original way [5, p. 102].

It should be noted, that pupils' cognitive activity is developed in line with the following principles:

Activity – a pupil gets knowledge not in the ready-made form, but acquires it independently, in the process of individual educational activity.

Succession – the logical structure of the sequence of learning at the level of technology, content and methodology.

Openness – universal access to data and educational information.

Variation – the formation of the ability to consider various options and to choose the optimal solution to the problem.

Integrity – formation of the holistic worldview.

Therefore, one of the ways of boosting cognitive activity is the application in the educational process of cognitive tasks, which require a pupil to perform certain actions, such as:

- independently transfer previously acquired knowledge and skills into a new situation;
- understand the structures and characteristics of objects;
- search for alternative solutions or ways of solving problem assignments;
- combine previously mastered methods of solving problem assignments into new ones [5, p.102].

As scientists point out, the problem of pupils' cognitive activity development as a way of obtaining a new quality of the individual is not exhaustively developed, and the holistic systematic vision of the cognitive abilities development process as of the individual's ability in the process of learning is not formed, either [7, p.10-17].

The development of pupils' cognitive abilities is a long process. In addition, to develop pupils' cognitive abilities means to form motives for learning. Pupils must not only learn how to solve cognitive tasks, they need to develop their desire to solve these problems. At present, one of the main tasks of modern school is to foster pupils' motives [8].

This approach will enable the pupil to form cognitive competence.

Cognitive competence is the pupil's ability to independently engage in activities

that include elements of logical, methodological, heuristic, general educational activity, correlated with real objects that are perceived by the pupil. This includes the knowledge and skills of organization of goal-setting, planning, ideas generation, analysis, reflection, self-assessment of educational and cognitive activity [9, p.102]. In relation to the objects under study, the pupil acquires the creative skills of productive activity, namely: obtaining knowledge directly from the surrounding world, mastering methods of action in non-standard situations and heuristic methods of solving problems. Within the framework of this competence, the requirements of the corresponding functional literacy are determined: the ability to distinguish between facts and second-guessing, ability to apply measuring skills, the use of probabilistic, statistical and other methods of cognition [9, p.105].

Guided by the nature of the pupils' cognitive activity in the process of mastering the substantive content, we distinguish two levels of cognitive abilities:

The first level: mastering the ready experience and reproduction of knowledge in the process of his/her activities

The second level: mastering the ready knowledge, deepening the acquired knowledge, formulation of the conclusions by the pupil is carried out using a variety of sources of information and the implementation of imaginary and practical actions.

According to these levels, we distinguish three interrelated groups of cognitive competences:

- ability to search and select the necessary information;
- ability to work with selected information;
- ability to produce new (subjectively new, new for the learner) knowledge, using available information [10].

In case when the task is solved in order to determine the required characteristics of the object, the basic data, which the object bears, will be called informational tasks. Among the informational tasks the most important place is occupied by the cognitive one [11].

The notion of "cognitive task" is considered in the general theory of problems, as a generalization of the same concept used in psychology, pedagogy, methodology of science [6].

We will give the advantage in the development of cognitive tasks to those that are implemented in class: a lesson, a home assignment, a practical task or a training project.

Taking into account the peculiarities of the process of cognition, which is carried out on the basis of solving cognitive tasks, we define it as a fundamental one in teaching pupils.

It should be noted that in today's digital world the opportunity to access educational resources is increasing. There appear different types of computer simulation processes, phenomena, objects of living and inanimate nature, which can be applied to model various cognitive tasks.

4.2. Examples of Implementation

The main objective of special subject teacher's work is the development of cognitive abilities of pupils. The achievement of this objective allows completing the main tasks of studying, that is, to provide the stable and conscious knowledge of teaching material; to prepare pupils to close involvement in productive activity; to form the ability to enrich their knowledge independently [8].

In view of the above-mentioned, we can distinguish the main levels of cognitive tasks according to pupil's way of thinking:

- learning-reproductive, that is, solving a typical problem;
- analytic-theoretical, that is, drawing general logical conclusions to the content line and practical part of a problem;
- applied, that is, solving an untypical task;

According to the level of complexity, cognitive tasks should also be classified into easy, advanced and difficult.

According to the way of forming pupils' cognitive abilities, cognitive tasks are subdivided into the following types [12, p.351]:

- emotionally-figurative, which allows creating the "image' of solution to a problem, thinking intuitively, applying mental images, "getting into" the object under investigation;
- evaluation-educational – thinking critically, comparing and correlating different points of view, evaluating, making predictions and formulating hypotheses, reflecting on one's activity;
- practical-educational – constructing, conducting trials and experiments, observing and modeling.
- theoretically oriented – creating "new" knowledge, generating ideas, asking questions;
- information-oriented – generalizing, systematizing and modifying educational information, "encoding and decoding teaching material", interpreting information.

According to the main types of educational activity, we can distinguish the following cognitive tasks: research, problem-solving and creative.

Research – organizing and conducting investigation of a problem on the basis of education.

Problem-solving – solving an education problem (within one discipline, project activity).

Creative: generalizing data and developing one's models, solutions.

Let us specify certain aspects of creative tasks. Thus, A. V. Khutorskyi suggests implementing the following classification of creative tasks: cognitive, creative, organizational-activity [12, p.356].

Cognitive tasks aim at forming and developing pupils' cognitive abilities: the ability to ask questions, feel the world around, conduct trials and experiments, and find reasons for the occurrence of phenomena.

Creative tasks provide forming creative personality traits: the ability to make predictions, notice contradictions, flexibility, imagination, the ability to create

something new.

Organizational-activity tasks form the ability to realize and formulate the aim of one's educational activity, ensure one's growth in education, recognize the results of one's education, and make judgments [12, p.368].

We can identify the following requirements for creative tasks:

- openness (the content of problem situation or contradiction);
- conformity between the statement and chosen creative methods;
- variability of solutions;
- monitoring the current level of development;
- considering pupils' age peculiarities [13, p. 84].

Summarizing the aforesaid, we come to a conclusion that the role of cognitive tasks in teaching mathematics is to serve as a basis for organization of pupils' education process in form of statements and search for solutions to education problems for the purpose of cognitive ability development.

As O. Yu. Burov states, one should also bear in mind the fact that pupils' cognitive abilities depend not only on skills and motivation, but also objective external factors that are usually not considered in the context of personality [14]. Organizational efforts are required to compensate for a gap between pupil's abilities and his/her conditions of education.

Therefore, we can regard the following categories as the components of forming pupils' cognitive abilities on the basis of use of cognitive tasks in educational process:

- cognitive basis (curiosity, learning new things, making decisions);
- cognitive processes (understanding, analysis, evaluation; creating new knowledge);
- cognitive activity (discussing, generating hypotheses, making conclusions, planning);
- cognitive features (perception of information (by tactile, visual, auditory channels), memorizing, reproduction, understanding).

The development of information and communication technologies has facilitated an opportunity to design cognitive tasks using computer modeling.

Modeling as a cognitive method has a centuries-old history. By different means (verbally, graphically, with the help of mathematic formulas, physical and technological patterns), a human being was trying to describe the phenomena he/she was observing as well as the objects surrounding him/her.

As N. Daneshjo mentions, computer models fall into two types [20].

The first type. Computer models which enable analyzing objects or systems, checking, observing and specifying their characteristics. Nowadays, a significant number of computer models for natural processes and phenomena are available, which allows conducting the process of objects' analysis in a simpler, more educational, interesting and profound way.

The second type. Computer models which emerge as a result of development and design (e.g. a model of household plot). This activity is usually supported by computer technologies. Thus, we are talking about methods of automatic designing that requires special software.

We will denote the experimental procedure with a model as *simulation*.

Experiments in the sphere of modeling allow conducting a thorough analysis and defining the characteristics of an object, searching for alternatives or solutions of the problems formulated.

As **computer modeling system** (CMODS) we will define software, intended for visualization of phenomena and processes, conducting numerous calculations of any level of difficulty, aimed at clarifying and solving problems of different types.

Two types of computer modeling systems are appropriate for teaching scientific and mathematical disciplines to pupils when they are only exploring the world and lack visual objects, or when natural processes show dangerous features.

Let's consider the computer modeling of the first type (simulation of the first type) on an example of models Phet (phet.colorado.edu) for conducting classes in mathematics. Mathematics is considered one of the most complex subjects of the school course. In algebra lessons, for example, more attention is paid to working out the skills of solving various examples and tasks. There is practically no time left for conducting cognitive workshops. So, when studying the topic "Quadratic function, its graph and properties", pupils of the 9th grade would be offered to independently determine the properties of the parabola and the features of graphing.

To organize such a cognitive workshop, the pupils would only need to download the Phet simulator (phet.colorado.edu) and analyze the properties of the parabola by specifying different values of the variables a, b, c (Fig. 2).

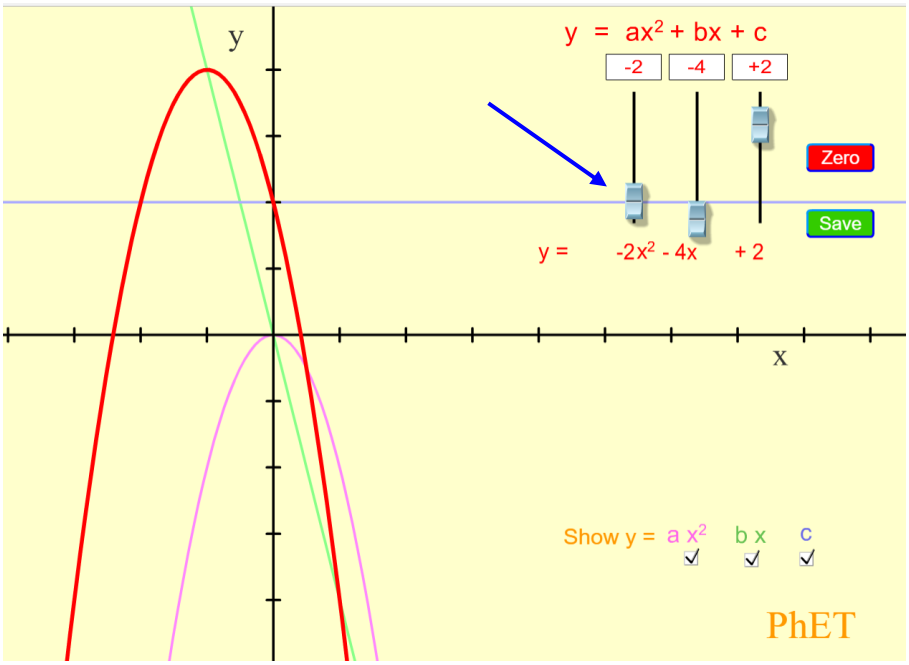

Fig. 2. An example of the Phet computer modeling system application

In order to deepen knowledge, pupils are also encouraged to find the range of

values, the intervals of decline and growth, constant signs, the greatest and least value of the function, to analyze the results and to formulate general conclusions.

An example of computer modeling of the second type (simulation of the second type) can be the implementation of research cognitive tasks:

1. Realization of cognitive activity by the pupil:
   - to find an image of the Cheshire cat on the Internet, to find out who he is;
   - examine his smile;
2. Implementation of cognitive tasks on the basis of computer modeling:
   - to project a smile of the Cheshire cat in the Phet computer simulation system (phet.colorado.edu), using the computer model “Graphs” (Equation Grapher);
3. Development of cognitive abilities:
   - to compare the projected smile with the image;
   - to find out how the projected smile will change if the mood of the cat changes.
   - to summarize the properties of the projected smile (parabola), etc.
4. Identification of the level of pupils’ competences formation (see Fig. 1).

To project the described sequence of ***mini-tasks*** in Desmos environment (desmos.com) (Fig. 3).

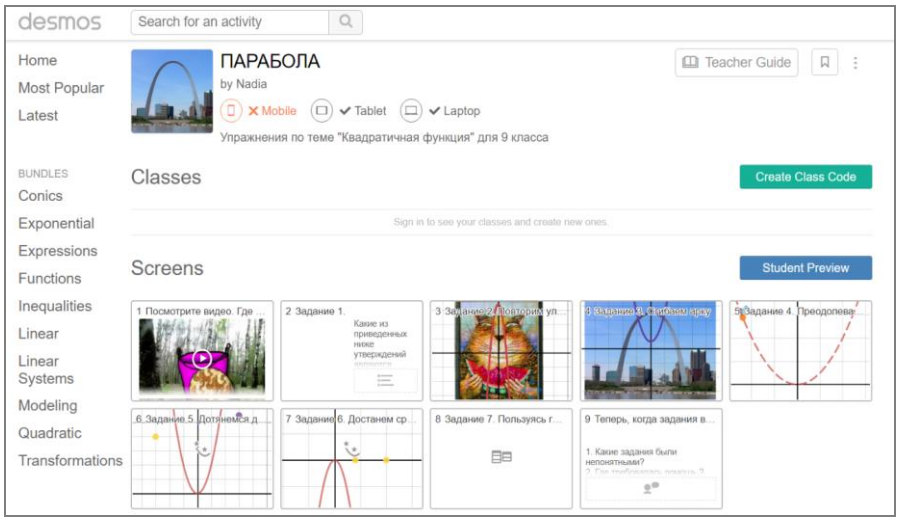

Fig. 3. An example of projecting a cognitive task in Desmos

The work with pupils could be carried out in small groups using tablets or mobile phones. Main results are recorded in the tables.

The purpose of this work is to independently acquire knowledge about the basic properties of a parabola.

For pupils who work in cloud-based learning environments, the results of work are saved in tables (Excel Online), which can be accessed by all members of the group.

Such work on data collection will be faster and the work results will be

monitored by all group members. Each pupil can write intermediate deductions in OneNote, and then the group members can summarize the results using the Padlet service (padlet.com) [15, 16,17].

Let's project the described task in accordance with Fig. 1, taking into account the pupils' work in the cloud-oriented environment (Table 1).

Table 1. Projecting a Cognitive Task Using Systems of Computer Modeling

The number of the stage	**The title of the stage**	**The content of the stage**	**Tools, services, organizational components**
0	Preparatory stage (performed by the teacher)	a thematic online notebook is created	OneNote (в Office 365)
		access to it is provided to all class pupils by the appropriate link	Administrative component
		the link to the novel "Alice in Wonderland" by Lewis Carroll is placed in the notebook	Forming component
		the link to the computer modeling system is placed in the notebook or the computer model is embedded as an object	Forming component
		the dashboard for discussions "Cheshire cat and parabola" is created	Padlet.com
		the questionnaire of formative assessment is created	Forms (in Office 365)
1	*Implementation by the pupils of cognitive activity*	to find the image of the Cheshire cat in the novel	One Note (in Office 365)
		to study its smile (to note down hypotheses)	OneNote (в Office 365)
2	*Completion by pupils of cognitive tasks based on computer modeling*	to project the smile of the Cheshire cat in the system of computer modeling	*phet.colorado.edu*, computer model "Graphs" (Equation Grapher)
		the screen copies are placed on the dashboard	Padlet.com
3	*Development of pupils' cognitive abilities*	to compare the projected smile with the image, presented in the novel	OneNote (в Office 365)

		find out how the projected smile will change if the cat's mood changes (conclusions are written on a shared board)	Padlet.com
		generalize the properties of the projected smile (parabola)	OneNote (in Office 365)
4	*Level of formation of pupils' competences in mathematics*	to implement the formative assessment of pupils (we consider the service to be a means of determining the level of competences formed by pupils)	Forms (in Office 365)

Let's consider another option of the cognitive task that is implemented in the system of computer modeling of the second type Desmos (desmos.com) while studying the topic "Graphic solution of inequalities" (Fig. 4).

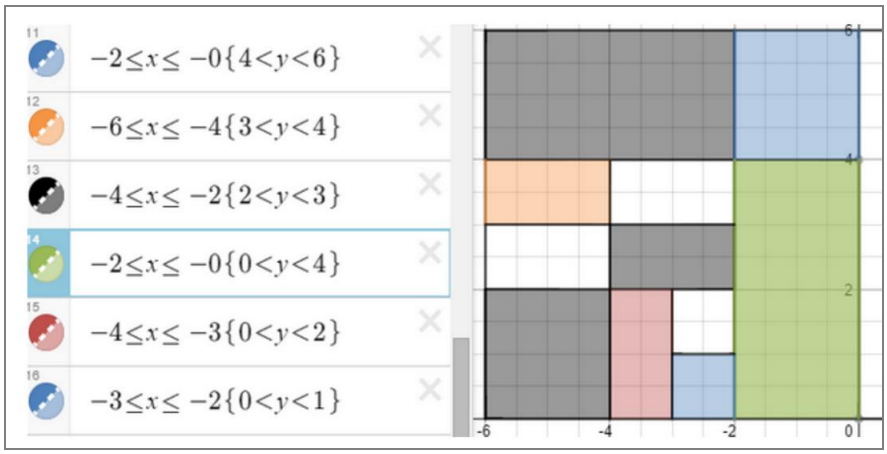

Fig. 4. An example of a creative cognitive task of increased complexity (Desmos)

Task. The school announced a competition for the best design of windows in the corridors. The teacher of mathematics offered the pupils to think, develop a design of stained glass and present their projects in the form of a system of inequalities. Let's consider the accomplishment by the pupils of the creative cognitive task of increased complexity in more detail.

1. Realization of cognitive activity by the pupil:

- to find the images of stained glass on the Internet, to find out what it is;
- to study types of stained glass.

2. Implementation of cognitive tasks on the basis of computer modeling:
- to project a color scheme of stained-glass window;
- to project the stained glass for the window in the mathematics study in the system of computer modeling Desmos.
3. Development of cognitive abilities:
- to compare projected stained-glass windows;
- to find out how the projected stained-glass window will change if you change the marginal values of inequalities;
- to summarize pupils' knowledge of the graphic solution of inequalities, etc.
4. Identification of the level of pupils' competences formation (see Fig. 1).

The system of computer simulation Desmos uses not only the internal mathematical system of calculations, but also adds elements of color gamut. This aspect gives the opportunity to diversify the results of pupils' work, to provide the process of mastering the mathematical foundations with a certain artistic design, to bring the tasks to real life needs. For example: to project a fragment of a decorative design of a ceiling or a floor, to project a design of a bag or a cover of a pupils' notebook.

The main types of lessons are identified on the basis of the activity approach (according to L. G. Peterson):

- the discovery of new knowledge: the formation of the ability to independently build new concepts and methods of action;
- construction of a knowledge system: the formation of the ability to generalize and structure knowledge;
- developing monitoring function: the formation of the ability to exercise monitoring function;
- reflection (final lesson of the topic): the formation of the ability to spot their difficulties in the activity, to identify their causes, to find ways to solve them [22, c. 141].

The computer modeling may be used both at the lessons and in thematic groups, in the process of preparing the works for the competition of the Minor Academy of Sciences, at elective course, during the summer expeditions and practical exercises.

5 Conclusions and Recommendations for Future Research

The development of pupils' cognitive abilities is one of the priority directions of institutions of general secondary education advance. The use of the system of cognitive tasks in the process of learning subjects of the natural and mathematical cycle will contribute to a greater understanding of the content of the subject and the reflection of the information received on the environment, which, in its turn, will help the pupils form a holistic view of the world.

Teaching pupils based on the system of cognitive tasks should be aimed at the ability of pupils to transfer the existing abilities to other types of social activities, to strengthen and develop both general and personal (innate) abilities, which makes them more flexible to the conditions of the modern world.

Different types of cognitive tasks (emotional-figurative, evaluation-educational, practical-educational, theoretically oriented, information-oriented), taking into account their complexity levels (educational-reproductive, analytical-theoretical, applied, research, creative), form the system of cognitive abilities development of a high school pupil. Assessment of such a system will be carried out against the following criteria: cognitive basis, cognitive processes, cognitive activity and cognitive qualities.

Computer modeling of cognitive tasks will ensure their variability, level of complexity, universal access for individual and group work.

The researchs of foreign colleagues (Sahin S., Choi B. S., Gennaro E., De Jong T., Van Joolingen W.R., Dwyer W. M., Lopez V. E.) confirm too that computer simulations are good supplementary tools for classroom instruction and science laboratories. Multimedia supported, highly interactive, collaborative computer simulations appealing growing interest because of their potentials to supplement constructivist learning [23-26].

Further research is needed to define the concepts and terms used, in particular, such notions as “computer modeling”, “computer model”, projection of cognitive tasks; generalization, selection and justification of the use of computer models in the educational process and generalization of information about mathematical competence of pupils at establishments of general secondary education also need to be further investigated.

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