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PEDAGOGICAL MODELS FOR PREPARING GIFTED AND EXTRA-GIFTED STUDENTS FOR NATIONAL AND INTERNATIONAL COMPETITIONS IN INFORMATICS

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Summary. It is argued the need to develop new pedagogical models for preparing gifted and extra-gifted students for national and international competitions in Informatics. The models in question have to be based on a common structure and be oriented towards the development of an extended set of competences specific to Informatics and Mathematics, competences which cannot be found in the national curriculum. The teaching strategies will be based mainly on simultaneous teaching, self-learning and the creation of simulated competition environments.

Key words: Informatics, Olympiads, specific competences, pedagogical models, didactic strategies.

MODELE PEDAGOGICE DE PREGĂTIRE A ELEVILOR DOTAȚI ȘI SUPRADOTAȚI PENTRU COMPETIȚIILE NAȚIONALE ȘI INTERNAȚIONALE DE INFORMATICĂ

Rezumat. Este argumentată necesitatea elaborării unor noi modele pedagogice de pregătire a elevilor dotați și supradotați pentru competițiile naționale și internaționale la Informatică. Modelele în cauză trebuie să se bazeze pe o structură comună și să fie orientate spre formarea unui set extins de competențe specifice Informaticii și Matematicii, competențe ce nu se regăsesc în curriculumul național. Strategiile didactice se vor baza, în principal, pe predarea simultană, învățarea de sine stătătoare și pe crearea de situații simulate de competiție.

Cuvinte cheie: Informatică, olimpiade, competențe specifice, modele pedagogice, strategii didactice.

Short history

In Republic of Moldova every year, starting with 1985, the Republican Informatics Olympiad is held. On the whole, the problems proposed to the competitors at these national competitions are algorithmic in nature and require from the competitor the development of computer programs that would conform to predetermined memory and execution time restrictions. For the most part, the knowledge and skills required to be mastered by competitors fall within the school course of Informatics, the high school level of general education. Ten years after the launch of Republican Olympics in Informatics, Republic of Moldova also started participating in the International Olympiad in Informatics (IOI), this had a profound impact on both the teaching of Informatics within our country and on the preparation processes of students for national and international competitions. Obviously, with the development of Informatics as a science and the improvement of its teaching-learning-evaluation methods as a school discipline, the need has emerged to systematize

the process of preparing gifted and extra-gifted students and to base it on the principles of constructivist learning.

Article goal

The purpose of this article is to develop a pedagogical model for the training of gifted and extra-gifted students for national and international competitions in Informatics, based on the principles of constructivist learning and the full exploitation of the opportunities offered by the new computer-assisted training systems.

Comparative analysis of the IOI Sylabus and the Informatics school curriculum in Republic of Moldova

It is a known fact that the International Olympiad in Informatics is held on the basis of a curriculum approved by the International Scientific Committee, a document which is updated practically every[1]. This document, de facto, only contains what knowledge (content) the IOI participant must possess, without making an explicit reference to his/her competences. The contents in questioner are grouped into the following areas of knowledge: Mathematics; Computing Science; Software Engineering; Computer Literacy.

Until 1999, Informatics, as a school discipline, was taught on the basis of programs which only listed the contents to be learned, without explicitly formulating learning objectives and the competences expected to be trained and developed in students. Starting with the year 2000, the teaching of Informatics in Republic of Moldova schools was carried out on an objective-based curriculum, starting with 2010 – on the basis of a competency-based curriculum. Currently, starting with the 2019/2020 school year, the teaching of Informatics in the Moldovan schools is based on a modernized curriculum, which is also based on competences [2].

Unlike IOI Syllabus, the central pillar of the National Informatics Curriculum consists of a set of digital competences, formulated according to the following definition:

> "School competence is an integrated system of knowledge, skills, attitudes and values which are: acquired, formed and developed through learning; whose mobilization allows identifying and solving different problems in diverse contexts and situations" [3].

Since the contents of the School Curriculum in Informatics are only recommendations, a direct comparison with the IOI Syllabus is difficult. However, starting from the fact that knowledge is an indispensable component of the "integrated system" that constitutes the actual competence, an indirect comparison of the documents in question is possible. For this purpose, we will treat the contents as connecting elements that lead to digital competences [4], implicitly assumed by IOI Syllabus and explicitly stated in the school curricula in Informatics and Mathematics.

Table 1. The knowledge required by IOI Syllabus and the school curricula in Informatics and Mathematics

IOI Syllabus Topics	School curricula	
	Informatics	Mathematics
Arithmetics and Geometry	-	+
Functions, relations, and sets	-	*
Basic logic	+	+
Proof techniques	-	*
Basics of counting	-	+
Graphs and trees	-	-
Programming Fundamentals	+	-
Algorithms and problem-solving	+	-
Fundamental data structures	*	-
Recursion	+	-
Event-driven programming	-	-
Basic algorithmic analysis	+	-
Algorithmic strategies	*	-
Algorithms	*	-
Data structures	*	-
Automata and grammars	+	-
Geometric algorithms	*	*
Software design	-	-
Using APIs	-	-
Software tools and environments	+	-
Software processes	-	-
Software requirements and specification	-	-
Software validation	-	-
Software project management	-	-
Formal methods	-	-
Computer Literacy	*	-

Legend: “-” – missing; “+” – is studied in full; “*” – is partially studied.

From the data presented in the table above it can be concluded that the school curricula in Republic of Moldova does not cover all the topics required by IOI Syllabus and, consequently, the preparation of students for participation in international competitions requires teaching-learning-evaluation activities that cannot be carried out only based on the classical pedagogical models, currently used in general education.

Typology of problems proposed to students in the Republican Olympics in Informatics

The analysis of problem statements proposed to the students in Republican Olympics in Informatics during the 2010-2019 years, shows that they can be classified, with small exceptions, in the following categories: Combinatorics; Computational graphics; Graphs; Computer arithmetic; Information theory; Simulation; Formal grammar.

A very small number of problems, especially those of advanced complexity (about 5% of those proposed to the competitors of said competitions), relate to two and even three of the categories listed above. Such were the problems attributed to each of the respective categories.

From the data presented in Figure 1 it is observed that most problems, 29.2% of those proposed to contestants, are in the field of combinatorics, the students having the task of implementing a programming technique (Greedy, Backtracking, Divide et Impera, etc.) which would count, generate, analyze or determine the "largest", "smallest" or "best" object from an set. We emphasize that the mathematical and informatics fundamentals of this type of problems are indeed studied within the respective school disciplines.

Formally, the problems in the following weight categories – Computational graphics (20.0% of proposed to competitors) and Graph theory (18.5%) cannot be solved based on only the subjects studied in the school disciplines of Mathematics and Informatics. Despite this fact, annually about 5-10% of contestants solve such problems in full, which once again confirms the significant role or formal, non-formal and informal extracurricular preparation of students gifted and extra-gifted in Informatics.

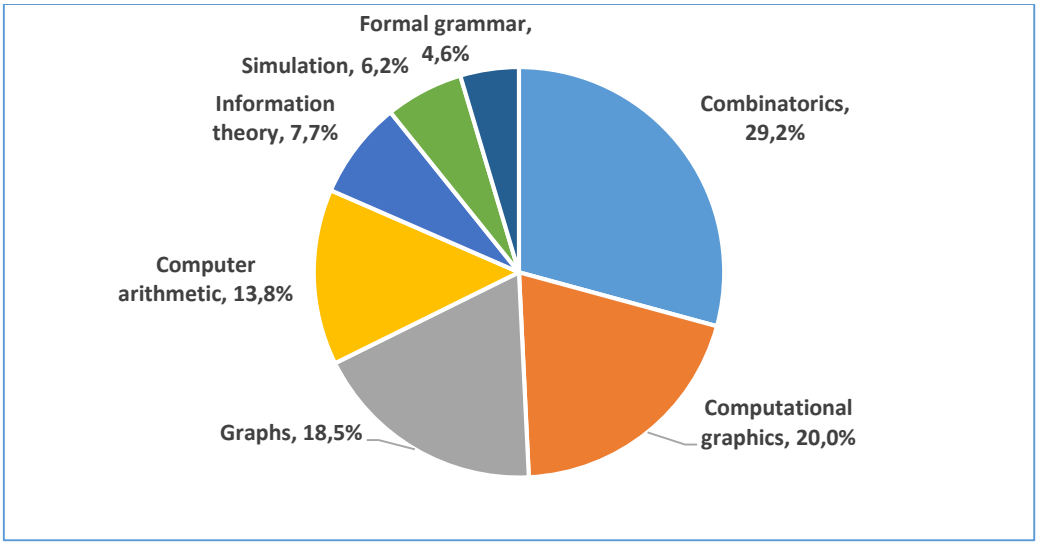

Figure 1. Distributions of problems proposed to contestants in the Republican Olympics in Informatics (years 2010-2019, high school grades)

The remaining problem categories – Computer arithmetic (13.8%), Information theory (7.7%), and Formal grammar (4.6%) – can surely be solved based on the subjects studied in the school disciplines of Informatics and Mathematics, however, as evidenced by the student results at Republican Olympics in Informatics from 2010-2019, their power

of competitor ranking is reduced. An exception to this rule is attested by the results from the Simulation (6.2%) problem category, solving which requires from competitors not only the application of traditional programming techniques, but also of creative approaches.

The skill set required to be developed as a priority in the process of preparing gifted and extra-gifted students for national and international competitions in Informatics

According to the regulation in force [5], the subjects proposed to students in general education competitions must comply with the provisions of the school programs and be related to their higher demands, both in terms of objectives volume and their degree of complexity.

We emphasize that in the framework reference of the national curriculum the term "programs" has the meaning of "curricula by disciplines". Therefore, students who would be selected only on the basis of national competitions, conducted off the "school curricula", would by definition not be prepared to participate in international competitions. Moreover, the experience of organizing and conducting the 32 Republican Olympics in Informatics clearly demonstrates that the use of only the subjects that correspond to the school programs does not even allow the classification (ranking) of students according to their performances, as such topics are solved within 20-30 minutes by most contestants. Therefore, the pedagogical model expected to be developed must be based on a broader interpretation of the term "school programs", including in them subjects studied in extracurricular activities, such as: Informatics clubs (groups) in educational institutions and student creativity centers, the numerous projects implemented by big companies in the field of information technology and communications, the online programming projects implemented by enthusiasts in the field of computer science, etc.

At the same time, in the process of preparing gifted and extra-gifted students for national and international competitions in Informatics, emphasis will also be placed on the formation and development of transversal key-competences, as explicitly indicated in both national documents [6, 7], and in European ones [6]. In particular, we will insist on two of them, as defined in Council Recommendation of 22 May 2018, specifically (1) Personal, social and learning to learn competence, and (2) Entrepreneurship competence. According to this document, the respective competencies are defined as follows:

> „*Personal, social and learning to learn competence* is the ability to reflect upon oneself, effectively manage time and information, work with others in a constructive way, remain resilient and manage one's own learning and career. It includes the ability to cope with uncertainty and complexity, learn to learn, support one's physical and emotional well-being, to maintain physical and mental health, and to be able to lead a health-conscious, future-oriented life, empathize and manage conflict in an inclusive and supportive context.
>
> *Entrepreneurship competence* refers to the capacity to act upon opportunities and ideas, and to transform them into values for others. It is founded upon

> creativity, critical thinking and problem solving, taking initiative and perseverance and the ability to work collaboratively in order to plan and manage projects that are of cultural, social or financial value" [8].

An advanced development of especially these skills would allow students to go beyond the limits imposed by the school programs and to acquire, by themselves or under guidance, the subjects that cannot be found in the Mathematics or Informatics curriculum, but explicitly assumed by the IOI Syllabus.

We emphasize that the training of gifted and extra-gifted students for national and international competitions in Informatics involves the formation and development of a set of competences required to act autonomously. The set in question is explicitly defined in the documents of OECD (Organization for Economic Co-operation and Development) [8, 9] and assumes:

- Act within the big picture;
- Form and conduct life plans and personal projects;
- Defend and assert rights, interests, limits and needs.

In the case of preparing students for national and international competitions in Informatics, a very important role belongs to the competence of *Form and conduct life plans and personal projects*, defined in the documents cited above as follows:

> "This competency applies the concept of project management to individuals. It requires individuals to interpret life as an organized narrative and to give it meaning and purpose in a changing environment, where life is often fragmented. This competency assumes an orientation toward the future, implying both optimism and potential, but also a firm grounding within the realm of the feasible. Individuals must be able, for instance, to:

- Define a project and set a goal;
- Identify and evaluate both the resources to which they have access and the resources they need (e.g. time and money);
- Prioritize and refine goals;
- Balance the resources needed to meet multiple goals;
- Learn from past actions, projecting future outcomes; and
- Monitor progress, making necessary adjustments as a project unfolds" [7].

Obviously, in the process of preparing for national and international competitions, the student must have the ability to define as specifically as possible the goals to be achieved, to stagger the activities to be carried out over time, to rationally use the available time resources, to prioritize and redefine the goals. At the same time, it requires the development of resilience to stress, awareness of own limits and objective evaluation of own achievements.

Overall, the set of skills needed to be developed as a priority in the process of preparing gifted and extra-gifted students for national and international competitions in Informatics will include:

- Scientific perception of the role and impact of Informatics phenomena in the contemporary society;
- Use of informatics and mathematical concepts, methods and algorithms in various application contexts;
- Applying informatics and mathematical reasoning in identifying and solving problems;
- Exploring problem situations through modeling, planning and conducting virtual experiments within digital environments;
- Developing strategies and designing activities for solving problems and problem-situations;
- Algorithmization of methods of analysis, synthesis and solving of problem-situations;
- Implementation of algorithms in programming environments;
- Analysis of problem solving, problem-situations in the context of correctness, simplicity, clarity and significance of results.

The taxonomies used to establish the objectives of student preparation

In the National Curriculum of the Republic of Moldova, the basic taxonomy recommended for establishing the learning objectives is that of Bloom-Anderson [10]. We'd like to remind you that in this taxonomy the following hierarchical levels of cognitive abilities are established: (1) remember; (2) understand; (3) apply; (4) analyze; (5) evaluate and (6) create. The complexity of the cognitive capacities increases with the progression from the lower hierarchical level (reproduction) to the higher one (creation). Starting from the fact that in the process of teaching-learning-evaluation the emphasis must be placed not only on the formation of the cognitive competences, but also of the functional-actionable ones, the Curriculum of Informatics for general education in the Republic of Moldova also proposes the use of Simpson's taxonomy [11], especially of the higher levels: Adaptation (adapts, alters, changes, rearranges, reorganizes, revises, varies) and Origination (arranges, combines, composes, constructs, creates, designs, originates).

Worth mentioning that on the Internet there are works that try to adapt Bloom's taxonomy to the specifics of digital skills training and development. Initially the works in question were referring to digital literacy [12], but subsequently they included the development of algorithms and their implementation on the computer [13]. Thus, in the case of the Analyzing level we will mention the action words: Calculating, Estimating, Integrating, Planning, Structuring; in the case of the Evaluating level – the action words: Assessing, Checking, Detecting, Measuring, Monitoring, Testing, Validating; in the case of the Creating level, the action words: Composing, Designing, Developing, Integrating,

Inventing, Making, Originating, Producing, Programming, Publishing, Simulating, Solving etc. Obviously, these verbs should be used to define the learning and evaluation objectives when preparing gifted and extra-gifted students for national and international competitions in Informatics.

The structure of the pedagogical models for preparing the gifted and extra-gifted students in Informatics

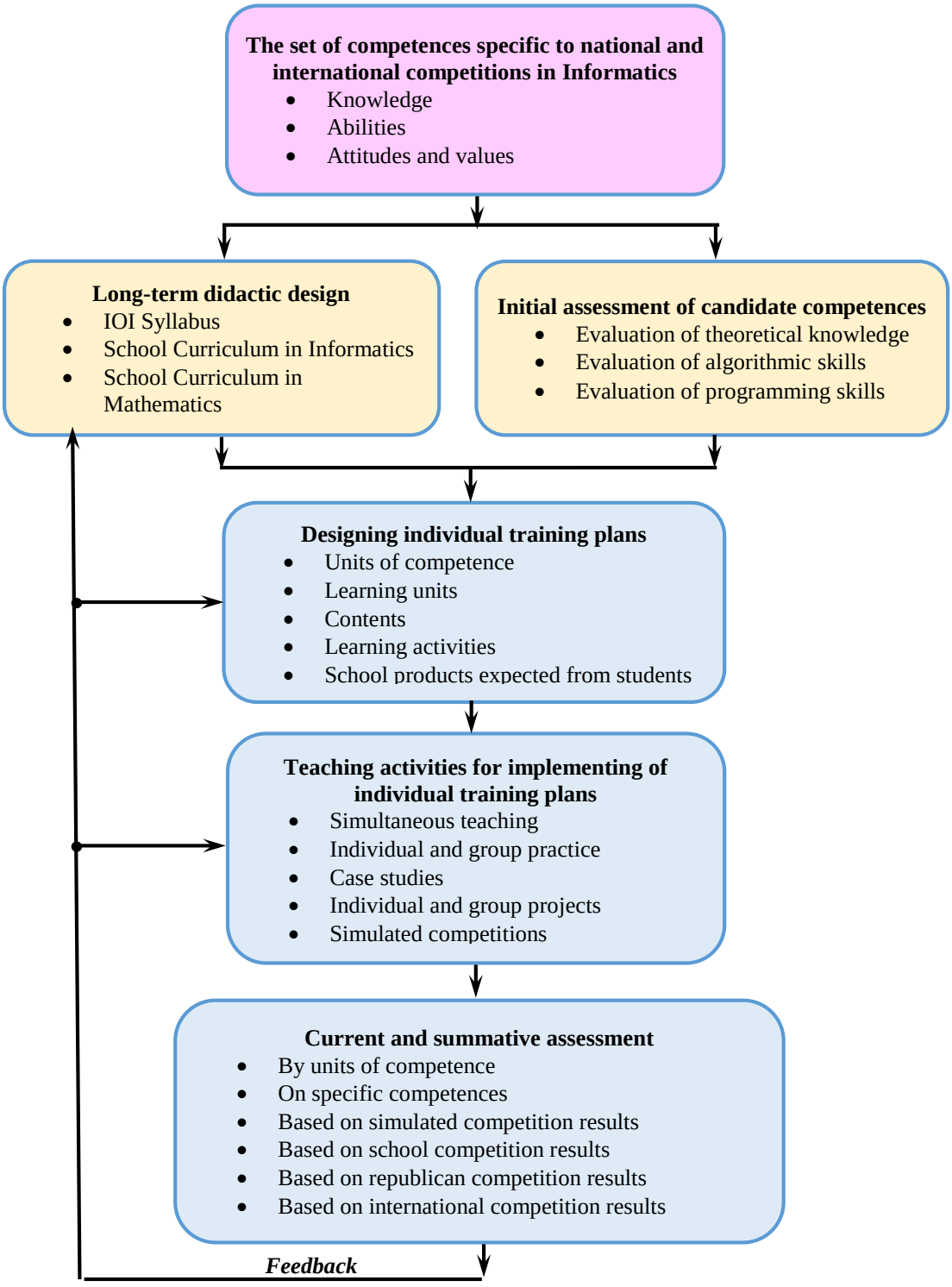

Figure 2. The structure of the pedagogical models for preparing the gifted and extra-gifted students in Informatics

The structure presented in figure 2 allows the generation of several pedagogical models for preparing gifted and extra-gifted students for national and international competitions in Informatics. The models in question are obtained through the concrete set of skills to be trained and developed in students according to their initial level of education and age groups of participants: if junior or senior for international competitions, grammar school or high school classes in the case of national competitions.

The long-term didactic design will aim to narrow down the specific skills for the initial and continuous training of gifted and extra-gifted students in Informatics, with the emphasis being on:

- Algorithmizing methods of analysis, synthesis and solving of problem-situations, educating in students creativity and perseverance;
- Implementation of algorithms in programming environments, training students in concentration and resilience;
- Exploring problem-situations through modeling, planning and conducting virtual experiments in digital environments, educating in students the analytical spirit, clarity and brevity.

Depending on the initial level of mastery of the mathematical and informatics skills required by IOI Syllabus, for each of the students an individual Training Plan will be developed, which will ensure that each of them will progress at their own pace. The teaching strategies (the forms of organization, the teaching resources, the methods of current and summative evaluation) will be based, mainly, on the simultaneous teaching, the learning on their own and on the creation of simulated competition situations. In order to develop students resilience to stress, the simulated competition environment will be similar to those that they would meet in the national and international competitions in Informatics, with the same style of problem statements, same methods of evaluation, and same style of interaction with the jury and the scientific committee.

The evaluation models used in the training of gifted and extra-gifted students in Informatics will be based on the criterion of appreciation, i.e. they will provide functional information, mobilizing students on achieving the expected objectives, to create those computer programs that comply with the restrictions imposed in the competition problem statements, while offering, at each stage, improvement solutions. The models used for the evaluation must have a corrective character, which offer the students opportunities to improve the developed products according to the feedback received from the teaching staff.

As a whole, the didactic activities required to realize the individual Training Plans must be based on the large-scale use of means and methods of computer-assisted training, using for this purpose interactive multimedia lessons, automatic knowledge testing systems, content management systems, learning management systems. It is important that the development of computer programs, their testing and debugging, the evaluation of the

programs by the teachers will be carried out in development environments similar to those used in international informatics competitions.

Conclusions

The organization of national and international competitions in Informatics only on the basis of general education school curricula does not ensure the ranking of competitors. The lessons learned during the organization of such competitions in the Republic of Moldova (years 1985-2019) and our country's participation in international competitions (years 1996-2019) confirm that the training of gifted and extra-gifted students in Informatics should be based mainly on extracurricular activities. There are significant differences between the national curriculum in Informatics and Mathematics and the IOI Syllabus, the latter including subjects characteristic of university education. This fact argues the need to develop and implement pedagogical models for the training of gifted and extra-gifted students for national and international competitions in Informatics oriented to the formation and development of an extended set of specific competences in Informatics and Mathematics and to organize the teaching-learning-evaluation process according to individual Training Plans. The teaching strategies will be based mainly on simultaneous teaching, self-learning and the creation of simulated competition situations.

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