Algorithmic Thinking as One of the Factors Determining the Quality of the Educational Process in the Field of Mathematics, Computer Science and Project Activities*

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Abstract. The article studies the formation of an algorithmic culture of students and pupils in learning mathematics, computer science, and project activities. The objective of this work is to study the level of involvement of the algorithmic approach in the educational process with the help of various educational technologies in the study of mathematics, computer science, and the use of project approach in future engineers' training. The introduction discusses the historical aspect of the origin of the terms "computational thinking" and "algorithmic thinking" and their relationship with different types of learning activities in mathematics, computer science, and engineering education. It is further noted that the terms "algorithmic approach" and "algorithmic culture" are used in the context of the usage of the concepts "algorithmic thinking" in solving educational and research tasks. In the main part of the work, the problem of using algorithmic thinking is considered using multiple examples. The authors also analyze the problem of using an algorithmic approach in training future teachers of mathematics and computer science, in basic training of engineers and computer software specialists.

In conclusion, the authors suggest that the algorithmic approach and algorithmic thinking are among the fundamental factors that determine the quality of mathematical and computer education. The algorithmic culture of future specialists should be developed and maintained throughout the training process.

Keywords: algorithmic thinking, algorithmic culture, information technology, educational process, project-based approach.

1 Introduction

The modern education system imposes new requirements on students that determine the amount of knowledge and skills that they should get by taking part in the educational process. An important place is given to the way or culture of thinking that contributes to the better assimilation of this knowledge. This is largely due to the rapidly growing need to train not only highly qualified information technology professionals, but also people who could get only familiar with these technologies at least at the basic level.

Experienced teachers note that the result of students' activities at different levels depends on how clearly and consistently the student realizes and implements the algorithmic value of their actions. What and in what sequence he does, as well as what he needs to acquire and what the expected result of his actions should be are only a few examples of what to be thoroughly understood. To a larger extend, this is related to the algorithmic culture of the person, which is characterized by the ability and willingness of the student to make and use various algorithms as part of the educational and extracurricular activities. In this regard, it should be noted that the constant use of algorithms in the classroom should guide students to the understanding and awareness of every step and action.

In educational communication, awareness and handling of linguistic and algorithmic elements are an important integral part of the educational process. Due to this, in modern education there is a new school subject – Algorithmics, which is aimed at the formation and development of algorithmic thinking of students, providing for learning basic algorithmic structures and algorithms of various types.

We know that foreign scientists also carry out research that is related to algorithmic culture and algorithmic thinking. It suffices to say that historically, we encounter the term "computational thinking" first. Wing's works, (Wing, 2006, 2008) [1, 2], (Grover & Pea, 2013) [3] are among the first papers that should be attributed to the basics that define the concepts "computational thinking" and "algorithmic thinking". In his first research (Wing, 2006), Wing defines "computational thinking" as "solving problems, designing systems and understanding human behavior, based on concepts fundamental to computer science". Searching for an approach to the definition of "computational thinking", Wing uses a rather vague phrase, combining various forms of intellectual activity: "thinking recursively", "using abstraction and decomposition when solving large and complex tasks or designing complex systems", "using heuristic reasoning to find solutions". However, from the above reasoning, it is difficult to build a clear understanding of what is meant by the term "computational thinking". Although the examples allow seeing the general trend, something in common, the underlying reasoning about computations and algorithms. In Aho's (2012) work [4], we find somehow clearer definitions: "computational thinking" as the thinking, the process is involved in the process of formulating a problem, so that its solution can be represented as computational steps and algorithms. It is also important to understand the "computational" and "algorithmic thinking" as the distinction between the concepts "conceptual" and "procedural" knowledge, the discussion of which began from Hiebert and Lefevre in 1981. In their work [5] "conceptual knowledge" is treated as knowledge built on relationships, "knowledge-rich in relationships" (a so-called network model of knowledge). Aho defines "conceptual knowledge" as a connected network, in which the connecting relationships are as significant, as the individual pieces of information. "Procedural knowledge" is defined as knowledge that consists of two parts. One part consists of a formal language or symbolic representations. The other part relates to algorithms or rules aimed at the solution of mathematical or other computational tasks. The authors

[6] tried to compile (construct) the definition of "algorithmic thinking", based on the experience of the discussion of "computational thinking" and the results of a survey of several prominent mathematicians on the methods and approaches they used in their work when solving complex problems. As a result, it has been concluded that "algorithmic thinking" is close to the concept of "procedural knowledge". In this case, "algorithmic thinking", as the researchers note, "...goes beyond the implementation of a procedure or even explanations why the procedure works. This type of thinking includes planning and development steps of the algorithm, to understand the general meaning of what I have to do the algorithm, and the availability of parts for the successful implementation of the algorithm" [6].

A lot of works has been dedicated to the development of both computational and algorithmic thinking among students and schoolchildren. The authors of the paper [7], as an example, consider algorithmic thinking as the key to developing the talent for understanding computer science. For the development of this type of thinking, it is proposed to use difficult-to-solve problems that become more understandable if they are correctly defined and visualized. The work [8] also discusses ways to improve the understanding of algorithms through their graphical representation and animation. In [9], it is noted that algorithmic thinking is considered to be an important step towards learning to program for novice programmers. This paper describes a game specifically designed to improve their algorithmic thinking skills. After introductory training, using game technology, the authors conducted a survey and compared the answers given by young men and women to the same questions about their attitude to this game. The authors of the article mention that young men were more interested and point out the positive impact of the proposed gaming technology. The article [10] considers the possibility of teaching children algorithmic thinking, starting from preschool age. The main paradigm of the proposed approach is to demonstrate to children an ability to find solutions to problems that arise in front of them, by dividing the problem into parts and finding the solution step by step. We see that in several works, the authors, using the established terminology, do not focus on the differences between computational, computer, or algorithmic thinking, considering these concepts as synonymous. So in the study [11], we reveal the material that describes a special scale that is designed to determine the levels of computational thinking skills (CTS). As a result of the analysis, the researchers conclude that the scale is an effective and reliable measurement tool that could adequately assess students' computational thinking skills. Another interesting approach is found in [12], which facilitates revealing the level of programming knowledge obtained before entering the technical faculty by conducting special surveys and tests.

Thus, we have shown that the problem of educating algorithmic culture and using algorithmic thinking has not lost its relevance in different educational systems over the years.

Now, we are going to see to what extent the algorithmic approach can be introduced into the educational process with the use of various educational technologies.

2 Results

Forming of the algorithmic culture of students contributes to the conscious perception of educational material. When building a training algorithm, the following components are to be remembered:

- understanding the basics of the algorithm and its properties;
- understanding the basics of the language as a means to write an algorithm;
- knowing of techniques and tools for recording algorithms;
- understanding the algorithmic nature of the subject's methods and their applications;
- being competent at school course algorithms;
- understanding the basics of computer programming.

It should be noted that the formation of the algorithmic culture of students can be carried out by various methods and means. Such tools can be selected, for example, through project training, practical work in a group, drawing up algorithms, reporting an algorithmic model on a training topic, etc.

The characteristic of the algorithmic approach to learning for different categories of students indicates the features of its use in different educational environments. Here are some examples.

In shaping the professional focus of future mathematics teachers, students are offered to construct some algorithms. In this regard, it is important to know that the school course of mathematics in this aspect offers a wide range of algorithms, e.g., the algorithm of reduction of fractions to a common denominator; the algorithm for the solution of construction tasks; the algorithm study of the function and construction of its graph; the algorithm for calculating the area of a curvilinear trapezium; the algorithm study of the mutual location of two straight lines, etc.

Analysis of the educational experience in school leads to the conclusion that teaching mathematics necessarily involves learning algorithms, therefore, the ability to formulate and apply algorithms in the study of any subjects of the school course of mathematics is extremely important. The advantage is, of course, the method that allows students to open the necessary algorithms on their own. In this case, it involves the implementation of three stages of learning mathematical material, which is summarized in Table 1.

Table 1. The stages of learning mathematical material

Decomposition of the material into independent parts and structuring them as separate steps of the algorithm
Formulation of algorithm steps for students by using clear wording in the form of deterministic instructions
Applying the generated algorithm concerning different examples (using different input data)

Describing training activities with specific regulations or rules is a substantial part of the process of building algorithmic elements. Further, specific subject content can be presented in the form of "a teaching algorithm", which has a methodological focus. For this purpose, to build an algorithm for a training session, students who study to be math teachers should learn to analyze the content, goals of training, the students' activities for learning it, and the teacher's activities for organizing this learning, and to build an algorithm for studying a specific mathematical topic.

We believe that algorithmic problems play an important role in forming the algorithmic culture of students. Moreover, the compilation of algorithms in the course of mathematics is also valuable for a variety of problem types. Educational practice shows that the most effective of them is the execution of tasks according to the algorithm, the development of a sequence of actions with justification, the compilation, and testing of algorithms, and the design of algorithms. About a particular subject area, in teaching to solve stereometric problems as part of a course on analytic geometry, these are algorithms that are used to solve such problems using a vector-coordinate method to find the angle between the crossing right lines, as well as the angle between the planes, between the line and the plane, the distance from the point to the right line, the distance from the point to the plane and the distances between the crossing right lines.

Some effective ways of using algorithms in the educational process in doing graphic tasks in the process of teaching graphic disciplines, as part of, let’s say, the study of design geometry, have been proposed by teachers of Novosibirsk State Architectural Construction University (SIBSTRIN) [13; 14].

Another example in our research concerns using an algorithmic approach and presents the field of further education. It associates with work on interdisciplinary projects, which are based on the use of information technology. In Fig. 1, we show a block diagram of the algorithm that is based on a similar project. At the beginning of the project session, the project manager explains to the project team that the work on the project will be most efficient if the entire design process is divided into a certain number of steps performed in a given sequence. The work on such projects should begin with formulating a problem (elaborating technical specifications). Simultaneously the team should examine the relevance of the issue and reveal "the interested parties". At the next step, the whole group participates in the search for possible solutions to the problem. The expected outcome of this work should be finding conceptual solutions to the problem. Once the conceptual solutions are chosen, the team performs the architecture design of the project, i.e. working out the component-relating details. This step can be associated with the construction of a structural model of the project.

After that, the choice of basic components and a description of the rules of interaction between them (the construction of a functional model) are made. The next stage involves drawing up tentative estimates of costs of the project and the creation of a prototype device (in most cases devices are technical solutions).

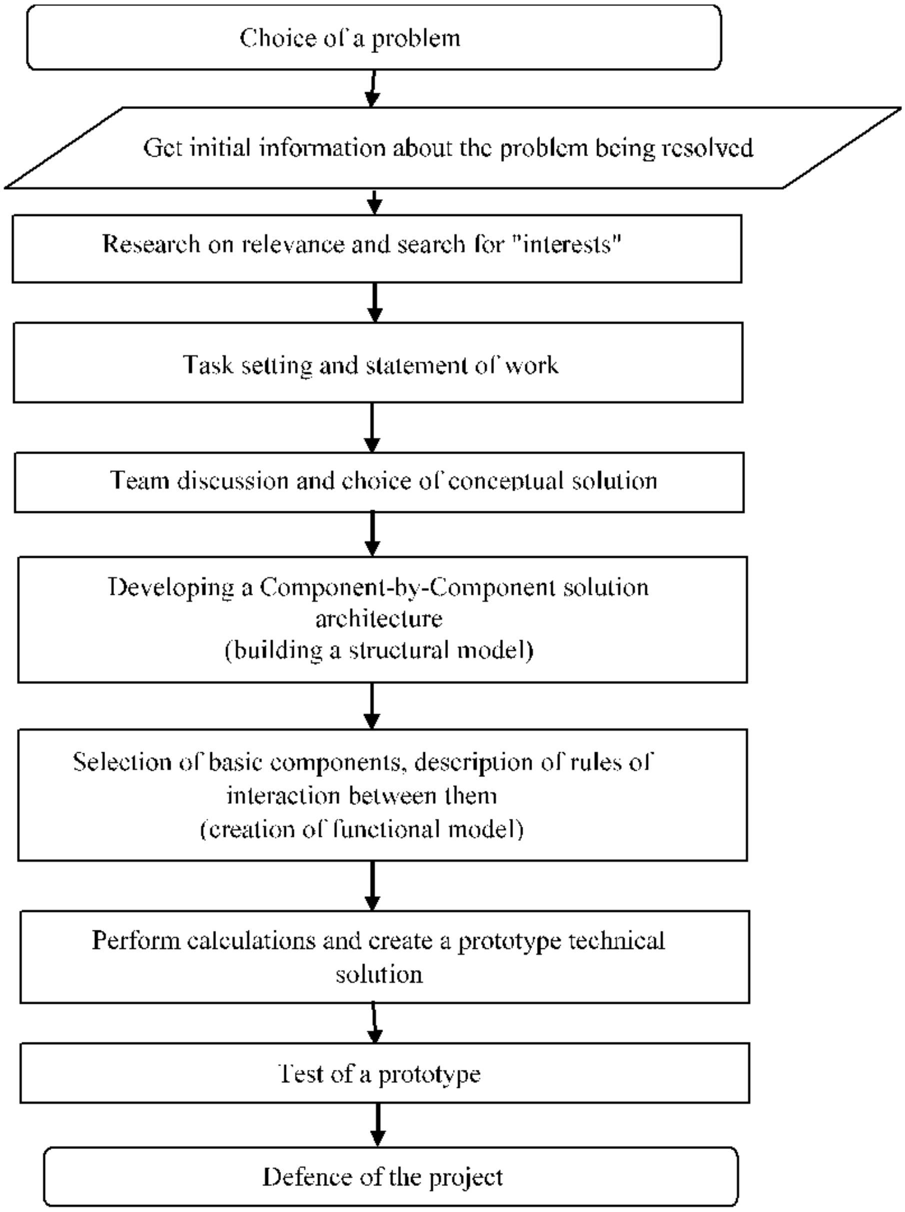

Fig. 1. Block diagram of project work within the design session

The final phase of work is to defend the project with a demonstration of positive and negative features, justification for the need for development, and showing the uniqueness of the development. Before the final part, the prototype must be tested and information about the test results is used to finalize the project.

The functional model can also be described as an algorithm for the functioning of the developed device. The fact that it is one of the models used in the design process once again confirms the need to develop algorithmic thinking among students and schoolchildren who are involved in project activities.

As an additional example of using the algorithmic approach, we can review the experience of projects that used the interface method [15]. Based on Gorno-Altai State University in 2016, an educational "blitz" project was implemented. Its main task was to develop a system of ozonation of vegetables for long-term storage. It was necessary to develop an ozone generator of vegetables (implements for comparative analysis of different methods of ozone treatment), to devise technology for the process of ozonation, and methods of evaluation of results of the experiment. It was an interdisciplinary project. First, it was necessary to develop and manufacture the device (ozonizer), to develop and implement a method of calibration of a product that would be efficient in determining the quantity of ozone generated in a certain period and processing of vegetables, the technology of analysis of the quality of the vegetables before processing, and through particular periods during the storage.

The project was divided into four project modules, each had its interface with other modules and with the "environment". The functioning of each of these design modules is easily represented in terms of a simple "quasiparallel" algorithm (part of the steps that can be performed simultaneously). "Ozonation": the creation of devices that generate a controllable portion of the ozone; "Analysis of concentration": the development of chemical analysis technologies ozone concentrations; "Processing": development of technology for processing of vegetables; "Quality Analysis": the analysis of quality of vegetables [15]. A schematic presentation of the decomposition results is shown in Figure 2.

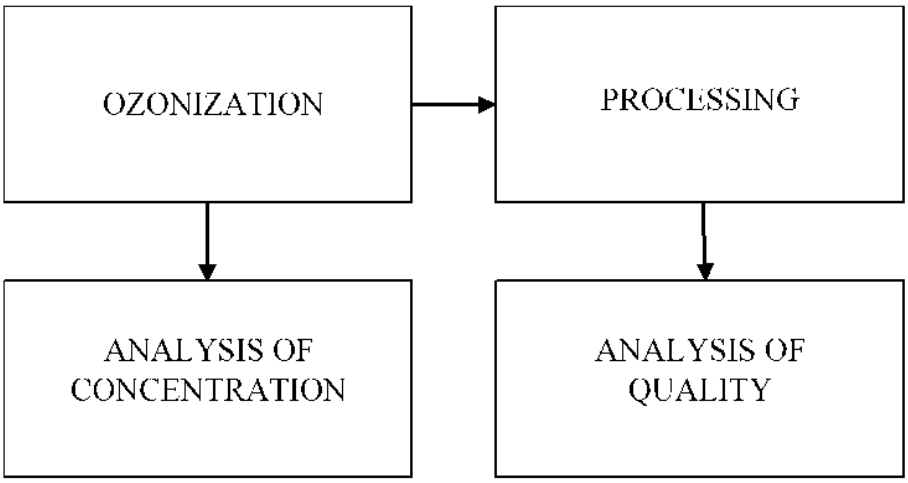

Fig. 2. Decomposition of the design modules

The project interfaces method, proposed in [15], allows breaking a complex project into simple functionally complete "stand-alone" projects, which may be interpreted as steps of the algorithms, which interact with each other through a predetermined format for the exchange of information. It is agreed that there is a particular member of the team, who is in charge of the information exchange part. There is a project to create an interdisciplinary assessing polygon by a creative team of employees of Physics, Mathematics and Engineering Technology Institute of Gorno-Altaisk State University (PMETI GASU). The project has been accomplished, but the work is still developing. Its first idea was to organize an infrastructure that could be used to simplify the processes of preparation and to conduct various measurement experiments on Earth Sciences. The polygon was supposed to ensure uninterrupted power supply, systems for data transmitting and storage, video monitoring, organization of thermally stable spots for taking measures, as well as boxes and greenhouses with particular microclimatic parameters specified by the program change of the internal temperature, humidity, and light needed to conduct agro-technological experiments.

In the process of implementation of the pilot version of "The measuring polygon", the project was divided into smaller complementary projects, the work on which was carried on for three years. Thus, the research team singled out and realized the following modules: "Measurement and monitoring", "Data pre-processing and archiving", "Visualization and search of events" and "Research and modeling". All such projects can be managed either by one person, or a project team consisting of several students, postgraduates, and teachers. The algorithm for the interaction of the project modules in "The measuring polygon" is shown in Figure 3.

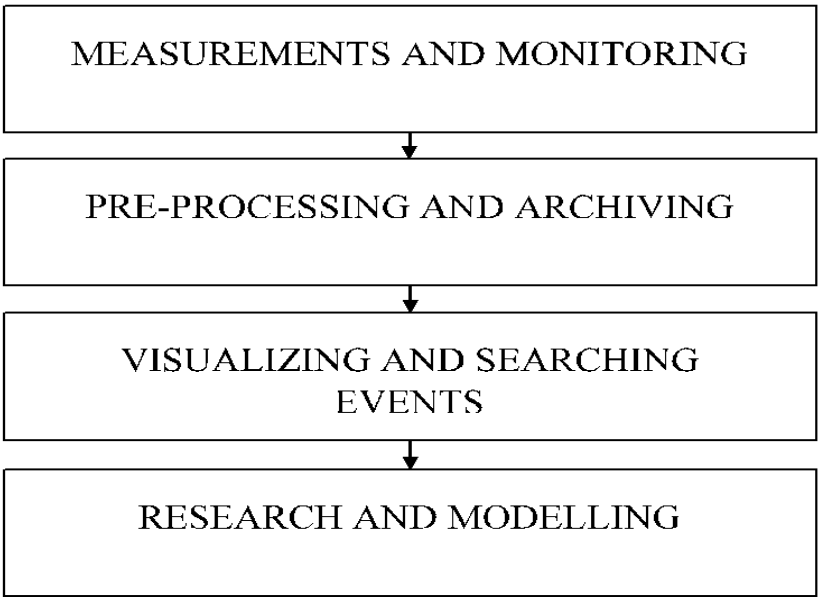

Fig. 3. The algorithm of the interaction of the project modules of "The measuring polygon"

There is a positive experience in project work that is based on using the algorithmic approach. We refer to the project "Establishment of a network of schools implementing innovative programs to test new technologies and content of training and education through competitive support of school initiatives and networking projects", held in the framework of special federal programs designed for education development in 2016–2020. The work was carried out at "Gorno-Altaisk Lyceum-School No. 6 n.a. I. Z. Shuklin", where the algorithmic approach was applied to a project "Intelrob Resource Center of Educational Robotics" [16].

In the system of basic school education, the algorithmic approach is introduced into the educational process, when the case-study method is used as a means to form meta-subject universal educational actions in school students.

To determine the effectiveness of the usage of the case-study method, a variety of techniques have been used by researchers [17]. The problem of meta-subject development of universal educational actions of school students as one of the most important problems in modern education is connected with different aspects of the concept of "meta-results" and a wide range of elements in its composition [18].

When we use the project method, the implementation of the pedagogical potential of case-projecting in the development of meta-subject universal educational actions makes it possible to determine the need for scientific verification, development, and testing of this technology and to consider it as an effective means of developing the investigated quality in students of the school. In the process of experimental work that was carried out based on School No. 5 of the Altai Krai in Altai District, the case-study technique was developed and introduced at the level of general education [18]. The process of case-projecting is presented in the form of steps the following algorithm:

1. acquiring case information (analysis, identification of case accessories, search problems, object definition of the research subject, the nomination of hypotheses);
2. the individual creative activity of a student for creating a new content (formulation of a plan, collecting information, conducting experiment, synthesis, making conclusions and interim assessment of the case-projects through the submission of performance in competitions and conferences);
3. defense of the case-study project at a school event (festival), the expert evaluation result of the case-study project.

The assessment of the level of how efficiently the meta-subject results form and develop in students when the case-study method is applied reveals positive dynamics of the development of meta-subject of universal educational actions of the students at the level of general education.

3 Conclusion

The examples of the application of the algorithmic approach in the process of teaching students help to the conclusion that the algorithmic approach and algorithmic thinking are among the fundamental factors that determine the quality of mathematical and computer education. We believe that the algorithmic culture of future specialists should be educated and supported throughout the teaching process.

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References

1. Wing, J. M.: Computational thinking. Communications of the ACM. 49(3), 33-35 (2006). DOI: 10.1145/1118178.1118215
2. Wing. J. M.: Computational thinking and thinking about computing. Philosophical Transactions of the Royal Society A: Mathematical, Physical and Engineering Sciences, 366, 3717-3725 (2008). DOI: 10.1098/rsta.2008.0118
3. Grover, S., Pea. R.: Computational thinking in K-12: A review of the state of the field. Educational Researcher. 42(1), 38-43 (2013). DOI: 10.3102/0013189X12463051
4. Aho, A.V.: Computation and computational thinking. The Computer Journal, 55(7), 832-835 (2012). DOI: 10.1093/comjnl/bxs074
5. Hiebert, J., Lefevre, P. Conceptual and procedural knowledge in mathematics: An introductory analysis. In J. Hiebert (Ed.), Conceptual and procedural knowledge: The case of mathematics, pp. 1-27. Hillsdale, NJ: Lawrence Erlbaum (1986). DOI: 10.4324/9780203063538
6. Lockwood, E. E., DeJarnette, A., Asay, A., Thomas, M. Algorithmic thinking: an initial characterization of computational thinking in mathematics. In M. B. Wood, E. E. Turner, M. Civil, & Eli, J. A. (Eds.), Proceedings of the 38th annual meeting of the North American Chapter of the International Group for the Psychology of Mathematics Education, pp. 1588-1595. Tucson, AZ: The University of Arizona (2016).
7. Futschek, G.: Algorithmic Thinking: The Key for Understanding Computer Science. In: Mittermeir R. T. (eds) Informatics Education – The Bridge between Using and Understanding Computers. ISSEP 2006. Lecture Notes in Computer Science, vol 4226, pp 159-168. Springer, Berlin, Heidelberg (2006). DOI: 10.1007/11915355_15
8. Mudner, T., Shakshuki, E.: A new Approach to Learning Algorithms. In: Proceedings of International Conference on Information Technology: Coding and Computing, 2, 141-145 (2004). DOI: 10.1109/ITCC.2004.1286440
9. Iqbal, S., Mathew, R., Tawafak, R. M., Khan, I.: Gender Difference in Perceiving Algorithmic Thinking In An Introductory Programming Course, EDULEARN19 Proceedings, pp. 8246-8254 (2019). DOI:10.21125/ edulearn.2019.2042
10. Havlaskova T., Homanova Z.: Methodology for Developing Algorithmic Thinking in Preschool Education. ECEL 2019 18th European Conference on e-Learning. 200-206 (2019). DOI: 10.34190/EEL.19.027
11. Özgen Korkmaz, Recep Çakir, M. Azər Özden: A validity and reliability study of the Computational Thinking Scales (CTS), Computers in Human Behavior 72, 558-569 (2017). DOI: 10.1016/j.chb.2017.01.005
12. M. Hrubý, K. Hasilová: "Education of human resources for contemporary technical society", Efficiency and Responsibility in Education 2018. ERIE 2018: proceedings of the 15th International Conference, pp. 103-109, (2018).
13. Ten M. G. Reshenie aktual'nyh problem modernizacii prepodavaniya graficheskih discipline [Solution of urgent problems of modernization of teaching graphic disciplines]. Aktual'nye problemy modernizacii vysshej shkoly: modernizaciya otechestvennogo vysshego obrazovaniya v kontekste nacional'nyh tradicij mate-rialy materialy XXX mezhdunar. nauch.-

met. konf. (Novosibirsk, 30 yanvarya 2019 g.). Sibirskij gosudarstvennyj universitet putej soobshcheniya. Novosibirsk : Izd-vo SGUPSa [Actual problems of modernization of higher school: modernization of domestic higher education in the context of national traditions materials materials XXX international scientific and methodological conference. (Novosibirsk, January 30, 2019). Siberian State Transport University. Novosibirsk: Publishing house of SGUPS]. 219 p. Pp. 275-278. (In Russ.)

14. Ten M. G. Sovremennye metody prepodavaniya graficheskih disciplin []. Usloviya effektivnosti kachestvennoj professional'noj podgotovki v universitete: materialy mezhdunarodnoj nauch.-metod. konf. (31 yanvarya 2017 g.). Novosibirsk: Izd-vo SGUPSa [Conditions for the effectiveness of high-quality professional training at the university: materials of the international scientific and methodological conference. (January 31, 2017). Novosibirsk: Publishing house of SGUPS]. 2017. 302 p. Pp. 199–202. (In Russ.)
15. Kudryavtsev N., Temerbekova A. Special features of the project interfaces method as a mechanism of developing a project approach to the educational process and children's technical creativity. Novosibirsk State Pedagogical University Bulletin, 2018, vol. 8, no. 6, pp. 167–182. DOI: http://dx.doi.org/10.15293/2226-3365.1806.11
16. Temerbekova A. A. Sistema formirovaniya IKT-kompetentnosti pedagoga na osnove ispol'zovaniya social'nyh setej v obrazovatel'nom processe: opyt i perspektivy: monografiya [The system of formation of teacher's ICT competence based on the use of social networks in the educational process: experience and prospects: monograph]. A. A. Temerbekova [i dr.]; pod obshch. red. A.A. Temerbekovoj, L.A. Al'kovoj. Gorno-Altajsk : BIC GAGU [A. A. Temerbekova [and others]; under total. ed. A.A. Temerbekova, L.A. Alcove. Gorno-Altaysk: BITS GAGU]. 2017. 119 p. (In Russ.)
17. Savenkov A. I. Metodika issledovatel'skogo obucheniya mladshih shkol'nikov [Research teaching methodology for primary schoolchildren]. Samara: Izdatel'skij dom «Fedorov» [Samara: Publishing House "Fedorov"]. 2016. – 192 p. (In Russ.)
18. Leushina, I. S. Kejs-tekhnologicheskoe proektirovanie na osnove setevogo vzaimodejstviya [Case-based technological design based on network interaction]. Mir nauki, kul'tury, obrazovaniya [The world of science, culture, education]. 1(62), 136-138 (2017). (In Russ.)