Development of Teachers' Digital Competence through Algoritmization and Programming*

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Abstract

The problem of developing students' algorithmic competence as a basis of digital competence of future teachers is investigated. The aim of the study is to identify the optimal learning conditions for algorithmization and programming for students — future Computer Science teachers. As part of the study, the problems of modular education, identification and application of Computer Science classes of problems according to B. Bloom's taxonomy and its teaching method, development and application of electronic learning resources in blended learning conditions were investigated. The methods of the system and competence approach, the Fisher method were applied to assess statistical validity of the results and to confirm the hypothesis on the efficiency of the use of electronic learning resources (ELR) to develop algorithmic competence of students. The results of the study: the concept of algorithmic competence of university students is clarified as it implies students' readiness to develop algorithms and programs and to use them in teaching Computer Science in the conditions of digital economy, development of ELR, self-education in Computer Science. Classes of problems for the development of algorithmic competence with students according to B. Bloom's taxonomy (knowledge, comprehension, application, analysis, synthesis and evaluation) are identified. The classes of problems correspond to ELR of a certain structure and composition. The efficiency of application of ELR for development of algorithmic competence of students has been statistically confirmed.

Keywords: *digital competence, algorithmic competence, computer Science teacher, blended learning, B. Bloom's taxonomy, electronic learning resources*

1 Introduction

The modern stage is characterized by the transition to a large-scale use of information technology tools in Russian education system at all levels — the digital education stage [Baranova & Vereshchagina, 2018]. First of all, we are talking about the wide introduction of high-quality electronic learning resources in training process, open online courses, remote access to educational materials presented in digital format for students of all levels of education, etc.

The development of digital education involves improving the efficiency of learning by increasing the motivation of students and improving the way they work with information, and developing teachers' digital competence. The term "digital competence" has two implications. On the one hand, it describes requirements for people's knowledge and skills in the digital economy, defined in any regulations, for example, in educational standards. On the other hand, it describes the personal characteristics (for example, of a teacher), characterizing his willingness to solve certain classes of problems based on the digital technologies, their mechanisms and methods and the ability to select, efficiently apply them, and to use specific tools of digital technologies.

Digital competence is characterized not only by understanding and adequate use of digital technologies and information systems in life and professional activities, but also confidence in their use creatively, critically, independently (without assistance).

The Digital Competence Framework 2.0 by the European Commission[1] distinguished 21 components of digital competence, combined in 5 groups: Information Processing; Communication, Content Creation, Safety and Protection, Problem Solving. The criterion for grouping is based on classes of problems to be solved, characterized by the type of object of research, object development and its modification with the use of digital technologies, and types of activity which are being implemented for this.

Skills according to each component include achieving a certain level of algorithmic competence, the basis of which is formed in the school, develop in the next stages of education and throughout life. This determines the need for training teachers, primarily Computer Science teachers algorithmization and programming at a sufficiently high level [Baranova & Simonova, 2018].

The aim of the study was to identify the optimal learning conditions of algorithmization and programming for students, consisting in modular representation of content, blended learning, use of classes of problems identified in accordance with the B. Bloom's taxonomy on computer science and methodology of its teaching, and application of electronic learning resources. We understand algorithmic competence as the readiness of students to design algorithms and programs, their use in professional activities in the process of Computer Science teaching, electronic learning resources (ELR) development, self-education in the Computer Science field.

The development of algorithmic competence in the training of teachers is carried out on a staged basis in various modules of the educational program. The article considers two major modules "Foundations of Computer Science and Programming Techniques" and "Theories and Methods of Computer Science Teaching at School". The content of the first module is aimed at the establishment of student's theoretical knowledge in Computer Science and algorithmic competence development. The module content is aimed at the development of methodological competence of the future Computer Science teacher, reveals the system of concepts of teaching methods, general and Computer Science specific, taking into account interdisciplinary connections with Pedagogy and Psychology.

The main means of developing algorithmic competence, according to the authors, is a system of problems on Computer Science and methods of its teaching. The system of problem developed by the authors is based on B. Bloom's taxonomy of pedagogic objectives [Bloom et al., 1956], which includes six categories of objectives: knowledge, comprehension, application, analysis, synthesis, evaluation. The article describes sample problems of the determined modules, and electronic learning resources for students to solve problems. The results of the pedagogical experiment prove the effectiveness of the developed ELR for the development of students' algorithmic competence.

This study and many years of practical experience in training implementation have shown the advantage of modular and blended learning. This approach allows for a flexible training system, individual educational routes and the development of information technology tools [Baranova et al., 2016]. The analysis of various studies:[Sellahewa, 2015], [Thoma, 2017], [Zylka, 2015] shows the relevance of the development of educational learning materials for blended learning implementation, including ELR. This approach will allow to vary the forms of blended learning: online, "flipped classes", etc.[Jansen, 2009]

The designed model of training is aimed at students' algorithmic competence development and is based on the B. Bloom's taxonomy of pedagogical objectives. This determines the logic of the formation of classes of problems, the readiness to their solving develops in students directed from reproductive activity to partly searching and researching. The structure, content and functionality of

[1] https://ec.europa.eu/jrc/en/digcomp/digital-competence-framework

ELR should correspond to the selected classes of problems. The use of ELR provides an opportunity to individualize the rate of learning, its place and time. The inclusion of resources in the LMS Moodle ensures ELR systematization, the ability to manage training activities, both in the classroom and online, allows teachers to carry out tutoring, implement group discussion of problems to solve [Baranova, 2015]. The ELR system allows each student to determine her/his initial level of algorithmic competence development and build a comprehended individual educational route.

2 Research Methods

The activity orientated approach and the theory of the B. Bloom's classification and blended learning provide the methodological framework for the research. To solve the problem of the research a set of methods based on the analysis of Russian and foreign pedagogical and psychological theory and practice in the area of computer science were used. Those were general scientific methods, such as modeling, association, comparison and generalization, as well as experimental methods using diagnostic toolkit, expert evaluations and statistical processing of results of pedagogical experiment. F-test was used for the assessment of statistically significant differences of the correctness of student's actions within monitoring and experimental groups for each of the six categories of objectives: knowledge, comprehension, application, analysis, synthesis, evaluation.

3 Results of Research and Discussion

3.1 Foundations of Computer Science and Programming Techniques

The module content is aimed at the formation of students' theoretical knowledge in the field of Computer science and the development of algorithmic competence. Students study the concepts of the Theory of Algorithms, Mathematical Logic, Formal Languages and Grammars, Relational Algebra, Information Theory, etc. The module implements interdisciplinary connections with the mathematical module, which studies the mathematical apparatus forming the basis of Theoretical Computer Science [Baranova et al., 2014].

The development of algorithmic competence is carried out in the disciplines devoted to the study of modern programming paradigms and involves students' mastery of algorithmic and programming methods. Students acquire knowledge of basic concepts, principles and methods of programming, on the basis of which they develop the ability to design information models, algorithms, data structures, databases, computer programs, information systems and web resources for solving problems from various fields, including the field of future professional teaching activities, by means of information technology.

The study of basic concepts, principles, and algorithms of compilation theory contributes to the formation of students' systematic understanding of the sources of syntax errors and skills to develop syntactically correct programs [Kwon & Cheon, 2019].

The peculiarity of the discipline is the need for individualization of learning, taking into account different competence levels of students in the programming field: over 50% of students do not have or have a vague notion of this type of activity, only 10% of students usually have notion of programming and are ready to successfully solve complex problems.

Conditions for the establishment of individual educational routes for students are provided with a set of sample problems of different complexity levels and electronic learning resources presented in LMS Moodle. Table 1 presents module sample problems and corresponding ELR associated with B. Bloom's categories.

Table 1: Sample Problems and Electronic Learning Resources

Foundations of Computer Science and Programming Techniques		
B. Bloom's Categories	**Computer Science Sample Problems in Accordance with Pedagogic Objectives**	**Electronic Learning Recourses to Achieve Pedagogic Objectives**
Knowledge	Performing basic operations with data presented by various structures;	"Data structures" containing a description of data structures, basic access operations, examples that illustrate ways of access and results of operations;
Comprehension Application	Development of algorithms (computational) and programs based on the known mathematical apparatus; Development of algorithms and programs modeling phenomena, processes, behavior of objects from different areas;	"Processing algorithms of data structures", containing a brief description of basic data processing algorithms presented in different structures, interactive demos, self-assessment questions;
Analysis Synthesis Evaluation	Development of algorithms and programs for the analysis of data presented in various structures and for the formation of data according to a given scheme; Development of multi-module programs for solving educational and professional problems related to future professional activities.	Information Systems and Web Resources containing a brief description of design stages, examples of implementation stages in the form of ready-made applications; The integrated resource Syntax Analyzer aimed at the development of students' concepts and algorithms in Theoretical Computer Science

3.1.1 Sample problems for students

The achievement of learning objectives is carried out by using a system of sample problems designed to develop students' algorithmic competence, including the readiness to describe and create data structures of different complexity levels, to develop and implement algorithms for solving problems from different fields. The first type of problems involves performing basic data operations represented by various structures: arrays, lists, records, object classes, database tables, etc. Such operations include: creating, changing values, deleting. To solve these problems, students should know the appropriate syntactic structures, the results of the implementation, including the control structures of the programming language under studies, ways to describe data structures and to access their elements. For example, when learning object-oriented paradigm (OOP) programming languages, the central data structure is an object class. To solve the problems, students should know the basic principles of OOP (encapsulation, inheritance, polymorphism), class structure, ways of description and access to the fields and methods of the class.

The problems of the second type are focused on identifying the acquirement of algorithmic competence at the comprehension level, and involve the design of computational algorithms and programs based on the known mathematical apparatus. These are, for example, approximate calculations, calculation of series sums, matrix processing, calculation of geometric objects parameters, etc. At this stage students should be ready to interpret the mathematical model, transform it to the information one, create a data structure adequate to nature of mathematical objects, implement a "translation" from the language of Mathematics to the language of Computer Science.

The problems of the third type involve the development of algorithms and programs that simulate phenomena, processes, behavior of objects from various domains. When solving such problems, the acquirement of algorithmic competence at the level of application, the readiness of students to solve problems in new situations based on known facts, models and rules are verified. This type includes problems on visualisation of known algorithms operation involving new interface elements, software implementation of simple models describing phenomena from various fields of knowledge, science and technology, development of game situation fragments, etc.

At the next, fourth stage, the readiness to analyze the data, to identify the relationships between the data elements, to determine the principles of data organization is formed. The problems of the fourth type include development of algorithms and programs for analyzing data presented in various structures, and formation of data according to a specified scheme: algorithms for searching and sorting, formation of arrays, lists with a specified structure, creation of object classes with a specified behavior, definition by means of SQL language of values characterizing data in a database table, creation of related data sets according to a specified scheme. Particular set of problems is determined by the data structures being learned.

The synthesis category in Bloom's taxonomy of pedagogic objectives involves the ability of combining elements to produce a unity that is something new, and includes the development of the action plan, the production of a new product. When teaching algorithmization and programming with such a new product, the result of educational activities of students is a computer program. The problems of the fifth type involve the development of multi-modular computer programs, including those for solving educational and professional problems connected with future professional activities. With regard to the training of future teachers in the field of Computer Science, it can be electronic learning resources on various topics of school subjects, information systems and web resources for the organization and management of the educational process, testing systems, etc. It is assumed that the sequence of actions of students in the process of information systems design is close to the stages of the life cycle and includes the analysis of the subject area, design, software implementation, testing. When performing these tasks, the student's readiness to assess the quality of the product created is checked, using her/his internal, personal assessment, which appears in the process of debugging and testing, as well as external assessment in the process of testing with the participation of her/his group students.

3.1.2 Electronic Learning Resources

For mastering the module, a system of electronic learning resources has been designed to improve the efficiency of students' learning the content of the module and achieving learning objectives. The Data Structure resource contains a systematic description of the studied data structures, basic operations of access to the elements of data structures, examples, illustrating the ways to access and the results of operations. Depending on the studied data structures, programming language operators of the selected paradigm, SQL statements, etc. are described. The resource contains tasks of a reproductive nature: to describe the structure representing the data of a specified type, the object class performing a certain functions, the structure of related tables representing abstraction of some subject area [Baranova et al., 2019].

The Processing Algorithms of Data Structures resource contains a brief description of the basic data processing algorithms presented in various structures, interactive demos — software applications that simulate the operation of algorithms. Such computer models provide a visual display of the algorithms operation for various data sets, allow students to understand the essence of algorithms on the basis of experiments with different data sets. For example, to evaluate the effectiveness of sorting methods, to understand the peculiarities of the execution of statements over the data of the database, to learn how to understand the results of executing complex queries of the SQL language, develop such queries, etc. The tasks included in the resource involve the modification of the considered algorithms for use in the new environment [Baranova et al., 2016].

The Information Systems and Web Resources ELR is used at the final stage of learning and is aimed at developing students' readiness for independent design of algorithms and programs that implement the specified functions. The resource contains a brief description of the design stages including design of specifications, information model, database structure, software implementation, testing. Professionally executed examples of software applications will help students learn how to analyze the subject area, create their own software products and evaluate their quality.

The integrated Syntax Analyzer ELR developed by the following authors [Baranova et al., 2014], includes several software modules representing valuable concepts and algorithms of Theoretical Computer Science. First of all, these are models of compiler components: lexis and syntax analyzers, code generator. Working with models, students learn methods of analysis and syntax parsing of chains of formal grammars that describe the sentences of the programming language. Mastering compilation techniques allows students to learn how to design syntactically correct programs. The models use complex data structures to represent the components of formal grammars, trees, graphs. Students learn to analyze algorithms of Theoretical Computer Science, evaluate their effectiveness, "predict" the results of algorithms for different data sets and develop algorithms using complex data structures. The resource is of interdisciplinary nature. It is also used in learning process of the mathematical module for mastering various concepts of Discrete Mathematics and methodical module as a tool for teaching Computer Science in the profession-oriented school [Baranova & Simonova et al., 2019].

The described system of problems and electronic learning resources is used during the whole period of training in the field of algorithmization and programming. Seniors learn more complex structures and algorithms, and students' performing the tasks lets their independence grow. By the end of training, the level of algorithmic competence in students allows them to independently analyze the subject area, design data structures and algorithms adequate to the problem being solved, create a new software product, and evaluate its quality. The students, who are the most capable and motivated in the field of algorithmization and programming, perform final qualification work on the creation and use of electronic learning resources in the educational process.

3.2 Theories and Methods of Computer Science Teaching at School

The module content is aimed at the development of methodological competence of the future Computer Science teacher, reveals the system of concepts of general teaching methods taking into account interdisciplinary connections with Pedagogy and Psychology in terms of Computer Science.

It describes the stages of content development of Computer Science as a school subject in connection with the development of the science of information and information processes, computer as a universal means of information processing, software. The content highlights the concept of "information", "algorithm", "model" and classes of problems whose solving requires comprehension and application of these concepts. Classifications, visual schemes, illustrations, computer models and presentations are used. Conditions for the establishment of individual educational routes for students are provided with a set of sample problems of different complexity levels and electronic learning resources presented in LMS Moodle. Table 2 presents module sample problems and corresponding ELR associated with B. Bloom's categories.

3.2.1 Sample problems for students

Developing methodological competence of a future Computer Science teacher implies an understanding of a set of concepts which develop the structure and functions of the methodological educational system — goals, contents, forms, methods, educational resources and knowledge on key principles of teaching Computer Science at school, on definitions and sample problems of the school subject at all levels of formal education: primary, secondary, high. To achieve this, in the course of training tasks facilitating memorization and understanding of key concept logical interrelations are applied. The tasks involve creating logical schemes of concepts for one or more topics following the material specified in secondary and high school textbooks, independent construction of working definitions for the words "computer", "information", "algorithm", "model", etc. with the help of computer tools; analyzing contents of Computer Science secondary and high school textbooks, and identifying changes, with regard to the stage of training, in the volume and contents of definitions for "algorithm", "program", "model", and "information process". The results are to be prepared with the help of computer tools:

logical schema editors, text and table editors, etc [Kostousov & Simonova, 2019].

The teacher is mainly involved in planning the educational process for the whole period of the secondary or high school, drafting course schedules for the term and creating notes for lessons. Sample problems for teaching this activities to students concern developing course schedules for Computer Science for one secondary school term; creating task sheets to support these schedules and arrange individual educational routes for students; writing notes for lessons on one of the school Computer Science course topics with detailed descriptions of the lesson, educational resources and methods; analyzing video lessons made by Computer Science teachers under suggested criteria; own assessment of goals fulfilled, quality of the resources used, and student motivation approaches [Bocharov et al., 2019].

Students should be ready to adapt and create sets of educational problems for a Computer Science lesson, didactic computer games, exams, including tests with the use of IT resources. Such skills are acquired when developing sets of differentiated tasks for secondary school students so that they strengthened knowledge on algorithmization, and implementing tasks with the help of training executor while facilitating future transfer of this knowledge to other areas of programming.

Table 2: Theories and Methods of Computer Science Teaching at School

Theories and Methods of Computer Science Teaching at School		
B. Bloom's Categories	**Goals of Methods of Computer Science Teaching at School in Accordance with Pedagogic Objectives**	**Electronic Learning Recourses to Achieve Pedagogic Objectives**
Knowledge Comprehension	Knowledge acquirement related to basic principles of Computer Science teaching at school, the structure and functions of the methodical system of education: objectives, content, forms, methods, teaching tools.	Methodical System of Computer Science Teaching at School contains theoretical material, examples of Computer Science teaching in various conditions of equipping with IT and needs of students.
Comprehension Application Analysis	Acquiring skills to describe plans and notes on the Computer Science lessons, including goals, contents, methods and educational resources; explaining problem solutions with diagrams, figures, computer models; analysing educational and methodological materials, lessons conducted by Computer Science teachers	Educational and Methodological Materials for School Computer Science Lessons contains examples of notes for Computer Science lessons made by teachers, links to video lessons where challenging problems are explained, and a set of computer models promoting intersubject problems.
Analysis Synthesis Evaluation	Acquiring skills to adapt and create sets of educational problems for Computer Science lessons, exams, including tests with the help of IT; drafting plans and approbating the materials with students.	Network Services for Creating Multimedia Educational Content contains detailed instructions on creating graphic illustrations, animations, processing audio and video files with network services, samples.

Spread of network communities has led to the need of developing the skills to participate in network discussions and come up with solid arguments with regard to Computer Science education at school. The future teacher should be able to develop and describe a plan and scenario of a network discussion on topical computer science issues for secondary or high school.

3.2.2 Electronic Learning Resources

Electronic learning resources have been developed to support students' independent work and individual educational routes during the development of module material. These resources comprise of systematized theoretic material by topics and presentations which focus on the main aspects of a topic, conclusions and questions for self-reflection, and tests. Students' practical activity in mastering the subject is supported by laboratory work. The resources are implemented in LMS Moodle.

Methodical System of Computer Science Teaching at School contains lectures, scientific articles on the methods of Computer Science teaching, articles with the concepts by authors of Computer Science textbooks for school, videos with speeches by scientists and practitioners at thematic conferences, links to video Computer Science lessons, implemented in various conditions of equipping with IT tools and students' needs using various pedagogical technologies, bibliography to be studied by students and links to sources, solving problems examples. These materials can be used to perform sample tasks, the list of which is presented in the resource [Kostousov & Simonova, 2019].

Educational Learning Materials for the Computer Science Lesson at School contains examples of Computer Science teachers' lesson plans, links to video lessons with explanations on how to solve complex problems, links to Internet resources with relevant information on new methods and means of Computer Science teaching at school, a set of computer presentations for lessons dedicated to certain topics, a set of computer models in support of solving cross-subject problems, analysis examples of Computer Science lessons according to specified criteria.

Network Services for Creating Multimedia Educational Content contains detailed instructions for creating graphic illustrations, animations, processing audio and video objects, using freely distributed network services, examples of objects created by students in previous years of study, examples of their use in Computer Science lessons, test tasks for each topic for self-reflection, tasks for independent work. The resource is implemented as a website with free access. The teacher interacts with students via the group in the VKontakte network community. The resource is used by students throughout the whole period of training to create educational learning materials for lessons [Simonova & Ustyugova, 2017].

3.3 Experiment

Two groups of students of Years 2 – 4, trained in the study field of Teacher Education, specialization Computer Science and Information Technologies in Education, Herzen State Pedagogical University, Saint Petersburg, took part in the experiment to assess students' readiness to solve the allocated classes of the problems aimed at algorithmic competence development. The control group consisted of 48 students, while the experimental group numbered 52.

Prior to the experiment, both groups received initial training in Computer Science and Teaching Methods. At the beginning of Year 2, both groups had to solve problems in Computer Science and Methodology, focused on the achievement of various categories of achievement of B. Bloom's pedagogic objectives. Table 3 presents the results of the tasks performed by the students of the control and experimental groups. The analysis of the results (Table 3) shows that there were no significant differences between the readiness levels of students in both groups to solve sample problems. It should be noted that the problems related to the analysis, synthesis and evaluation of data are quite challenging for students. Further training in the experimental group was carried out in the form of blended learning and was based on the application of the described ELR classes. ELRs were not used in the control group. After the modules study completion, the final test was carried out, including the same tasks for both groups. The tasks of the control group were aimed at checking the achievement of B. Bloom's pedagogic objectives [Baranova et al., 2019].

The analysis of the results of the final test (Table 3) showed that the results to achieve all pedagogic objectives in the control and experimental group increased. The increment in the experimental group is significantly higher. On the basis of the data given in Table 3 we obtained the following Fisher's ratio test (F-test) values which are presented in Table 4 that shows differences in students' readiness to solve problems in Computer Science and Methodology focused on achieving different B. Bloom's categories between the experimental and control groups before and after the experiment.

The critical Fisher's ratio test value for 1% of the significance level $\varphi_{cr} = 2.31$ and for 5% of the significance level $\varphi_{cr} = 1.64$. Before the experiment, there were no statistically significant differences

Table 3: Experimental data on the development of students' readiness to solve classes of problems

	Before the experiment				After the experiment			
	Control Group		Experimental Group		Control Group		Experimental Group	
Number of students solving the problems	Number of people	Percentage share	Number of people	Percentage share	Number of people	Percentage share	Number of people	Percentage share
B. Bloom's categories								
Knowledge	37	0.7708	35	0.6731	32	0.6667	50	0.9615
Comprehension and application	39	0.8125	43	0.8269	26	0.5417	40	0.7692
Analysis	27	0.5625	34	0.6538	27	0.5625	44	0.8462
Synthesis and evaluation	15	0.3125	14	0.2692	16	0.3333	27	0.5192

Table 4: Fisher's ratio test value for assessing differences in students' readiness to solve classes of problems between the experimental and control groups

B. Bloom's categories	Fisher's ratio test value (φ – Fisher's angular transformation)	
	Differences between the experimental and control groups	
	Before the experiment	**After the experiment**
Knowledge	1.0939	4.1775
Comprehension and application	0.1875	2.4240
Analysis	0.9364	3.1942
Synthesis and evaluation	0.4763	1.8900

in all four categories of the studied features in the control and experimental groups at the specified significance level, since all empirical Fisher's ratio test values before the experiment were lower than the critical value.

The value of the Fisher's angular transformation after the experiment is higher than the critical value equal to 2.31 to achieve the first three pedagogic objectives and higher than the critical value equal to 1.64 for the fourth objective. Together with the fact that before the experiment there were no statistically significant differences in the control groups, and after the experiment such statistically significant differences appeared, we can claim that — with a probability of 99% — statistically significant differences in the students' training after the experiment were established for the categories: knowledge, comprehension and application, analysis; and — with a probability of 95% —statistically significant differences in the students' training after the experiment were established for the synthesis and evaluation category.

Conclusions

The present study showed that the development of algorithmic competence of future teachers of Computer Science is contributed by:

- the content presented in the modular structure and implemented in a mixed form,
- classes of problems in Computer Science and Methods of its Teaching focused on students' achievement of the pedagogic objectives in B. Bloom's taxonomy,
- the system of electronic learning resources, whose structure and content correspond to the selected classes of problems in Computer Science.

The directions of the research development may be connected with the transfer of the proposed approach to other modules of Computer Science training of teachers, as well as to Computer Science training of specialists of other spheres.

Acknowledgements

The research was supported by the Ministry of Science and Higher Education of the Russian Federation (project No. FSZN-2020-0027).

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