RESEARCH NOTES

A New Dimension of Learning in Higher Education: Algorithmic Thinking

Una nueva dimensión del aprendizaje en la educación superior: el pensamiento algorítmico

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Summary

The relevance of this article is due to the need to form and develop algorithmic thinking of higher education students as the main requirement of the information society following 21st century skills and competences for new millennium learners. The purpose of the article is to consider algorithmic thinking as a new dimension of learning in higher education. The leading approach to the study of this problem is the analysis of methodological literature, and the experience of students, teachers, and academic staff. The article considers the essence, main properties, and characteristics of algorithmic thinking, suggests the universal sequence of algorithm development and model of algorithmic thinking as well as determines its importance for any subjects outside the information and communications technology area. The materials of the article can be useful for lecturers, professors, and other academic staff of universities and institutes when studying any subjects related to the basic and professional training of students.

Keywords: higher education, new dimension of learning, algorithmic thinking, universal sequence of algorithm development, model of algorithmic thinking.

Resumen

La relevancia de este artículo se debe a la necesidad de formar y desarrollar el pensamiento algorítmico de los estudiantes de educación superior como el principal requisito de la sociedad de la información después de las habilidades y competencias del siglo XXI para los estudiantes del nuevo milenio. El propósito del artículo es considerar el pensamiento algorítmico como una nueva dimensión del aprendizaje en la educación superior. El enfoque principal para el estudio de este problema es el análisis de la literatura metodológica y la experiencia de estudiantes, docentes y personal académico. El artículo considera la esencia, las propiedades principales y las características del pensamiento algorítmico, sugiere la secuencia universal de desarrollo de algoritmos y el modelo de pensamiento algorítmico, así como determina su importancia para cualquier tema fuera del área de la tecnología de información y comunicaciones. Los materiales del artículo pueden ser de utilidad para conferencistas, profesores y resto del personal académico de universidades e institutos al momento de estudiar cualquier tema relacionado con la formación básica y profesional de los estudiantes.

Palabras clave: educación superior, nueva dimensión del aprendizaje, pensamiento algorítmico, secuencia universal de desarrollo de algoritmos, modelo de pensamiento algorítmico.

Introduction

According to scientific, technological progress and the development of socio-economic and political relations between countries, the modern information society is constantly and continuously changing, evolving, and expanding its influence on all areas of human life. Such rapid development creates a constantly growing flow of information in the future profession, which makes it almost impossible to take it into account in the training process of future professionals, which is the main task of the system of higher education. Also, the urgency of the problem also grounds on the fact, that the current generation of Ukrainian university students has not been able to study algorithms in primary school, which is a prerequisite to use PCs, information technologies, and technologies in other areas, in the context of future profession.

One of the most promising solutions to this problem is the development of algorithmic thinking, which in conditions of information society becomes an integral part of a person's scientific world-outlook. The importance of algorithmic thinking is based on the everyday person's needs to plan affairs, describe in detail actions that will be taken to achieve the goal, and determining their sequence. No less importance has the ability to recognize and understand algorithms created by others. Developed algorithmic thinking allows future professionals to split the general task into subtasks; plan the stages and time of their realization; evaluate the effectiveness of activities; search, process, and perceive new information (Vinichenko et al., 2018; Khalimon et al., 2019; Zashchirinskaia, 2020).

In this regard, defining an essence, main properties, and characteristics of algorithmic thinking is very important to ensure the proper level and quality of training of future professionals in universities according to the requirements of the information society. Additionally, algorithmic thinking is on the top of the main requirements of the information society, as well as one of 21st century skills and competences for new millennium learners (Ananiadou & Claro, 2009). All this becomes the basis to consider algorithmic thinking as a new dimension of learning in higher education. Problems of formation and development of algorithmic thinking have become the subjects of study for many Ukrainian and foreign scholars.

In particular have been studied: the problem of formation of algorithmic thinking (Tadevosyan & Shevchuk, 2014); the practical significance of algorithmic thinking style (Kopaev, 2003); semantic aspects of algorithmic thinking (Kovalchuk, 2018); the algorithmic thinking as one of ICT competences (Zsakó & Szlávi, 2012); the algorithmic thinking as component of ICT competence (Byrka et al., 2019); the formation of algorithmic thinking in teaching game programming (Cheburina, 2017); development of algorithmic thinking by developing and testing algorithms (Futschek & Moschitz, 2011); development of algorithmic and operational thinking in the process of studying applied software (Barbolina, 2010); methodical methods of development of algorithmic thinking of the future teacher of computer science (Gubina, 2016); pedagogical conditions of the organization of algorithmic activity of future teachers of social and humanitarian direction (Smetanina, 2010); the process of encouraging algorithmic thinking without a computer (Burton, 2010), and examples of algorithmic thinking in programming training were given in J. Hromkovič et al. (2016).

Although a lot of articles have been presented in this field, very few works explore the problem of algorithmic thinking beyond the ICT context, which determines the relevance of our study. Our study aims to identify the essence, main properties, and characteristics of algorithmic thinking and to suggest the model of algorithmic thinking and determine its importance for any subjects, which is beyond the ICT area. The study was used as a qualitative, inductive, research design with all appropriate ethical concerns taken into consideration to comply with the norms and standards of the field. The following theoretical methods were used in the research methodology: a comparative analysis of scientific-pedagogical and psychological sources on the research issue; conceptualization of the essence, main properties, and characteristics of algorithmic thinking; modeling of the structure of the algorithmic thinking; study of the importance of the algorithms and algorithmic thinking for subjects beyond ICT area through the questioning of students, teachers, and academic staff. The empirical survey was conducted among students and academic staff of Classic Private University (Zaporizhzhia, Ukraine), Zaporizhzhia National University (Zaporizhzhia, Ukraine), Zaporizhzhia Polytechnic National University (Zaporizhzhia, Ukraine), and among teachers who attended training courses at the Institute of Postgraduate Pedagogical Education of Chernivtsi region (Chernivtsi, Ukraine). A total of 352 people took part in the survey.

The essence, main properties and characteristics of algorithmic thinking

Based on the scientific analysis, we conclude that algorithmic thinking can be useful not only in the ICT area, but has great importance beyond it for any higher education subjects because algorithmic thinking has substantial value in the context of future profession, and everyday life in conditions of the information society. The algorithmic thinking, we consider as a person's ability to recognize, adapt, and create new algorithms in the context of education, future profession, and the modern information society. The main properties of algorithmic thinking include discreteness, abstractness, formality, integrity, and effectiveness. The best way to develop algorithmic thinking for a future specialist is by developing his own algorithms aimed at solving different problems related to learning and everyday life issues. Consequently, we offered a universal sequence of algorithm development, which consists of five major steps. The presented universal sequence is adapted to higher education and can be used for solving issues in any basic and professional subjects beyond the ICT area (Malyshkin & Halimon, 2018).

For effective use of the presented universal sequence of algorithm development, we created a model of algorithmic thinking that include five kinds of thinking and represent relations between them. The survey results have shown a very low level of respondents in an understanding of algorithm basic concepts, its main properties and advantages, and their role in solving future professional and everyday life problems. Therefore, considering algorithmic thinking as a new dimension of learning in higher education is feasible and very vital for Ukrainian universities. First of all, for a better understanding of algorithmic thinking, it is necessary to determine its essence, main properties, and characteristics (Kostruba, 2018; Golub et al., 2020).

The concept of "algorithmic thinking" in modern psychological and pedagogical studies is interpreted in different ways that reflect various aspects of its vision by scientists, but common to all points of view is the determination of an algorithm as a result of the algorithmic thinking. According to T.N. Gubina (2016), algorithmic thinking is a system of mental techniques, constructions, a set of methods of activity, necessary to solve a particular problem. This kind of thinking is realized by identifying separate subtasks of solving a problem, building an information model, organizing the search of the necessary information, and obtaining the appropriate algorithm.

M.B. Kovalchuk (2018) understands this concept as a set of mental actions, techniques, and forms, where the means, object, and result of mental work are algorithms. A.V. Kopaev (2003) interprets the algorithmic thinking as a system of mental ways of acting, techniques, methods, and mental strategies aimed at solving both theoretical and practical problems, the result of which are algorithms as specific products of human activities. O.V. Cheburina (2017) defines algorithmic thinking as a set of mental actions and techniques aimed at solving a specific problem, as a result of this the corresponding algorithm is created. Herewith noting that this type of thinking allows making any abstract idea into a certain sequence of actions (algorithm), the consistent implementation of which will contribute to the implementation of this idea in practice.

In this context, is very interesting the idea of M.B. Kovalchuk (2018), which claims that the algorithmic thinking is an integrated complex that includes other types of thinking: abstract thinking – to discard insignificant details in creating a general image of the problem, and logical thinking – to determine the sequence of actions needed to solve this problem. Partially agreeing with the author, we should note that algorithmic thinking, in our opinion, is impossible without other types of thinking, for example – figurative thinking, which is necessary to create a general image of the problem and separate it into small subtasks (Skydan et al., 2019; Golub et al., 2019).

However, algorithmic thinking as a pedagogical construct has certain properties and characteristics. According to L.S. Smetanina (2010), the specific properties of the algorithmic thinking are discreteness, which involves step-by-step execution of the algorithm, specification, and structuring of the entire execution process; abstractness, which involves abstraction from specific input data and embodies the possibility of moving to a solution to the problem in general; formality, which implies the need to present the algorithm in a certain formalized form. But, O.V. Cheburina (2017) claims that the critical properties of the algorithmic thinking are integrity and effectiveness, which allow us to see the problem generally, and to focus on the desired result.

As stated by A. Gazeykin (2003), the main characteristic that indicates the level of algorithmic thinking of a person is the ability to create algorithms, which requires the formation of those schemes of thinking that contribute to seeing the problem in general and highlighting and separating of large blocks that can be further detailed. T.M. Barbolina (2010) among the characteristics of the formed algorithmic thinking of a person identifies the following skills:

- to build a model of the problem-solving process;
- to determinate of the necessary result and selection on this basis of initial data for the decision of a problem;
- to identify the main actions needed to solve the problem;
- to organize the actions necessary to solve the problem;
- to correlate the obtained results with what was expected.

V.V. Vdovenko (2017) among the characteristics of the algorithmic thinking distinguishes the ability: to formulate commands for the executant, to look for errors in the sequence of commands, to analyze the content of tasks, to compile the algorithm for executants, to look for different options, to choose and justify the most effective execution, to formulate statements with a logical sequence, etc. However, M.B. Kovalchuk (2018) states that algorithmic thinking is impossible without understanding the essence of basic algorithmic constructions (linear sequence, conditions, loop, cycle, transition, etc.). Consequently, the author adds to this list the following skills: to write down the algorithm, to perform parsing of the compiled or proposed algorithm; to optimize the algorithm. The analysis of presented scientific studies concerning the essence, main properties, and characteristics of the algorithmic thinking allows us to formulate the following conclusions:

- the algorithmic thinking, we consider as a person's ability to recognize, adapt, and create new algorithms;
- the algorithmic thinking is an integrated complex that includes other types of thinking: abstract, logical, and figurative thinking;
- the main properties of the algorithmic thinking are: discreteness, abstractness, formality, integrity, and effectiveness;
- the main characteristics of the algorithmic thinking are: to build a model of the problem-solving process; to determinate of the necessary result and selection on this basis of initial data for the decision of a problem; to identify the main actions needed to solve the problem; to organize the actions necessary to solve the problem; to correlate the obtained results with what expected ones; to write down the algorithm; to parse compiled algorithm; to optimize the proposed algorithm.

The universal sequence of algorithm development

In our opinion, the best way to develop algorithmic thinking for a future specialist is developing his algorithms aimed at solving different problems related to learning and everyday life issues. Thus, it is necessary to determine the universal sequence of algorithm development, in other words – to determine the algorithm of algorithm development. In this context, is a very useful study of L.S. Smetanina (2010), in which it is author proposed the following sequence of six steps, which also are components of algorithmic thinking:

1.   analysis of the desired result and the selection on this basis of the initial data to solve the problem;
2.   analysis of the initial data of task, selection of task objects (real and abstract), building their hierarchy;
3.   choice of methods, tools, and techniques for the implementation of the solution system;
4.   arranging operations and building algorithms for decision systems (including graphical representation);
5.   implementation of algorithms of the decision system and correlation of obtained results to the desired result;
6.   analysis of system behavior and correction of initial data, properties of objects, and algorithms of event processing (in case of discrepancy of the obtained result with the desired one).

The defined sequence of algorithm development meets all the requirements of algorithmization and provides a solution to the problem. However, in our opinion, this algorithm is overloaded with unnecessary information, which is important only for developing algorithms related to the ICT area, but in a universal context is not important. R.G. Tadevosyan and O.F. Shevchuk (2014) offer a more comprehensive version of the universal sequence of algorithm development, which takes into account the actions of executant, and including five steps:

1.   Clear task statement.
2.   The choice of methods and ways to solve the problem.
3.   Construction of a work plan (scheme, project) and determination of the executant for its implementation. The plan is based on:
–   starting position (starting point of the executant) and goal (completion of the algorithm);
–   certain basic concepts – a set of elementary facts that must be unambiguously interpreted by the executant;
–   sets of rules based on which clear and unambiguous commands (steps) of action of the executant from a set of elementary facts or previous commands (steps) are formed.
4.   Any action of the executant, regardless of its location, is clearly defined and leads to the goal.
5.   The executant realizes the plan in a "reasonable" (which makes sense to solve the problem) time.

This algorithm has numerous advantages over the previous version, detailing such critical aspects of its implementation as a set of facts about the problem, actions of the executant, and the time of operations. Based on conducted scientific analysis, we offer our version of the universal sequence of algorithm development, which is adapted to higher education and can be used for solving problems in any subject, which is beyond the ICT area. The algorithm consists of five major steps:

1. clear formulation of expected results that should be obtained after solving a problem;

2. determination of all properties of the problem, and detailing constraints of resources (time, logistics, finances, etc.);

3. selection and sequence determination of main actions that are necessary to solve the problem;

4. implementation of this sequence of actions considering all properties and constraints of the problem;

5. comparison of the obtained results with the desired ones, and, if necessary, adjustment of the sequence of or the set of defined actions.

The presented universal sequence of algorithm development can be used as an effective instrumentality for forming algorithmic thinking of future specialists in learning both basic and professional disciplines of professional training in higher education. As we mentioned above, algorithmic thinking is an integrated complex that includes other types of thinking: abstract, logical, and figurative thinking. However, in our opinion, to use effectively the presented universal sequence of algorithm development future specialist needs to apply additionally conceptual thinking and constructive thinking, which play an important role in performing of some steps of the proposed algorithm. For instance, to perform step one and two of the proposed universal sequence of algorithm development (clear formulation of expected results that should be obtained after solving the problem and determination of all properties of the problem, and detailing constraints of resources (time, logistics, finances, etc.) should be used both abstract thinking and conceptual thinking (Kostruba, 2019; Skydan, 2009).

To perform step three (selection and sequence determination of main actions that are necessary to solve the problem) it is necessary to use logical, constructive, and figurative thinking. Performing of steps four (implementation of this sequence of actions considering all properties and constraints of the problem) and five (comparison of the obtained results with the desired ones, and, if necessary, adjustment of the sequence of or the set of defined actions) is impossible without conceptual, logical, constructive, and figurative thinking. Therefore, the model of algorithmic thinking should include all five mentioned kinds of thinking and represent relations between them. Our vision of the model of algorithmic thinking graphically is illustrated in Figure 1.
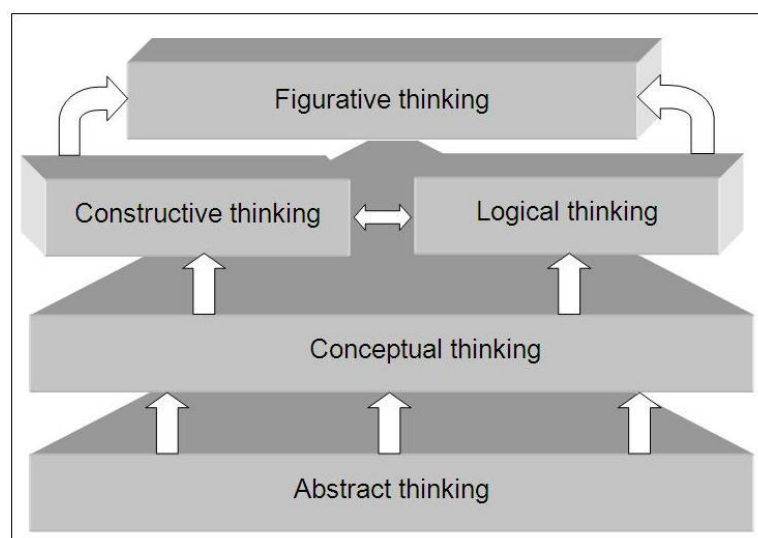

Figure 1. Model of algorithmic thinking

The presented model is the basis for the development of algorithmic thinking of future specialists in any subject outside the ICT area, which is especially important in the context of

modernization of higher education and information society. To determine the level of understanding of algorithms and their role in future professional activities and everyday life as well as their importance for any subjects outside the ICT area, we conducted the survey among 352 respondents: 295 students, academic staff, and teachers from Classic private University (Zaporizhzhia, Ukraine), Zaporizhzhia National University (Zaporizhzhia, Ukraine), Zaporizhzhia Polytechnic National University (Zaporizhzhia, Ukraine), and 57 teachers who attended training courses at Institute of Postgraduate Pedagogical Education of Chernivtsi region (Chernivtsi, Ukraine).

Conclusions

The development of algorithmic thinking of future professional on non-ICT specialties is very vital for Ukrainian higher education because it helps to train them according to requirements of the modern information society, and makes it possible to take into account all up to date information in the context of the future profession, as well as provide them with effective instrumentality to solve issues of everyday life. The proposed model of algorithmic thinking should be widely used in the learning process for any subjects outside the ICT area through the presented universal sequence of algorithm development, which involves abstract, logical, conceptual, constructive, and figurative thinking.

According to the survey, 72% of respondents could not explain what is an algorithm, more than 90% do not know its main properties and advantages, and only 26% think that algorithm can be used in a subject outside the ICT area. Additionally, 24% of respondents noted that they use algorithms in learning and everyday life very often. Moreover, more than 15% of survey participants believe that they are able to recognize algorithms developed by other persons, and 10% of respondents indicated that they can develop their own algorithms. The acquired survey results are substantial to make the conclusion that considering of algorithmic thinking as a new dimension of learning in higher education is feasible and very vital for Ukrainian universities because the responders demonstrate a low level of understanding of algorithms, algorithmic thinking, and their role in future professional activities and everyday life in conditions of the information society.

The materials of the article can be useful for lecturers, professors, and other academic staff of universities and institutes when studying any subjects related to the basic and professional training of students. Further research will focus on elaboration and experimental approbation of technology of algorithmic thinking development in higher education considering the context of future profession and personal abilities of students.

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