

Natalia V. Olkhova*

Lesya Ukrainka Volyn National University
43025, 13 Volya Ave., Lutsk, Ukraine

Development of Algorithmic Thinking in Primary School Students when Studying Computer Science

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Abstract. The relevance of the study is conditioned by the fact that modern society requires new generations to be able to plan their actions, find the information necessary to solve problems among huge information arrays (many of which are also not reliable), and model processes for the future. The set of certain tasks is synergised in the plane of the concept of algorithmic thinking. The purpose of the study is to track the educational and competence consequences of applying the developed approaches to stimulate algorithmic thinking in computer science lessons, to identify how they will contribute to the development of algorithmic thinking in primary school students. The paper states that categorisation of the concept of algorithmic thinking requires a broad understanding of the algorithm as a set and sequence of actions aimed at achieving the desired result. While algorithmic thinking is a way of organising mental actions and techniques for solving problems, as a result of which an algorithm is created – a specific product of human mental activity. Algorithmic thinking is not a compilation of algorithms, and its development is not limited to the mechanical memorisation of a number of algorithms. In the scientific literature and current policy documents on primary schools, the development of algorithmic thinking is perceived in the context of information and digital competence of schoolchildren and is associated with branches related to computer science: mathematics and logic. The emphasis on the potential for developing algorithmic thinking applies directly to the computer science course, but is not limited to it. The intention to stimulate the ability to think algorithmically is a requirement of the postmodern information era and the key to personal success, it is one of the tools of socialisation, and therefore, approaches to the development of algorithmic thinking should be comprehensively presented in the concepts of studying other compulsory and optional subjects. For the study, the authors developed and successfully tested a special eight-level diagnostic structure, which is presented in the paper. It can be used as a basis for conducting similar experimental studies. Further study on the topic should be organised around deepening the understanding and expanding the range of methodological approaches to the development of algorithmic thinking in schoolchildren of the New Ukrainian School (NUS), in particular, in computer science lessons

Keywords: algorithmisation of thinking, algorithm, informatisation, New Ukrainian School, information and digital competence, computer science

*Corresponding author

INTRODUCTION

Information and computer technologies today are one of the most dynamically developing spheres of human activity, and at the same time, are a key generator of economic and social progress. In a situation where the amount of information is constantly growing quantitatively, a modern person has to pass huge information flows through their

perception every day, and at the same time, be a producer of new information for themselves. All this requires the development of thinking mechanisms that would allow dealing with the necessary information, quickly finding optimal information solutions with the help of modern computer technology and gadgets, identifying new, essential things, and

using it in the necessary activity scheme for the effective achievement of personal goals. Any human activity and general existence in nature are inextricably linked with the algorithmic model, so from the earliest years, the relevance of building and developing algorithmic thinking of schoolchildren increases, in particular, in primary school students. On the other hand, a significant problem of modern school programmes in European schools, in particular, Ukrainian ones, is that digital competence is still not represented as a component of the implementation of these programmes, but only nominatively fixed in the description of the document. That is, today the true digital competence of students is more an idea than the result of educational activities in a non-specialised school.

The recommendation of the European Parliament and the Council (EU) "On Core Competencies for Lifelong Learning" of 18 December 2006 states that the priority idea of modern education is "learning for the sake of gaining knowledge", understood as the ability to achieve results in hard learning, organise their learning, in particular, through the effective use of time and information, individually and in groups [1]. In the concept of NUS, information and communication technologies are the central idea of reorienting school education to modern development vectors. The most important thing is that both the teacher and the student are equally important participative actors in the learning activities, between whom full cooperation is possible with the help of ICT. In the ten key competencies that the NUS concept defines, information and digital competence (central – fifth in the list) provides for such foundations as information and media literacy, mastering the basics of programming, working with databases, internet security and cybersecurity skills, and, most importantly, given the presented research topic, algorithmic thinking [2; 3]. At the same time, information and digital competence is interpreted as acting according to an algorithm and composing algorithms. The NUS concept also defines that the most valuable result of primary education in a separate personal dimension is a healthy child with motivation to learn successfully, a research attitude to life, the ability to hear other people, and an attitude to successful learning. In particular, this implies the image of a student who can learn using various sources, and be able to critically evaluate information [2].

Etymologically, the concept of an algorithm is related to mathematical options, because this term itself was introduced by the Uzbek mathematician Al-Khwarizmi, who called the process of performing four arithmetic operations an algorithm [4]. In the future, comprehensive automation and computerisation led to the fact that thinking was inevitably compared to the work of a computer, and now a person is considered in tandem with a computer. And this inevitably actualises the need for the algorithmisation of thinking – learning to think in standard, typical situations like a computer: on the one hand, this is necessary for more effective use of technology: to "talk" with the computer in one language – the language of algorithms. On the other hand, human algorithmic thinking is ahead of and exceeds the computer in its

qualities, being more perfect than the action of a programme or computer algorithm [4]. Algorithmic thinking is necessary for a person to be able to think and decide quickly, like a computer, but to take into account the range of related factors when making decisions that the computer is not able to respond to. Algorithmic thinking, among other things, is important for properly organising personal time and quickly performing a wide range of everyday tasks. In some countries, this idea is already integrated into the paradigm of general education schools. Thus, since 2020, the Ministry of Education, Culture, Sports, Science and Technology of Japan has been introducing the course "Algorithms and computer programming" as mandatory subjects for all primary school students.

All this creates the necessary context for paying attention to the peculiarities of developing algorithmic thinking of Ukrainian schoolchildren from the earliest stages of study. In particular, during the development of a computer science course and through the process of studying other compulsory and optional courses.

LITERATURE REVIEW

The concept of algorithmic thinking cannot be considered without understanding the essence of the algorithm. This is important because it is the algorithm that is the main tool for the data processing and the final result of algorithmic thinking [4]. J. Mezak, P. Papak [5] note the integration of STEM (S – science, T – technology, E – engineering, M – mathematics) principles into the modern educational environment. O. Sadykova notes that algorithmic thinking today is defined as a system of thinking techniques aimed at solving problems, which, however, is not unambiguous in a situation of life (in contrast to software algorithmic thinking, which is inherent in a computer), because in a situation of, for example, interpersonal interaction within the application of algorithmic thinking, a person must determine and consider not only the very presence, but also the scheme of "someone else's" algorithm – and only then can build own algorithm [4].

Now the problem of developing algorithmic thinking of schoolchildren and students, although generally recognised in the world (at least theoretically), but only a small number of students are able to comprehensively apply the operational components of algorithmic thinking in a holistic process of solving various problems, which also involves the skills to consciously manage their mental activity and think logically. The development of techniques of mental actions, which are the main components of algorithmic thinking (the ability to generalise, classify, draw analogies, logically establish patterns, and reason), contributes to better assimilation of exact sciences [6]. It is empirically confirmed that algorithmic thinking, developed primarily in the paradigm of studying computer science, has a positive effect on the result of mastering a number of other academic disciplines [11].

The methodological literature considers various content aspects of algorithmic thinking: ways to form algorithmic thinking through systematic and purposeful implementation

of the ideas of the structural approach [7; 12]; various structural components of algorithmic thinking and their adaptation to various subjects [8; 13; 14], [9; 15; 16]; some aspects of optimising the educational process that contribute to the development of algorithmic thinking and its connection with other types of thinking [10]; the ability to plan the structure of actions necessary to achieve a goal using a fixed set of tools [8].

J. Hromkovic and T. Kohn identify the main aspects of algorithmic thinking in research activities as the goal of educational programmes: the concept of formal language to express algorithms, abstraction and automation to transfer a proven strategy to new cases [17]. S.D. Yazvinskaya [18] defines algorithmic thinking as the art and ability to reflect, plan, consider various circumstances and act in accordance with them, and the ability to solve various problems related to the preparation of an action plan for solving problems. According to the researcher, the development of algorithmic thinking should begin already at the stage of preschool.

In addition to some subtleties of interpretation and semantic shades of definition functioning, there are also differences between researchers regarding approaches to teaching algorithmic thinking. Thus, at the Australian Informatics Competition (AIC), a special approach to developing algorithmic thinking skills is proposed, which differs from conventional methods of algorithmisation of thought using puzzles or multiple-choice tests. The innovation of AIC is to apply the three-step task methodology – these are groups of three related questions, each of which offers students to solve the same problem, but with larger data sets. First, students receive instructions and a general description of the task, followed by three sets of data, according to which they are formulated with three questions that involve working according to the same type of algorithm, but somewhat complicated at the 2nd and 3rd levels.

Sometimes algorithmic thinking is identified with a logical-algorithmic style of thinking [19; 20]. This style of thinking manifests itself in the skills of students, such as: to build logical statements about data properties and queries to search engines; to use inductive and deductive methods of mental operations when working with computers; to use the formalisation method to solve problems – up to the use of algorithmic language.

The difficulty of categorising algorithmic thinking lies in the fact that most authors consider algorithmic thinking, on the one hand, just a way of thinking. On the other hand, it is a certain system of discrete actions associated with the way thoughts are organised. Algorithmic thinking is the highest form of organisation of an individual's mental activity. Mental techniques in the context of algorithmic thinking form a single system consisting of two types of components (intermediate tasks and final – goal) and contain an understanding of the expediency and prospects of intermediate chain operations that should lead to the performance of tasks [4]. Algorithmic thinking is characterised by the following features: the ability to find the sequence of actions necessary to solve the problem, and the allocation of a number of simpler subtasks in the overall

problem, the solution of which will lead to the solution of the original problem. The presence of logical thinking does not necessarily (although quite often) imply the presence of algorithmic thinking. Developed algorithmic thinking is certainly based on formed and developed logical thinking.

The concept of computational algorithmic thinking (CAT) is also tangential, which implies the ability to design, implement, and evaluate the use of algorithms to solve a number of problems. This includes: 1) identifying and understanding the problem; 2) developing an algorithm or set of algorithms to solve the problem; 3) implementing the algorithm so that it solves the problem; 4) evaluating the solution based on a specific set of criteria. CAT is an important functional framework that allows students to develop computational thinking capabilities and apply computational thinking to problem-solving [21]. Methodologically, CAT is formed mainly at the intersection of computer and mathematical competencies.

As for the theoretical foundations, from the perspective of the current research, the study refers to a meaningfully broad definition of the algorithm presented by K. Utyumova: an algorithm is a rule, a sample of performing a system of operations in a strictly defined sequence, leading to solving problems of a certain type [22]. In addition, the study by J. Mezak, P.P. Papak [5], which has already been mentioned above, is ideologically and methodologically closer to this study. Firstly, the authors criticise the conventional role of the teacher as the main source and transmitter of knowledge. After all, in the modern age of information, the role of the teacher cannot remain monolithic unchanged and not evolve to understand the teacher as a facilitator, and not the key pillar of the entire educational process. This also requires adaptation of approaches to teacher training. Secondly, learning scenarios have the potential to influence the development of innovative ideas for the implementation of educational activities, in particular, scenarios based on the use of modern methods of teaching curricula using digital tools and digital content. Thirdly, the research focuses on the Erasmus+ project “Games for Learning Algorithmic Thinking”, which is relevant for the authors, and aimed at training primary school teachers who will further develop such learning scenarios and apply them in teaching their students. The paper presents how appropriate learning scenarios can stimulate the algorithmic thinking of younger students in everyday situations [5].

Thus, the problem of algorithmic thinking is relevant for modern Ukrainian and foreign studies. Researchers speak about the direct connection between the relevance of thinking according to the algorithm scheme and the correspondence of such thinking to modern realities of the digitalised world [23]. Algorithmic thinking seems to allow finding an understanding between a person, objective reality, and the computerised environment of existence. However, despite the positive perception of the potential of teaching algorithmic thinking, there is still a very limited range of methodological tools and specific tasks that would contribute to the development of algorithmic thinking in schoolchildren, in particular, primary school students.

The purpose of the study, therefore, is to trace the educational and competence consequences of applying the original approaches to develop algorithmic thinking and to identify how they will contribute to the development of algorithmic thinking in primary school students in computer science lessons. Achieving this goal involves the implementation of a number of tasks: 1) to develop a set of approaches to mastering the computer science course according to the NUS programme, to compensate for the lack of practice in the development of algorithmic thinking of schoolchildren in the context of computer education (in the Explanatory Note to the Computer Science curriculum for grades 1-2, it is just recorded that one of the tasks of studying the course is the development of logical, algorithmic, creative, and object-oriented thinking in students [24]); 2) to organise an experimental study, within which to investigate empirically the effectiveness of the developed approaches – through comparison and analysis of data obtained in accordance with the special scheme; 3) to summarise the results of the current stage of research on the problem of developing algorithmic thinking of primary school students and outline the prospects for further theoretical and experimental research on the topic.

MATERIALS AND METHODS

The study investigated two reference groups – students of parallel classes of the “Lutsk Educational Complex No. 9 of the

Lutsk City Council”: 2-A (27 students) – experimental group and 2-B – control group (30 students). During the entire academic year, students of the control group mastered the compulsory computer science programme for NUS schools – without special emphasis on the development of logical and algorithmic thinking, but within the limits of the requirements for the competencies of students in this age group.

Students of the experimental group, in addition to the material provided to the students of the control group, received additional homework assignments aimed at developing algorithmic thinking and logic. In the organisation of work with students of the experimental group, the emphasis was placed on a clear understanding of the sequence of actions to perform a certain task and working out these actions to automatism through performing the same type of tasks. In addition, considerable attention was paid to the development of speech of such students: they were required to have a clear understanding of the process, their own reflection and speech activity (here the concept of communication between speech and thinking was considered).

The research hypothesis was that students of the experimental group will demonstrate the best quality indicators of mastering not only key computer competencies, but also improve the ability to think logically and perform typical tasks.

The final evaluation of students in both groups took place according to the developed structure (Table 1).

Table 1. Structure of final tasks for evaluating algorithmic thinking of students

Type of task	Summary of the task	Score
Day 1		
1. Search the Internet for the necessary information	Find a graphic image of the map of Ukraine (10 points) Find text information about the highest mountains in Ukraine (10 points) Find a video about your hometown (10 points)	30 points
2. Define the sequence of steps for task performers	Describe the sequence of creating a house image in your paper album (10 points) Describe the sequence of creating a house image in the Paint image editor (10 points)	20 points
3. Find errors in algorithms	Adjust the algorithm of Olenka's actions. Explain what mistake she made. How did you find it? How long did it take you to do this? (<i>Students are offered an algorithm for collecting a school backpack. But it makes mistakes: the student did not check the class schedule based on the diary</i>)	20 points
Day 2		
4. Determine the result of performing a linear algorithm for constructing a simple geometric image	Complete the task in the Scratch environment	10 points
5. Develop your own algorithm for creating a simple geometric image	Complete the task in the Scratch environment. Display the sequence of actions using a text or graphic-text entry of the algorithm in your workbook	20 points
Day 3		
6. Create a drawing using a ready-made algorithm in the Scratch environment	Complete the task in the Scratch environment	20 points

Table 1, Continued

Type of task	Summary of the task Day 3	Score
7. Performing logical and arithmetic thinking tasks on the platform Learning.UA	On the application of algorithmic knowledge: https://learning.ua/matematyka/piaty-klas/alhorytmy Find the differences: https://learning.ua/matematyka/maliuky/znaidy-vidminnosti Find a picture without a copy: https://learning.ua/matematyka/maliuky/znaidy-kartynku-bez-kopii Find the extra: https://learning.ua/matematyka/maliuky/vykliuchaemo-zaive Find the same: https://learning.ua/matematyka/maliuky/znakhodymo-odnakove Logical series: https://learning.ua/matematyka/maliuky/lohichni-riady Simple logic problems: https://learning.ua/matematyka/doshkilniata/prosti-lohichni-zadachi	70 points
8. Self-assessment	Verbally substantiate and verbally describe your own perception of the tasks offered to you according to the following criteria: easy/difficult/difficult to say; I needed help/everything was clear; I understand the tasks/ I don't understand the tasks, etc.	10 points
Total: 200 points maximum ≥99 points – unsatisfactory 100-130 – satisfactory 131-170 – good 171-190 – very good 191-200 – excellent!		

Source: developed by the author

RESULTS AND DISCUSSION

As can be seen from the structure of Table 1, the control process took three days. This is conditioned by the age characteristics of second graders.

The results of the evaluation were grouped and analysed in an appropriate mathematical and statistical way to summarise the results of annual activities (Table 2).

Table 2. Results of evaluating the development of algorithmic thinking according to research criteria

Type of task	Experimental group		Control group		Difference
	Average result in the group		Average result in the group		
	Points	%	Points	%	%
1. Search the Internet for the necessary information	26.5	88.3%	23.4	78.0%	10.3%
2. Define the sequence of steps for task performers	18.1	90.5%	15.6	78.0%	12.5%
3. Find errors in algorithms	15.2	76.0%	11.2	56.0%	20.0%
4. Determine the result of performing a linear algorithm for constructing a simple geometric image	7.2	72.0%	6.1	61.0%	11.0%
5. Develop your own algorithm for creating a simple geometric image	8.2	82.0%	5.7	57.0%	25.0%
6. Create a drawing using a ready-made algorithm in the Scratch environment	17.3	86.5%	14.5	72.5%	14.0%
7. Performing logical and arithmetic thinking tasks on the platform Learning.UA	59.3	84.7%	40.9	58.4%	26.3%
8. Self-assessment	9.6	96.0%	7.8	78.0%	18.0%
9. Total points (averaged)	161.4	80.7%	125.2	62.6%	18.1%
Verbalised assessment	Good		Satisfactory		

Source: developed by the author based on research data

The results obtained are visualised in Figure 1.

The results show that special attention and correct methodological support of the teacher-facilitator during the organisation of regular work on computer science and extracurricular activities of students of the experimental group (subject to help and control by the parents of students) managed to achieve improved results according to all the criteria selected based on the analysis of literature and the compulsory curriculum of Computer Science. Separately, it should be noted that statistical data processing demonstrates the smallest gap in Point 1, which provides for the skills of searching the Internet for the necessary information (10.3%).

Interestingly, even the self-assessment point showed a large discrepancy (18.0%). This demonstrates the lack of skills in children in the control group to consciously perceive the learning process and understand themselves in this process. More attention to the components of algorithmic thinking, therefore, stimulates the processes of consciousness in general and self-reflection in particular, and trains the options of self-control and attention – at least during the performance of educational tasks. However, in the future, the improved algorithmic thinking skills will have a positive projection on other areas of the individual's life.

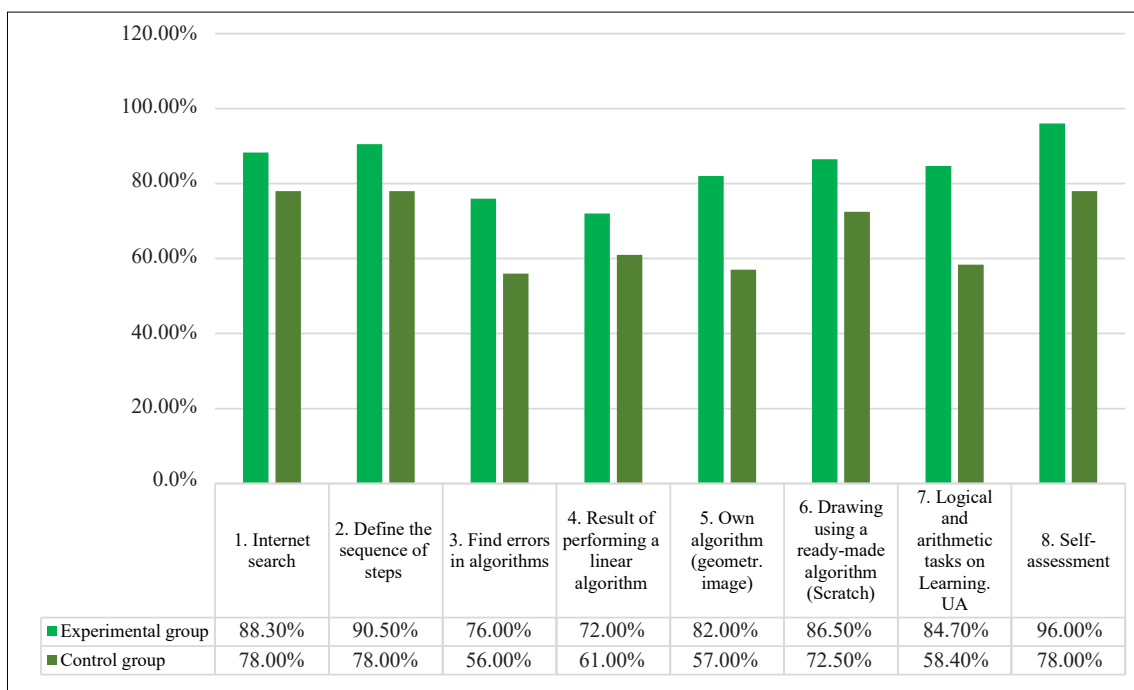


Figure 1. Results of evaluating the development of algorithmic thinking according to research criteria

Source: developed by the author based on research data.

The logic and results of the study are significantly different in content and organisation from the already presented research on the topic [25; 26]. Although theoretically they correlate, there is a correspondence concerning the ideological and conceptual definition of algorithmic thinking, the necessity of developing algorithmic thinking skills in modern schoolchildren considering the technologisation of the reality, technically the research is organised differently. In particular, due to the lack of an empirical, practical representation of the topic, it is impossible to compare the conclusions. This is evidence of the relevance of the current study, its originality, the actual implementation of the idea of avoiding formalism in approaches to the development of algorithmic thinking and declarative calls to rely on the child's life experience and use game techniques in combination with their optimal combination with information technologies [26].

At the same time, the presented experimental study has limitations, in particular, regarding the range of reference groups. It can be used in the future in a ready-made form only for primary school students. Potentially, the proposed scheme may give slightly different results, depending

on the pedagogical support, the environment, and the number of students involved in testing. However, hypothetically, the errors in testing cannot be fundamentally different from the key results presented. All these nuances can be revealed statistically and made clear in the course of subsequent research.

Therefore, algorithmic thinking needs to be developed in order to understand how the world around us and the processes in it work. In a broad sense, the whole reality around a person can be depicted as a super-complex, but harmoniously correlated set of algorithms. No process is complete without algorithmic thinking. The art of composing and solving problems requires special mental experience – algorithmic thinking, which people, as a rule, do not have from birth and cannot acquire without special training. This is exactly a skill – the ability to solve a particular type of problem, brought to automatism. Algorithmic thinking refers to the ability to think accurately, formally, and becomes one of the important features of the general human culture in today's high-tech world. However, the algorithmic way of thinking is not only related to computing or computer technology, it helps to solve problems in

any field of activity. In the process of life activity, a person somehow applies an algorithmic approach. In particular, the tools of algorithmic thinking are the following skills: 1) divide general tasks into subtasks; 2) plan the stages and time of their activities; 3) evaluate the effectiveness of activities; 4) search for Information; 5) process and assimilate information.

CONCLUSIONS

The problem of developing algorithmic thinking in primary school is one of the most important in psychological and pedagogical practice. The main way to solve it is to gradually form logical thinking techniques with a gradual transition directly to the elements of algorithmisation, especially during computer science lessons. Algorithmic thinking is characterised by formality, logic, clarity, and the ability to translate any abstract idea into instructions, the sequential execution of which brings the idea to life.

According to the results of an empirical study, namely, at the stage of final diagnostics, students of the control group demonstrated, in accordance with the assessment scheme developed by the authors, a level of algorithmic thinking of 62.7% ("Satisfactory" level). Students of the experimental group averaged at 80.7% ("Good" level). The difference between the control groups was 18.1% in favour of the experimental group. This confirms the effectiveness of the proposed approaches to the development of algorithmic thinking in younger schoolchildren, but requires further investigation of this problem, considering the increase in the effectiveness of pedagogical influence and the necessary deepening of the individual approach to students.

Since computer science is directly involved in understanding and constructing algorithms and learning their properties, studying disciplines related to computer science and programming will best contribute to the development of algorithmic thinking. However, in the future of deepening intersubject relations, it is necessary to further explore the possibilities of applying algorithmisation techniques of thinking in the context of studying other school disciplines.

The findings are of practical and theoretical significance. Theoretically, they can be used to understand the essence of algorithmic thinking and the basics of its development in primary school students, to compile methodological materials for developing the ability of younger students to think algorithmically. Practically, the empirical data provided in the process of revealing the topic can be used for broader generalisations, comparisons with the results of similar studies, and comparative investigations. The presented research scheme in its primary or adapted form can be used for conducting experiments with the involvement of younger schoolchildren in other educational institutions. The main messages of the research paper can help improve the implementation of information and digital competence of NUS students. Further study on the topic may relate to testing the effectiveness of practical training methods and the development of algorithmic thinking in students of different age groups. It is also appropriate to trace the relationship/connection between the level of development of algorithmic thinking and the overall academic performance of students.

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Наталія Володимирівна Ольхова

Волинський національний університет імені Лесі Українки
43025, просп. Волі, 13, м. Луцьк, Україна

Формування алгоритмічного мислення здобувачів початкової освіти під час вивчення інформатики

Анотація. Актуальність дослідження зумовлено тим, що сучасне суспільство вимагає від нових поколінь умінь планувати свої дії, знаходити інформацію, необхідну для вирішення завдань, з-поміж величезних інформаційних масивів (багато з яких до того ж не є достовірними), моделювати процеси на перспективу. Сукупність визначених завдань синергується в площині поняття алгоритмічного мислення. Метою статті є відстежити навчально-компетентнісні наслідки застосування розроблених нами підходів для стимулювання алгоритмічного мислення на уроках інформатики, виявити, як саме вони сприятимуть формуванню алгоритмічного мислення в учнів молодшого шкільного віку. У статті йдеться про те, що категоризація поняття алгоритмічного мислення вимагає широкого розуміння алгоритму як сукупності й послідовності дій, націлених на досягнення бажаного результату. Тоді як алгоритмічне мислення є способом організації мисленнєвих дій і прийомів для вирішення завдань, унаслідок чого створюється алгоритм – специфічний продукт людської ментальної активності. Алгоритмічне мислення не є копіляцією алгоритмів, а його розвиток не зводиться до механічного заучування низки алгоритмів. У науковій літературі та чинних директивних документах стосовно молодшої школи розвиток алгоритмічного мислення актуалізується в розрізі інформаційно-цифрової компетентності школярів і пов'язується з суміжними до інформатики галузями наук: математикою та логікою. Акцент у потенціалі формування алгоритмічного мислення стосується безпосередньо курсу інформатики, але не обмежується ним. Іntenція стимулювати здатність мислити алгоритмічно є вимогою інформаційної постмодерної епохи та запорукою досягнення особистістю успіху, є одним з інструментів соціалізації, а тому підходи до формування алгоритмічного мислення мають бути наскрізно представлені в концепціях вивчення інших нормативних та факультативних дисциплін. Для дослідження нами було розроблено та успішно протестовано спеціальну восьмирічну діагностичну структуру, що представлена в статті. Вона може бути взята за основу для проведення аналогічних експериментальних розвідок. Подальші дослідження з теми доречно організовувати довкола поглиблення розуміння і розширення спектру методологічних підходів до формування алгоритмічного мислення школярів НУШ, зокрема на уроках інформатики

Ключові слова: алгоритмізація мислення, алгоритм, інформатизація, Нова українська школа, інформаційно-цифрова компетентність, інформатика