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SOME CRITERIA AND INDICATORS FOR DIAGNOSIS OF THE FORMING OF ALGORITHMIC THINKING IN COMPUTER SCIENCE

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Abstract: The defining of the learning objectives is an important stage in the overall planning, conducting and result evaluation of the education. To operationalize and prioritizing goals and objectives of training are different taxonomies that allow versatile planning activities in the learning process and determination of measurement tools adequate to the set of targets. The paper presents some criteria and indicators for diagnosis of the forming of algorithmic thinking in computer science.

Key words: algorithmic thinking, computer science education, diagnosis of the educational objectives

Mathematics Subject Classification 2010: 97B20, 97Q20, 97Q50

1. Introduction

In the transition towards information society, within the conditions of constant interaction with the computer systems, the algorithmic style of thinking is a necessary basis for the actions of every modern man. The problem solving is inherent for every scientific field and academic discipline. Moreover, each scientific field is defined by the specifics of the problems it addresses, as well as by the methodology it uses for their solving.

As a result of the conducted research [9], observation and study of the scientific literature on methodology [3, 4, 8, 10, 12, 16] and psychology [15], we can come to the following conclusions: the programming is a specific type of human activity, the successful realization of which requires not only practical application of the knowledge and skills acquired during the learning, but it also requires a specific type of thinking; the new and fast changing content of the informatics teaching, requires the developments of methods, which can ensure not only the reproduction of a large volume of knowledge, but most of all the forming and development of competences in the students, which would allow them to actively master this knowledge, and also the building of skills for independent acquisition of new knowledge and its critical rationalization.

One of the major problems of both the theory and practice of the didactic testing is the determination of the objectives and tasks of the educational work, the achievement of which is diagnosed with tests [5]. The defining of the objectives is an important stage of the overall planning, conducting and result evaluation of the education. The concretization of the objectives is called *operationalization*, which is achieved through the respective approaches and methods or by using the existing taxonomies.

2. Structuring the learning objectives in computer science

The task of constructing a scheme for structuring the educational objectives was undertaken for the first time in the USA. In 1956 Benjamin Bloom published taxonomy of the educational objectives for cognitive activities, which proved to be extremely valuable for the diagnostics of the results from the educational work [1]. This theory bears the idea that the objectives and the outcomes of education are not the same. For example, the memorizing of the scientific facts, regardless of their importance, is at a lower level than the skills for their analyzing and evaluation. Bloom offers six levels: knowledge, comprehension, application, analysis, synthesis, evaluation. Many cognitive psychologists work on the development of more precise and adequate taxonomy for the basic cognitive conceptions and level of thinking.

The educational taxonomies, especially the Bloom's taxonomy for the cognitive activity has a significant effect on the development of educational programs in the last 50 years. Their application and use, however, creates a number of difficulties. The classification of the learning outcomes and the tests outcomes depends on their context. A task, which makes difficult the application of analysis and synthesis by a beginner in the field of educations, becomes a routine in the application of knowledge by more advanced trainees [11]. In the same way, a student, who is trained how to solve problems, which are extremely similar to the given tests, will demonstrate skills, which are at a lower level in the hierarchical taxonomy, than those demonstrated by a student, who has been solving problems based on principles.

These problems are general for all fields of education, but a number of educators [6] note that in teaching computer sciences, there also appear specific difficulties. They have established that the classical taxonomy is not suitable for evaluation of practical skills and determining the relevant difficulty of the cognitive tasks in the field of the computer sciences. A significant number of researchers believe that it is easier to apply the knowledge for solving simple problems, than to describe this knowledge. Moreover, they have established that the computer sciences lecturers do not find the terms “synthesis” and “evaluation” as the most important in describing the learning outcomes and the evaluation of the tasks in the programming courses, especially at the basic level of education. Instead, they see the application of knowledge as the highest skill, which the trainees should develop.

In 2001 Anderson and Krathwohl [1] specify and develop the taxonomy suggested by Bloom, emphasizing more on the *creative paradigm, in which the intellectual development is studied as a change of the thinking pattern of the trainees.* The new taxonomy makes distinction between knowledge on *what* “contains the cognitive activity” and knowledge on *how, i.e. the procedures used for solving the problems*. The skill to combine elements in order to obtain something new suggests creative activity with creation of new schemes and structures. In the words of one of the creators of the extended taxonomy, “You may be able to think critically – to support your position, to draw conclusions etc, without having creative skills, but the creative activity – to prove or reject ideas, to create new ideas, often requires critical thinking” [11].

Although the taxonomy of Anderson and Krathwohl is not the only possible way to classify the levels of thinking, it has a clear structure, facilitates the organization process of the intellectual development education, starting with the initial stage of mastering techniques for thinking activity, transition towards intellectual operations at a higher level and adopting habits for highly organized thinking. The cognitive objectives of the extended taxonomy have universal nature and could be applied in programming teaching.

3. Criteria and indicators for diagnosis of the forming of algorithmic thinking in computer science

According to the adopted by the European Qualification Framework (EQF) definition, the learning outcome is defined as an indicators of what the trainee knows, understands and is able to do on completion of the learning process [3].

Therefore, the emphasis is on the learning results, which are specified in three categories – knowledge, skills and competence. Within the context of EQF, competence means the proven ability to use knowledge, skills and personal, social and/or methodological abilities, in work or study situations and in professional and personal development.

The initial teaching of informatics and information technologies must form not only the basic concepts, skills and habits to work with computer, but also to provide development of certain style of thinking.

Thinking development in the learning process means the forming and the perfecting of all types, forms and operations of thinking, development of skills and habits of applying the laws of thought in the cognitive and learning activities, as well as habits to transfer the intellectual activity methods from one area of knowledge to another [2]. Most generally, the schematic and the intellectual development of the student may be described and understood through the categories of the knowledge – thinking – ability and the motivation of the mental self-development [14]. The volume of the knowledge defines the horizon, the parameters, and the limits, on which the thoughts and the fantasies of man spread. The knowledge is a necessary condition for the correct and sufficient thinking processes – comparison, analysis and synthesis, generalization and concretization. The correct management of these processes contributes for perfecting and enrichment of the knowledge [13]. Therefore, the thinking may develop when there is a certain amount of acquired knowledge.

After a research and analysis of the literary sources on psychology, didactics and methodology, as well as observations and experiment with students, we have determined the content of the concept of algorithmic thinking (AT) and formulated its main components [17]. We can define the algorithmic thinking as a way of thinking, which provides a solution for a specific task through a succession of elementary actions. AT consists of a wide range of abilities and is affected by many other cognitive factors. The initial course on informatics must introduce the students to the technology of design, developing and application of a computer program, to create habits, which may be applied and developed while learning other informatics disciplines. At the same time, the introductory courses must present the students to the basic intellectual aspects of the computer science [8]. The algorithmic thinking components are: analyzing – determining the initial condition, target, hypothesis and limitations; decomposition – dividing the problem to sub-problems and determining the basic solution operations; formalization in order to create a model – reformulating the problem with computer science terms, creating an algorithm and defining the relation between the subtasks; comprehension and applying formal ways for recording the algorithms; execution of a certain algorithm through formal and precise execution of the main activities; algorithm analysis in order to determine the optimal solution; modification of the known algorithms for their application in new situations; creation of a new (unknown) algorithm.

For the obtaining of objective information regarding the accessibility of the suggested educational content and the efficiency of the developed educational methodology, aimed at the development of algorithmic thinking, are necessary criteria and indicators for evaluation of the learning outcomes. The traditional structure of conducting pedagogical experiments includes three stages [5]: preliminary (ascertaining) experiment, procedure (forming) experiment and concluding experiment. The objective is to follow the development of the results from applying the constructed methodology. Since the suggested methodology includes the content of the course on “Basics of the Computer Science” and “Programming”, it is very difficult to create criteria and indicators for preliminary evaluation of the trainees, which could be used in both experiments – the ascertaining and the control experiment. The reason is the fact that in the last two stages of the experiment are observed concepts and algorithms, which cannot be known to the trainees preliminary and the degree of their mastery cannot be followed at the ascertaining stage. That is why most of the indicators used for the evaluation of the outcomes are with changed formulation for the preliminary and the concluding experiment (Table 1). For the operationalization of the objectives is used the extended Bloom’s taxonomy.

The main questions, which must be answered, are related to whether the objectives re achieved, what is the efficiency of the learning work, how good is developed the educational environment and technology of teaching, etc.

The result of the survey of the teachers in Computer Science at Plovdiv University regarding the degree of significance of the named skills and objectives for the basic training of the students in the major “Informatics” is shown in Fig. 1. The five-level Likert scale was used: 5 = Strongly agree, 4 = Agree, 3 = Neither agree nor disagree, 2 = Disagree, 1 = Strongly disagree. The received results show that as most important are considered the skills for problem analysis and algorithm analysis, followed in significance by the skills for formalization, abstracting from the specific input data and proceeding to the solution of the task in general aspect, as well as the using of general algorithm for solving a specific problem. The lecturers consider the creation of a new (unknown for the students) algorithm as difficult and less significant activity in the teaching of computer science and accentuate on the analyzing and formalizing skills.

The developed criteria and indicators for diagnosis of the outcomes form the pedagogical experiment are consistent with the expert evaluation of the computer science teachers.

Table 1. Criteria and indicators for diagnosis of results

№ crit	**NOTES EXPERIMENT**	**SUBSEQUENT EXPERIMENTS (INTERMEDIATE AND FINAL)**
Criterion I: Knowledge and skills related to problem solving		
1.	Ability to analyze problems and formulate key objectives.	Ability to analyze, define problems and identify appropriate data types.
2.	Ability to divide a problem into simpler components.	Ability to decompose problem into subtasks which decision can be differentiated into subroutines.
3.	Ability to define and use standard data types.	Ability to define and use abstract data structures (arrays, structures, strings, ...)
4.	Ability to implement linear and branched algorithm using standard data structures.	Ability to implement basic algorithms on abstract data structures.
Criterion II: Knowledge and skills related to understanding and implementing the algorithm		
5.	Understand and monitor the implementation of the elementary steps of the algorithm.	Understand and monitor the implementation of a program.
6.	Understands and explains the results of simple programs involving fundamental structures.	Understands and modifies the algorithm in context.
7.	Ability to implement the algorithm (program) with a specified input.	Ability to define an appropriate data structure and algorithm performs (execute).
8.	Ability to detect and correct syntax errors.	Ability to test and adjust a program and correct the errors in the algorithm.
Criterion III: Knowledge and skills related to analysis of algorithms		
9.	Analyze the correctness of basic algorithmic structures.	Analyze the correctness of the algorithm (first or otherwise).
10.	Compares various simple data structures and basic algorithmic structures.	Evaluates the effectiveness of the algorithm (time and memory use).
11.	Compares and analyzes different solutions to a problem.	Compares and analyzes different solutions to a problem.
12.	Ability to conduct a computer experiment and analyze results.	Ability to experiment, analyze the obtained results and correct input data if necessary.

The suggested criteria for evaluation of the AT formation are approbated during the lectures with first-year students in the major "Informatics" at the Faculty of Mathematics and Informatics at the Plovdiv University for the period 2009 – 2011. The teaching methodology used on the experimental group has achieved significant results. The main indicator for this is the statistical significance of the interaction effect between the factors of measurement stage and belonging to a control or experimental group.

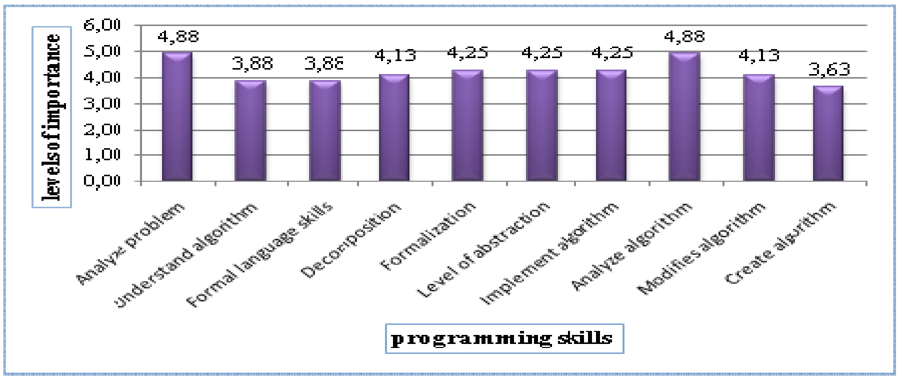

Figure 1. Results of a survey of teachers in Computer Science

4. Conclusions

The main educational activities, related to the forming of skills for problem analyzing, algorithm comprehension and execution, as well as algorithm analyzing are at higher cognitive level. They are exclusively *procedural and metacognitive type of knowledge*, and the levels of the cognitive process are also from a higher level – analysis, synthesis, evaluation. Therefore special efforts are needed for the forming and the perfecting of these skills. In our opinion the introductory courses on informatics must:

- introduce the students to the basic conceptions of the computer sciences;
- contribute for the development of the cognitive models of these conceptions;
- encourage the development of the students' skills, necessary for the application of conceptual knowledge.

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КРИТЕРИИ И ПОКАЗАТЕЛИ ЗА ДИАГНОСТИКА НА ФОРМИРАНЕТО НА АЛГОРИТМИЧНО МИСЛЕНЕ В ОБУЧЕНИЕТО ПО ИНФОРМАТИКА

Тодорка Терзиева

Резюме. Определянето на целите на обучението е важен етап от цялостното планиране, провеждане и оценка на резултатите от обучението. За да се операционализират и степенуват целите и задачите на обучението се използват различни таксономии, които позволяват разностранно планиране на дейностите в процеса на обучение и определяне на оценъчни инструменти, адекватни на поставяните цели. В изследването се представят някои критерии и показатели за диагностика на формирането на алгоритмично мислене в обучението по информатика.