Supporting Computer Science Education through Competitions

Valentina Dagiene

Department of Informatics Methodology, Institute of Mathematics and Informatics, Lithuania, dagiene@ktl.mii.lt

Abstract: The paper discusses the issue of supporting computer science (mainly focusing on programming) education through competitions for secondary school students. Competitions play an important role for learners as a source of inspiration, innovation, and attraction. When students start learning the basic concepts of computer science, they very soon can find a place where they are able to demonstrate their skills, share their interests, and to compare themselves with others. Running competitions in computer science for lower and upper secondary school students for more than twenty years (Dagiene, 2006b), we have noticed that the students consider the contest experience very engaging and exciting as well as a learning experience. Programming is a rapid, specific, and suitable way for students to gain experience of solving problems. Organizing contests is an excellent instrument to achieve this goal. An overview of infrastructure and development of competitions from international and regional levels to the national one (Lithuanian) is presented in short. Developing a contest from the national level to an international one is described here as well (the Bebras contest on informatics and computer literacy, originated in Lithuania). In the paper, the main attention is paid to the peculiarities and good practice in developing programming skills and motivation among students through Olympiads and other contests in computer science (informatics). Interest in competitions essentially depends on the problems. Attraction, invention, tricks, surprise should be desirable features of each problem presented to participants. Generating and designing interesting tasks (problems) is one of the most important issues bringing students into the Olympic movement. The paper discusses the problems of program (actually, code) evaluation (testing) during competitions, and online judge services.

Keywords: Secondary Education, Competition Paradigm, Computer Science, Programming, Problem Solving

1. Introduction

Developing abilities to master modern technologies and skills for solving problems is among the most important capabilities of an educated future citizen of

an information society. Problem solving by means of programming does not lose its importance in a contemporary school equipped with modern information technologies and it will remain as a very important part of understanding the information processing. Programming with the emphasis on algorithms remains the core of International Olympiads in Informatics (IOIs).

Programming is an activity made up of many components: comprehension of the problem, encoding it, debugging, and verification. Since many of the skills required for successful programming are similar to those required for effective problem solving, computer programming and particularly choosing one of several possible solutions and later debugging in a short period of time provides a fertile field for developing and practicing problem solving skills in an environment that is engaging for young students (Casey, 1997).

Competition makes teaching of computer science (especially programming) more attractive for students. Furthermore, computer programming is one of the appropriate and effective ways to develop problem solving skills for computer science learners (Dagiene, 1999). During contests students meet their peers from all over the country (or countries), make friends, and wait for the next competition ready to show their abilities which have improved since the last competition.

The contest on informatics and computer literacy named BEBRAS ("Beaver") may be the key to the potential of science knowledge and an attractive way to bind up technology and education. The Bebras International Contest on informatics and computer literacy is a motivation competition in informatics that addresses all lower and upper secondary school pupils divided into three age groups: Benjamin, age 11-14, Junior, age 15-16, and Senior, upper secondary level (Dagiene, 2005, 2006a, 2008a, 2008b).

2. International Contests on Programming for Secondary Education

There have been many academic contests throughout many years over the world. Contests are extracurricular activities that allow students to acquire their knowledge and understanding from the classroom and apply it within a competitive environment. These types of activities provide ways of challenging students in creative and innovative ways.

There are two main paradigms for developing competitions: from an international level to the local one (top-down strategy), and vice versa, from local activities to an international promotion (bottom-up strategy). The first paradigm is a challenge to find some suitable international contests, analyze, train students, and join them after intensive work. The second paradigm stresses an opportunity to establish the local contest and attempt to develop it to an international level. The IOI is a contest referred to the first competition paradigm while the Bebras International Contest on Informatics and Computer Literacy belongs to the second paradigm.

The IOI is one of the five international science Olympiads initiated by UNESCO in 1987. It is an annual international informatics competition for individual contestants from many countries over the world, accompanied by social and cultural programs (IOI Regulations, 2005). The IOI is modeled after the International Mathematical Olympiad (Horvath, 2003).

2.1 International Olympiads in Informatics

The primary goal of the IOI is to stimulate interest in computer science. The contest brings together exceptionally gifted students from various countries and to renders an opportunity them to share scientific and cultural experiences. To discover, encourage and train exceptionally talented young people in computer science is one of the main objectives in each country (Pohl, 2002).

The IOI is managed by the General Assembly, a temporary, short-term committee which is composed of the leaders of all the participating countries and by two long standing committees. They are the International Committee, which consists of representatives of the past, present, and future IOI's as well as several elected representatives. Its task is to retain the continuity of the IOI by finding future host countries. The second committee is the IOI Scientific Committee, the task of which is to ensure continuity and quality control of the IOI competitions (IOI Regulations, 2005).

The IOI is organized in and by one of the participating countries. Each participating country typically sends a delegation of four students accompanied by two leaders. Students are usually selected in the national Olympiads in informatics. Each of the two competition days lasts for five hours.

These competitions focus on informatics problems of an algorithmic nature. In the scope of IOI the concept *Informatics* means a domain that is also known as computer science, computing science and information technology, but not the domain of computer engineering.

The students compete individually and try to maximize their score by solving a set of problems during two competition days. The IOI contestants are required to express their algorithms in one of the allowed programming languages and they must engineer their programs to run flawlessly, because marking is based on automated execution (Verhoeff, 2002).

2.2 Regional Olympiads in Informatics

In order to ensure better preparation for the IOI and to strengthen regional relations, various regional Olympiads are being organized (e.g. African, Central European, Baltic, and Balkan Olympiads). While the national Olympiads represent informatics teaching traditions of each country, the regional Olympiads are

usually a mini model of the IOI, allowing the participants to experience what they will come through in the IOI.

The Baltic Olympiad in Informatics (BOI) was established on the initiative of three Baltic countries (Estonia, Latvia, and Lithuania). The BOI is an informatics (programming) competition for school students from the countries around the Baltic Sea. The main goals are: to provide the participating students with experience of an international competition; to encourage communication and exchange of ideas between the organizers of national programming competitions; to assist team leaders in selecting members for the IOI team based on the students' results in a competition similar to the IOI.

The BOI is a short-term (lasting 3-4 days) and inexpensive event. It can be distinguished for cozy and good neighborly atmosphere, which is highly important when motivating students for self-help.

Even though the BOI is a mini-model of the IOI, it has significant differences from the cultural and learning perspectives. The organization of the scientific part of BOI's is based on mutual trust of the participating countries. The leaders of all the participating countries offer problems for the nearest BOI. At first draft problem texts are offered, then the ideas are exchanged via e-mail, discussed, some problems rejected, while other problems are suggested to be modified and later are accepted. Most of the problems are translated to the native languages by the leaders before going to the BOI. This is a unique possibility for country representatives to gain experience in organizing the scientific part of a small international Olympiad as well as to raise their qualifications in algorithms.

The BOI is also a form of learning for its participants. On the one hand, they come to the BOI ready to gain some international experience after participating in the domestic contest. On the other hand, they know that their final destination is the IOI, and they try to learn as much as possible in the BOI. The organizers of BOI's try to follow as close, as possible, the newest IOI trends in problem types, compilers, platforms, and contest systems. Even though all the tasks are of the algorithmic nature they represent cultural and methodical differences. Since in the BOI much preparatory work has been done in advance, team leaders can discuss the tasks, possible solutions, technical issues, the BOI can be considered as a pre-arranged international way of learning.

2.3 Lithuanian Olympiad in Informatics

The first Lithuanian Olympiad in Informatics was organized in 1990, one year later than the first IOI. It was organized as a continuation of competitions at the Young Programmer's School (Dagiene, 2006b).

Since 1996 two difficulty levels (junior and senior) have been introduced and the students are ranked to those levels according to their grades, and since then only senior participants can qualify for the IOI. Starting from the same year the Olympiads are organized in four rounds.

The first round takes place at school and any willing secondary school student can participate in it. The school evaluation committee is responsible for tasks, evaluation, programming languages, compilers.

The second round is regional and the best first round contestants are invited to participate in it. The municipality school-boards are responsible for the organization of this round. The National Examination Centre (NEC) proposes possible tasks for the first and second rounds, but the local organizers are free to use them or not.

The third and the fourth rounds are the national rounds and are organized by the Lithuanian Ministry of Education and Science. From 200 to 300 contestants (regional round winners, there are 60 municipal regions in Lithuania) participate in the third round, so under Lithuanian conditions it would be a difficult task to organize a face-to-face competition with such a number of contestants.

Therefore the third round is an e-mail or an internet (since 2004) round. The tasks are prepared in advance, and distributed on the competition day through municipality school-boards. The third round starts on the same day and at the same time all over Lithuania. After five hours of competition, the solutions are sent to the NEC by e-mail or Internet. The top students are selected and invited to the fourth, face-to-face round. It lasts about a week with two competition days. The problems are similar to that of the IOI, representing the national trends in teaching informatics and information technology.

3. Contest on Informatics and Computer Literacy "Bebras"

The idea of the International Bebras Contest on Informatics and Computer Literacy originated in Lithuania in 2003 (the name Bebras – in English "beaver" – is connected with a hard-working, intelligent, goal seeking and lively animal living at lakes and rivers in Lithuania and other countries). It took almost a year to create the problems and to prepare the technology for implementing that: the first contest started in October 2004 (only in Lithuania). The organizers aimed at making the Bebras contest an international one (Bebras, 2008).

In May 2005, Lithuania was the host country for the well-known Baltic Olympiad in Informatics. It was a good opportunity to advertise the Bebras Contest at least for the participants of the Olympiad (from Denmark, Estonia, Finland, Germany, Latvia, Sweden, and Poland). During the Baltic Olympiad the international Bebras workshop was helt for developing tasks. Four more countries were invited and participated in the Bebras workshop (Austria, Egypt, Israel, and The Netherlands). The participants spent a lot of time discussing the structure and development of the contest as well as preparing problems. It was decided to run the Bebras Contest each autumn (October-November).

In spring 2006, the second workshop of developing tasks for the Bebras Contest was organized in Lithuania and the International Bebras Organizing

Committee was established (Bebras, 2008). The main goals of the Bebras workshops are to develop a set of tasks for the coming contest, to discuss them and come to an agreement among the countries with different curricula and traditions of teaching computer science in general education. Workshops for developing problems are being organized each spring. Some countries have already been running the international Bebras contest for their students, some are still in a preparation stage.

4. Learning by Competitions Based on Attractive Tasks

The quality of tasks is crucial for the success of all task-based competitions. Usually competitions have several goals and the tasks have to meet a wide variety of requirements. The tasks must reflect the goals of the competition and should be adequate to the applicants. With a view to motivate students to learn science issues more deeply, competitions are one of the best ways of attracting their attention. In educational competitions, the tasks should attract students and drive them to learn and explore as well as to develop skills in the particular area (Opmanis, 2006).

When teaching computer science through problem solving, it is very important to choose interesting tasks. Therefore, one should try to present problems from various spheres of science and life, with a lot of data. Processing large amounts of data becomes one of the most important aspects when learning programming.

Two learning approaches can be distinguished for teaching programming: 1) passive and 2) active. The approaches are based on priorities: whether the programming constructions (syntax) or problem solving are taught using the programming language. An active teaching is when the problems are solved, while the language constructions are mastered gradually when they are needed in the solution. It is highly important at the very beginning of learning, and the first stages of national Olympiads in informatics are related to this.

In the Lithuanian Olympiads in Informatics, problem solving is taught by means of programming in two ways: 1) development of algorithms, and 2) analysis of algorithms. The problems of writing algorithms strongly dominate in competitions. However, the acquaintance with various methods and styles of programming can be ensured by means of reading programs.

In the traditional IOI competition tasks, all input data are directly available to the algorithms, in one batch (Horvath, 2003). Reactive tasks, which involve a dialogue between the algorithm and its environment, and Output only tasks where the output but not the algorithm is evaluated, were introduced later. The same type of problems is used in the Lithuanian Olympiads in Informatics. Of course, the difficulty of the problems varies significantly from the first to the final stages. No matter how difficult the tasks are, they are often presented to the students in an attractive way.

The Bebras International Contest on Informatics and Computer Literacy addresses pupils from grade 5 to 12 (13 in some countries) and aims to motivate the participants to be interested in typical informatics problems. The students have to solve a series of tasks of three different difficulty levels. Each task takes from 1 to 4 minutes to be solved. Finding interesting and adequate tasks that can be solved in a few minutes seems to be much more difficult in the field of informatics than in the field of mathematics. The requirements for good tasks have been developed during the Bebras workshops (Dagiene, 2008a).

5. Evaluation and Online Judges

The Programming Contests stress a fast completion of a programming task and evaluates the results solely through black-box testing specified by the judges. There are some local (country) competitions that emphasize the quality of the process inherent in the software development and implementation. Examples can be the Olympiad at the College of Charleston Department of Computer Science, South Carolina (Bowring, 2008) as well as the Olympiad of the department of Computer and Information Science at Spellman College, Atlanta (Kearse, 2008).

However, in international competitions testing is the only way the solutions are evaluated. This is mainly due to the multilingual community and a huge amount of solutions to be evaluated in a short period of time.

Testing of batch-type problems involves creating a set of input data cases, running the program submitted by a contestant with those input cases and then analyzing the obtained outputs. There are some principles used for creating tests. First, various solutions of different efficiency are analyzed and programmed. Second, tests are generated or manually designed to reflect the efficiency of solutions and their correctness, boundary situations.

The programs submitted in IOI's are evaluated as black boxes. The contestants do not have an opportunity to submit their design ideas to be considered in the evaluation process. If they have a correct but inefficient program, they know it will not give them full marks (maybe 60%).

In the Lithuanian Olympiads in Informatics the program solutions are also tested, nevertheless program (algorithm) design ideas and programming style are evaluated additionally. During the contest students are asked to write down algorithm design ideas. Actually, the idea for algorithm design is an informal description of an algorithm. A description of the idea should be preferably short.

All the presented ideas are evaluated no matter whether a contestant scored some points for testing or not. This gives an extra opportunity for the students who for some reasons have failed to develop the final program or made some essential mistakes in the code, even if the algorithm itself was correct. This requires students to learn how to present their ideas briefly and intelligibly. When participating in the Lithuanian Olympiads the students learn to abstract the main

concepts and ideas, and to clearly describe them.

The programming style is evaluated only if the program scored at least 50% points for tests. It has been noticed that the programming style makes an impact on program correctness and the efficiency of programmer's work (Grigas, 1995).

During the final face-to-face round of the Olympiad the students come to the evaluation room not only to observe testing, but also to find out how their design ideas and programming style are marked. There they discuss with the members of the Evaluation Committee about their solutions, tasks in design idea description and programming style peculiarities.

There exist many online judges on the internet that can play a very important role for testing programs. Basically, an online judge is a server, which contains descriptions of problems as well as data sets to judge whether a particular solution solves any of these problems. Besides testing information students can receive information on the time that the code takes to run after improving the program and/or the algorithm used to solve the selected task. One of the main distinctive trait of the online judges is that they allow the users to learn informatics in their self-competitive style.

The UVa (University of Valladolid) Online Judge is an on-line programming trainer created in 1995 aimed at training the users who participate in worldwide programming competitions. Currently this tool has more than 80,000 users from many different countries and approximately 2,500 problems (UVa Online Judge, 2008).

By means of the UVA Online Judge students can develop technological and mathematical abilities, as well as motivation, creativity and abilities for time and knowledge management which are very important skills for subsequent learning processes and future jobs.

It is easy to understand that these sets of achievements are only possible within the frame of a collaborative project involving various experts and different areas of knowledge (Revilla, 2008). This is the origin of the EduJudge project. EduJudge is an innovative system based on ICT that can be incorporated into the learning processes in the mathematical and programming field and is addressed both to higher education and secondary education students. The main goal of the project is to give a greater pedagogic character to the UVA Online Judge, and adapt it to an effective educational environment for higher and secondary education. All that will contribute to the development of evaluation quality, and promote innovation providing new methods of teaching through competition.

6. Conclusions

Competitions play an important role as a source of motivation and inspiration. In order to encourage students to learn computer science, we have to look for such attractive forms. The Olympiads in informatics and contests on informatics and computer literacy could be useful examples of such forms.

Olympiads in computer science is an attractive form of learning and a very

important motive to improve programming skills for their participants. There is a steady infrastructure of international Olympiads in Informatics, a community of scientists, teachers, and other professionals in education has been formed. The regional Olympiads are organized based on the same principles.

Similar Olympic movements exist in many countries. The Lithuanian Olympiads in Informatics have a long tradition and experience. Various difficulty levels in Lithuanian national Olympiads render a possibility for the students with different experiences and knowledge of programming to participate in the Olympiads, and even the beginners in programming can acquire some motivation to participate and to learn.

Solutions of programming problems are mainly assessed through testing them. Even though it has some drawbacks, this form of evaluation is challenging for the students, – it is fast and impartial. On the other hand, the students often have to create tests themselves during the competition time in order to check the effectiveness of their programs. This makes testing a part of learning and problem solving. In Lithuania, the programming style as well as algorithm design ideas are also evaluated, which is an important part of teaching programming and makes the evaluation more complete.

The main principles of the Bebras competition are borrowed from the international mathematical contest Kangaroo, which is very popular in Europe. The main goals of the Beaver contests are to evoke interest in computer science (informatics) for all school students, to motivate students to learn and master technology. The competition should help children to take interest in computers and application at the very beginning of school.

The International Bebras Organizing Committee is open for all kinds of proposals and ideas of collaboration in a hope to find friends and partners in all countries. We are ready to share our experience, technology, and future plans with all who are interested. Integration of information technology into the teaching process and involving students to understand informatics should be our target, and we have to try to reach it together. We are sure that well-organized contests with interesting, playful, exciting problems, and attractive awards will invite pupils of all countries to use computer reasoning and to explore understanding of realities, possibilities, and failings of technology.

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