Problem Solving Olympics
Informatics and computational thinking in compulsory education

Olimpiadi di Problem Solving
Informatica e pensiero algoritmico nella scuola dell'obbligo

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1. Introduction and goals

The "Olimpiadi di Problem Solving – Informatica e pensiero algoritmico nella scuola dell'obbligo" (henceforth: OPS) is an initiative of the Directorate-General for Education Guidelines (D.g. per gli ordinamenti scolastici e per l'autonomia scolastica) of the Italian Ministry of Public Education (henceforth: MIUR), with the goal to foster both problem-solving and team-working skills in a single action.

Usually in the education world the expression "Olympics of X" means a competition aimed to single out and promote exceptional skills at the individual level in the age of 16-18. However:

- OPS are mainly training activities – the core of OPS are the *training contests*, followed by two rounds of *competitive contests* (regional and national);
- OPS are team-work activities – each team is composed of four people;
- OPS are aimed at all the compulsory education age range – activities are organized at *three levels*: the last two years of *primary school* (4th-5th grade), *junior high school* (6th-8th grade), the first two years of *high school* (9th-10th grade);
- OPS are aimed to reach *all* students, and not only exceptional ones – each school is encouraged to participate with as many teams as possible (for each level).
- OPS are gender neutral – each team is required to have people of both sexes.

It was recently noted by Nobel laureate Carl Wieman ("*Applying New Research to Improve Science Education*", Issues on science and technology, http://issues.org/29-1/carl/) that competitions outside of school fail to improve STEM education; since 2008 MIUR has promoted OPS as training/competition *within* the school system to pave the way for a more widespread introduction of computer science in curricula.

1.1 Goals

The main goal of OPS is to disseminate problem-solving skills and computational thinking in Italian education. Since no explicit provision of problem solving teaching is present in the Italian guidelines for primary and secondary education, OPS promote activities in this area with a trans-disciplinary approach, trying to captivate teachers of various disciplines. Being activities directly offered to classes as contests, they are appealing and have an immediate impact on the participating youngsters. However, no real successful participation is possible without support and training from local teachers. This implies that teachers should develop and promote curiosity, interest and consensus in his/her own class. Teachers themselves are therefore stimulated to engage in the game even if skills and competences needed are foreign, at least explicitly, even for them.

Problem solving – as interpreted in OPS – is intended as one of the most effective paths to the acquisition of computational thinking attitudes. For this purpose, one component of OPS is the ability to understand simple formal structures (such as terms and lists), and to follow, simple (and less simple) algorithms expressed in semiformal languages, thus forming the background on which an explicit teaching of programming and computer science may be based. This component is further strengthened (in grades 9 and 10) by administering some problems that require the execution of (easy) calculations to be repeated a number of times so large to make the solution feasible almost exclusively writing and executing a program.

We may therefore summarize the main goals of OPS:

- offer explicit problem solving training to students at the compulsory education age range (including team-working skills);
- involve the teachers in such a way that they also acquire and consolidate the needed skills (to use in their everyday teaching);
- use semiformal setting and pseudo language to embed problem solving in the context of computational thinking with the perspective of acquiring (eventually) programming skills.

2. Achievements

2.1 Joining the Project

Participation is on a voluntary basis. Italian teachers are expected to participate in "additional activities" as well as to teach their discipline. MIUR promotes various initiatives that qualify as additional activities: OPS is one of them.
In September/October, MIUR issues the annual bylaw for OPS, with the dates of the contests. Since participation in the project is the responsibility of the school complex, teachers have to negotiate adhesion with the principal.
Involved teachers (often in mathematics, but also in other disciplines) form teams from their classes; again participation of the students is voluntary, but very often discussion about OPS problems, assignment of exercises and study of problem-solving techniques are extended to the whole class and are not limited just to the team(s): this fact is the main added value of OPS.

2.2 Topics

OPS proposes at the three levels the *same kinds* of problems, with differences (among the levels) in *size* or *abstractness*.
Proposed topics are aligned with those used in international competitions of the problem-solving skills; each year five o six topics are chosen: from these, "*standard*" problem come up. In school year 2013/2014 the chosen topics where: formal deduction from a set of rules, paths in a maze or in a chessboard, knapsack, paths in a graph, planning a project.
Additional topics are comprehension of a text (in Italian) and of procedures written in a pseudo language (see [4] of the paragraph "Curricula materials available to teaching community" of this proposal, for a description of the language).
A semiformal syntax about *terms, list, strings* is used in problems and answers.
A contest consists of ten problems: the amount of work to be done in the allotted time (90 minutes) to solve them largely exceeds the effort that can be expected from a single participant; hence planning, collaboration, specialization and team-working are necessary.
Examples of a "standard" problem are shown in figure 1 and 2. The first problem is part of the second training contest for the *first level* (this school year): problems, on the same subject, in next contests have graphs gradually more complex, and the solution has to be chosen among up to a dozen of paths.
The second problem is part of the fifth training contest of the current school year, for the third level (9th-10th grade).
N.B. The problems have been translated from the Italian originals.
More examples of problems are in [8] and [10] of the paragraph "Curricula materials available to teaching community" of this proposal.

2.3 Comments to the solution

A key feature of the OPS is that, along with the solution of each problem, after each contest, "comments" are provided; in the current edition this feature is expanded and enriched and make up an outline for the in-depth study and analysis that teachers are invited to follow along with the students.
Figure 1 shows a problem at first level: the solution is simple and so the comments are not too elaborate; the comments to the (corresponding) standard problems of the higher levels provide the detailed construction of the tree of paths between two nodes. Figure 2 shows a problem for the third level: comments to the solution take one page and an half.

2.4 The training contests

In a training contest, on fixed date, problems are proposed on a secure web platform and are accessible for a suitable interval of time (e.g. 3 hours). Schools connect to the platform when they deem suitable (within the given interval of time) and, under the supervision (and the guarantee of fairness) of local teachers, the teams participate to the contest. Ten problems are administered and their solutions should be entered within 90 minutes from the first access. During the contest each team is allowed to use any additional material as it sees fit (books, notes, additional PCs, browsing the Internet, etc.), the ability to quick retrieve and organize relevant information being one of the key components of effective problem-solving.

When the access to problems is closed, correct solutions and comments are made available; then answers are evaluated and teams ranked.

In each contest there are:

– a problem of text comprehension in Italian;
– five “standard” problems;
– two problems regarding the comprehension of procedures written in pseudo language;
– two non “standard” problems, each time of a new kind, to stimulate creativity and the ability to deal with new situations;
– one or more problems formulated in English.

Three to five different training contests are organized in this way from November to March: the difficulty of the problems is gradually increasing.

Then, for each level, each school selects a team for a regional competition; the winning teams of each region (~20) meet in Rome for the final competition.

2.5 The final contest

The final contest is a real competition; around twenty teams for each level are invited in Rome and the contest takes place in classrooms provide by MIUR under control of a Jury and with strict rules:

1. Each team has the same type of workplace available, which includes one workstation.
2. Teams are allowed to bring books, notes and an extra PC.
3. Participants are not allowed to communicate with other persons during the contest, except with members of their own team and the Jury.
4. Use of hardware other than watches, medical equipment, the PC and the provided workstations is not allowed.
5. A team can be disqualified for any activity that jeopardizes the contest.
6. When a team presume that a problem is ambiguous or incorrect, the team can ask a clarification to the Jury. The Jury will respond and if the answer is relevant to all teams, the Jury will communicate the answer to all teams.

The Jury determines the final team ranking as follows (this procedure is identical for the three levels). Teams are sorted by the number of accepted solutions, in non-increasing order. When two or more teams have the same number of accepted solutions, these teams will next be sorted by total time, in ascending order. The total time is the time passed between the start of the contest and the time at which the last solution was submitted. There is no penalty for unsolved problems.

PROBLEM

In a map there are towns and roads between them: this situation can be abstracted with a *graph* in which *nodes* represent cities and the *arcs* represent roads. An arc (road) of the graph can be described by a term like:

arc(n4,n8,5)

which means that there is an arc between node n4 and node n8 and its length is 5.
Two nodes connected by an arc are said *adjacent*.
A *path* is (described by) a list of adjacent nodes. A *simple* path does not contain repeated nodes.

Consider a graph described by the following list of terms:

arc (n1,n5,3) arc(n3,n1,6) arc(n2,n4,2)
arc(n6,n3,6) arc(n5,n2,5) arc(n4,n6,1)

Draw the graph and determine:

1. the list L1 describing the *shortest* path between n1 and n6 and calculate its length K1;
2. the list L2 describing the *longest* simple path between n1 and n6 and calculate its length K2.

Enter your answer in the following table.

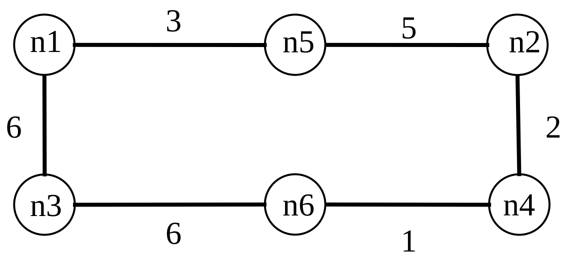
L1	
K1	
L2	
K2	

Solutions:

L1	[n1, n5, n2, n4, n6]
K1	11
L2	[n1, n3, n6]
K2	12

COMMENTS TO THE SOLUTION

After a few attempts the graph can be drawn in such a way that the arcs do not intersect, as in the following figure.



Note that a major difficulty lies in drawing the graph so that the arcs do not intersect; it is necessary to proceed by trial and error, by placing nodes in various ways until the drawing is satisfactory; *this can be done in many ways*.
Note also that the lengths that appear in the terms (that represent roads) are *not* proportional to those of the arcs of the graph (that are "*symbolic*" straight line segments).
The graph describes a "circuit" and it is easy to see that the possible paths between n1 and n6 and the relative lengths are:

path	**length**
[n1, n5, n2, n4, n6]	11
[n1, n3, n6]	12

Figure 1. Example of a *standard* problem for the first level (primary school, 4th-5th grade), given in the second training contest of the current school year.

PROBLEM

A *deduction rule* can be described by a term like

rule(3,[a,b],c)

which means that the rule (number) 3 permits to deduce **c** from (that means knowing) **a** and **b**; **c** is said *consequent*; **a** and **b** are said *antecedents*.

Rules can be chained for complex *deduction procedures*; a deduction procedure can be described by a list of rule numbers.

Consider the following rules:

rule(1,[f,g],h)	rule(2,[q,f],b)	rule(3,[p,q,c],a)	rule(4,[m,p],q)
rule(5,[a,b,c],d)	rule(6,[m,p],f)	rule(7,[p,h],c)	rule(8,[m],p)
rule(9,[e,f],c)	rule(10,[f,b],i)	rule(11,[c,e],r)	rule(12,[f,s],e)
rule(13,[e,t],b)	rule(14,[a,u],f)	rule(15,[e,b],v)	rule(16,[u,d],t)

Determine:

1. the list L1 that describes the shortest procedure to deduce **a** knowing **c**, **m**;
2. the list L2 that describes the shortest procedure to deduce **c** knowing **m**, **g**;
3. the list L3 that describes the shortest procedure to deduce **d** knowing **m**, **g**;

Criterion for the lists. List the (numbers of the) rules in the order that corresponds to the sequence of application of the rules: the first element (from the left) of the list must be the number that corresponds to the first rule to be applied; if there are several rules that apply at the same time, give priority to the one with lower number.

L1	
L2	
L3	

SOLUTION

L1	[8,4,3]
L2	[8,6,1,7]
L3	[8,4,6,1,2,7,3,5]

COMMENTS TO THE SOLUTION

To solve the problem, you can use the backward (or top-down) method, that is start from the unknown and try to find a rule to derive it. If there is a rule whose antecedents are all known (the data), the solution is found; otherwise you look for a rule whose antecedents are not *all known* and you continue to look for rules to derive the unknown antecedents (that appear in the rule).

For the first question, it is immediate to check that **a** appears as consequent only of rule 3 which has as its antecedent **p**, **q** and **c**: the first two are unknown, the last is given; **p** is deductible only by the rule 8 directly from **m** (given); **q** is deductible only with rule 4 from **m** (given) and **p**, just deduced. The procedure is illustrated by the tree in the figure below. The list L1 is [8,4,3].

For the second question, we immediately verify that **c** appears as the consequent in the rules 7 and 9. The rule 9 has antecedents **e** and **f**, both unknown; **e** is deductible by the rule 12 which has antecedents **f** and **s**: the latter can not be deduced with any of the given rules. Therefore, to deduce **c**, only rule 7 is usable; this rule has antecedents **p** and **h** both unknown; **p** is deductible only with rule 8 directly from **m** (given); **h** is deductible only with rule 1 from **f** (unknown) and **g** (given). At the end **f** is deductible by rule 6 from **m** (given) and **p** (already deducted) or by rule 14 from **a** and **u** (both unknown): it is clear that we must choose the first alternative. The proceedings is illustrated by the tree in the figure below. The list L2 is [8,6,1,7].

Figure 2, part A.

To answer the third question, we immediately verify that d appears as a consequent only in rule 5 that has antecedent **a**, **b** and **c** all the unknowns:

- to deduce **a** can be used partially what was said for the first question; rule 3 has antecedent **p**, **q** and **c**: **p** is deductible only by rule 8 directly from **m** (given); **q** is deductible only by rule 4 from **m** (given) and **p**, just deducted. **c** is deductible by the rule 7 or by rule 9: the first should be applied because of the two antecedents, **p** and **h**, one has already been deducted; **h** can be deducted only by rule 1 that has antecedents **f** (unknown) and **g** (given); **f** is deductible only by rule 6 that has antecedents **m** (given) and **p** already deducted;
- **b** can be deducted only by rule 2 which has antecedent **q** and **f**: both already deducted;
- **c** has already been deducted .

The overall process is illustrated by the tree to the right of the figure below. The list L3 is [8,4,6,1,2,7,3,5]: to build it is essential to keep in mind the criterion for the list given in the problem.

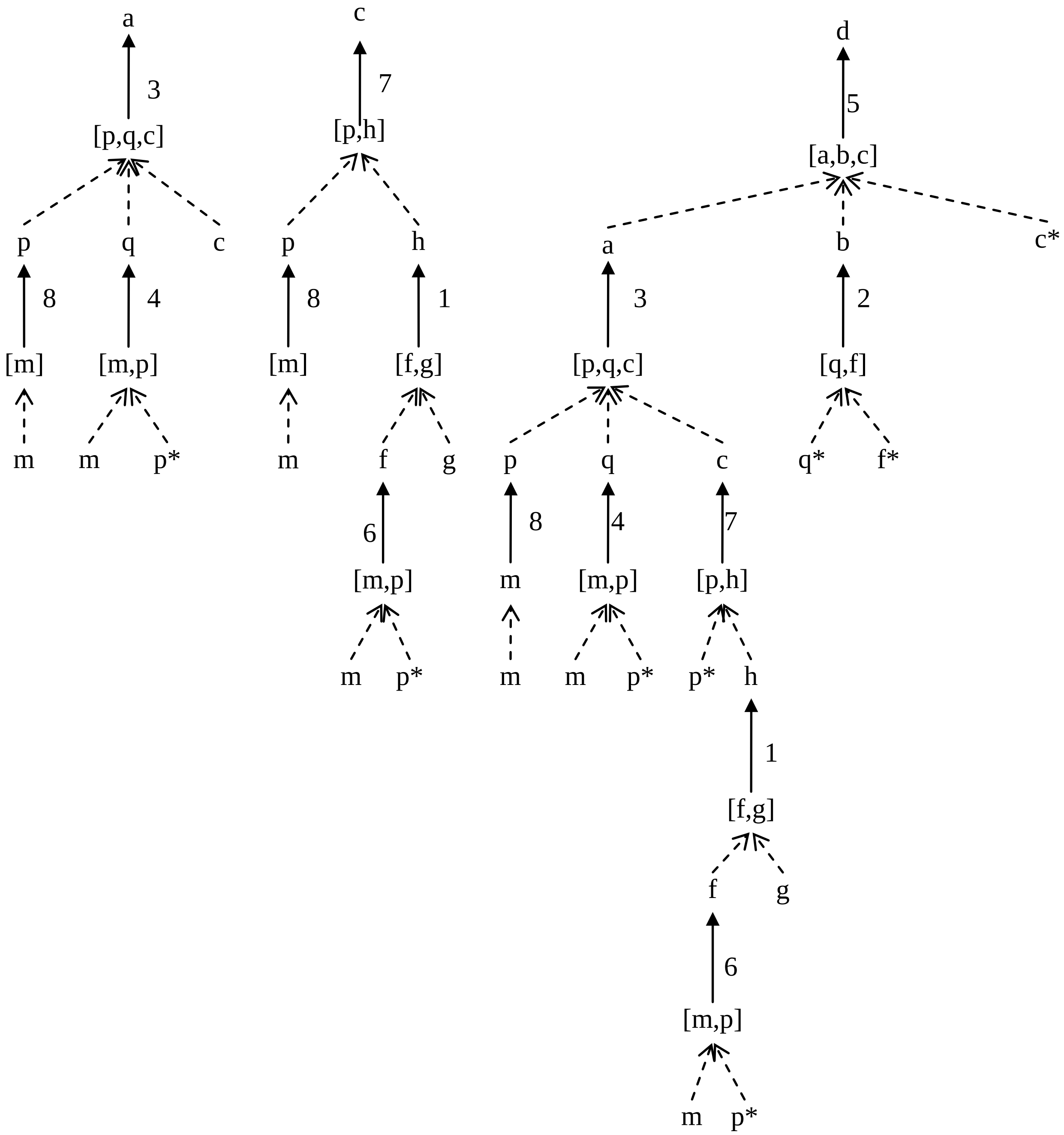


Figure 2, part B. Example of a *standard* problem for the third level (9th-10th grade), given in the fifth training contest of the current school year.

3. Curricula materials available to the teaching community.

N.B. All materials are in Italian.

1. Introduction to OPS. A page about goals and philosophy of the initiative. (http://www.olimpiadiproblemsolving.it/site/presentazione.php)

2. Bylaw, updated annually. http://www.olimpiadiproblemsolving.it/site/regolamento.php

3. How to get access (for school principals, teachers, etc.) http://www.olimpiadiproblemsolving.it/site/nota-tecnica.php

4. A description of the programming pseudo language Pascal-like used in many problems http://www.olimpiadiproblemsolving.it/documenti/manual-P2-3.pdf

5. "Annali della Pubblica Istruzione" : a volume of 200 pages on comments, experiences, etc. on OPS, edited by MIUR http://www.annaliistruzione.it/var/ezflow_site/storage/original/application/d6a170d678e2a43e7f22f49ef864e13c.pdf

6. A presentation (35 slides) on OPS at first level http://www.olimpiadiproblemsolving.it/documenti/Roma-30-09-09.pdf

7. A presentation (50 slides) on OPS with examples of problems http://www.olimpiadiproblemsolving.it/documenti/Sirmione_20102010.pdf

8. 270 problems given in past contests with solution and detailed explanations http://www.olimpiadiproblemsolving.it/site/archivio.php

9. A Thesis (plus an abstract of a talk given at Didamatica 2014) on OPS http://www.olimpiadiproblemsolving.it/site/archivio.php

10. More examples of problems http://www.olimpiadiproblemsolving.it/documenti/ORIENTAMENTI_PER_ALLENAMENTI_09_10.pdf

4. Impact

Table 1 shows the participation in OPS over the years.

school year	contests	teachers involved	students involved
2008/2009	3	550	10200
2009/2010	5	500	9850
2010/2011	6	400	7400
2011/2012	6	630	11400
2012/2013	4	880	16500

Table 1. In columns 3 and 4 figures are rounded up.

To benefit from the experience of others and maximize the impact of OPS, publications on the subject have been carefully studied.
The following is a short list of examples (the numbers are relative to the References).
There is a large range of opinions from the classical [1] of 1997, which traces the history of the competition in education, and particularly in computer science from IOI to ICPC and clearly supports competition in learning, to [2], which argues against any form of competition.
The most recent [3] cites several articles on the subject and discusses the characteristics that competitions should have in order to be beneficial (symbolic prizes, short duration, focus on learning). However the authors, relaying on the students' judgment, seem to miss the training value of repeated contests.
[4] brings the centuries-old experience of mathematicians. The paper describes enthusiastically over a century of mathematical competitions, and notes that among the several benefits of the competitions there is also the raising reputation of the institution that organizes them (taking as example the University of Waterloo, Canada). What pleased us mostly was the last section: "What to do next", because the first two subsections where "Algorithms in mathematics" and "Teamwork".
[5] is on motivation of students through competition; the paper analyses the different learning styles adopted by students (competitive, cooperative, individualized) regarding the use of a competitive e-learning tool. This study (although it refers to a university) comforted us to hypothesize an individual competition in the future, to support the individual learning style.
[6] argues that combining cooperation and competition enhances professional development of students, in addition to improve learning results; also stresses the importance of problem-based learning and the importance of group composition.

4.1 First results

The *comparative impact* of OPS on participants is difficult to establish due to a *selection effect*: in fact, participation in OPS is voluntary, so we expect that the best and most innovative teachers are better represented among those participating in OPS. Moreover, we cannot rule out that participating teams are made up of some of the smarter students in their classes. This selection bias is difficult to asses and avoid in data analysis; a comparison of the educational careers of those who have participated in OPS and students from another sample is an extremely delicate task (see next paragraph on future work).

On the other hand, the *training effect* on students is clearly visible, especially noting that the problems, from contest to contest, become progressively more difficult. Some examples can be given. Figure 3 shows the average scores of primary school teams who participated in the project during the school years 2010/2011 and 2011/2012. Apart from some slight fluctuations, the trend is posi-

tive in both years. The best performance in the second year can be attributed to a better awareness of the project by the teachers involved.
Figure 4 shows the average scores of junior high school teams that participated in the project during the school years 2010/2011 and 2011/2012. The trends show a significant improvement in the results with the progress of the training. They are more evident than the ones for primary school. Also in this case, the best performance in the second year can be attributed to a greater awareness by involved teachers and a keen interest of students.
Figure 5 shows the results obtained by teams of high schools[1] in text understanding in English and Italian (upper curve) and in algorithmic problems (lower curve). It is evident the training effect for algorithmic skills (when compared to the more modest evidence for text understanding, a subject on which clearly students work a lot also independently from OPS).
Similar results can be obtained from the data of the other school years.

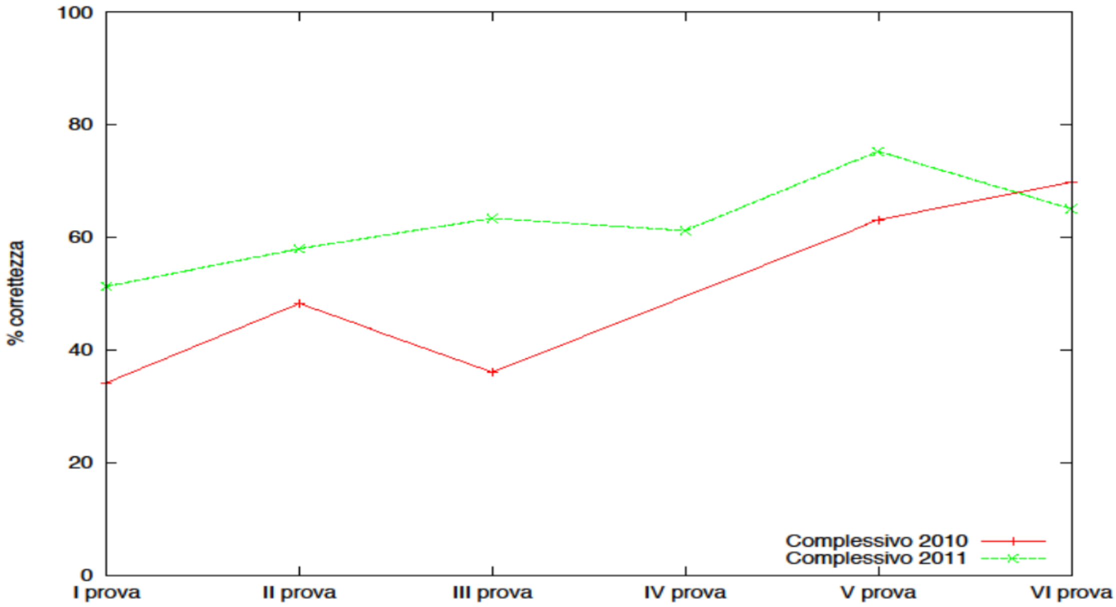


Figure 3. First level (primary school): average score in the six contests for school years 20010/2011 e 2011/2012

[1] Recall that only the 9th and 10th grade (the first two years of high school in the Italian education system) are admitted to OPS.

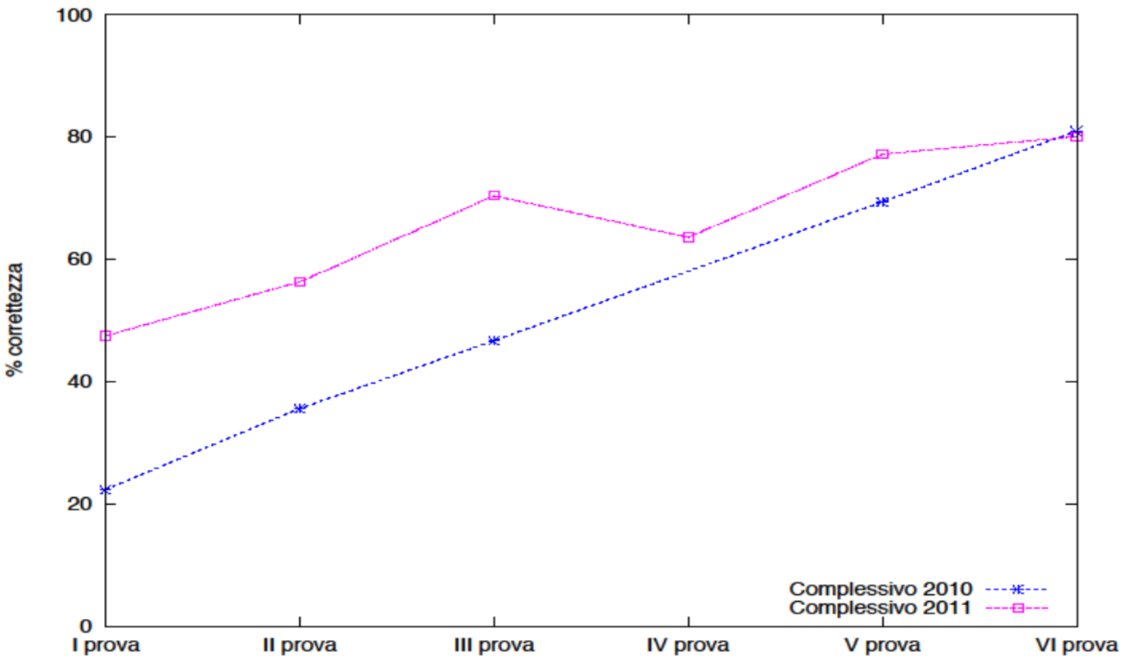


Figure 4. Second level (junior high school): average score in the 6 contests for school years 20010/2011 e 2011/2012

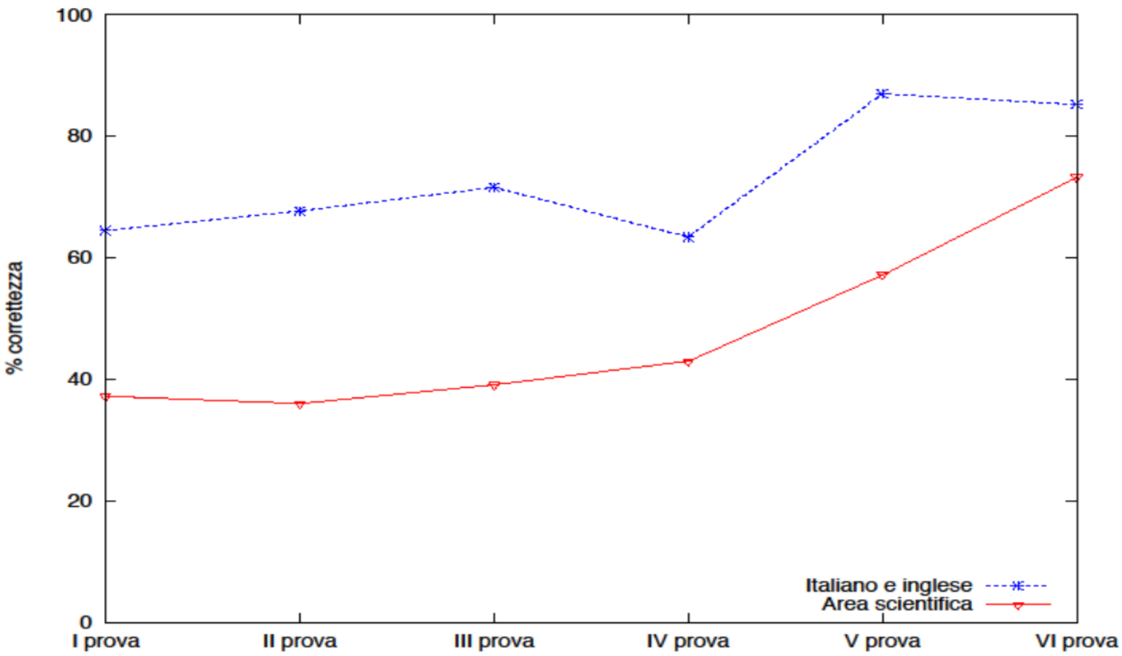


Figure 5. Third level (first two years of high school): average results in the 6 contests for school year 2010/2011; upper curve is the average score for comprehension of texts in Italian and English; lower curve for is the average score in algorithmic problems.

Another impact difficult to assess is on teachers; it was noted that the competitions (at least in computer science) encourage teachers to learn more to support their students; currently, besides a qualitative confirmation, it does not seem possible to measure this effect.

4.2 General impact and future work

Extended direct feedback from the teachers involved in OPS makes evident a positive correlation between participation to OPS and general performance of students (as measured in standard tests, like PISA). This has been a *working hypothesis* of our work since the firsts editions of OPS. Turning this hypothesis into a scholarly acceptable evaluation is one of the main directions of our current work on the evaluation and assessment of OPS. In the following, we briefly outline the planned methodology.

INVALSI (www.invalsi.it), established in 2007, is the Italian agency responsible for managing the national evaluation system (SNV) on education. In particular, it administers annual performance tests for *all* students at certain grades, maintains historical data, compiles statistics and comparisons at the international level, etc. Of course, while aggregated data are publicly available, accessibility to specific data – even at the class level – is limited by Italian legislation on data protection and privacy.

For a better assessment of OPS impact (and somewhat avoid the sampling bias we mentioned at the beginning of this section) we plan to:

1. (for a specific year and level) single out the teams participating in the training contests;
2. characterize the components of these teams, classifying them by gender, age, geographical distribution, etc.;
3. determine the initial evaluation (*before* participation in OPS) of this sample with INVALSI data;
4. construct a *random* sample of the same size and with the same profile by gender, age, geographical distribution, etc. and the same INVALSI evaluation;
5. follow in time the performances of the two samples.

This research program is expensive and challenging. Indeed, we need to match *personal* OPS data with *personal* INVALSI scores, even if the data would be made available to the research team in an anonymized form. Negotiations between OPS committee and INVALSI on this subject are underway.

5. Reference List

[1] The Role of Competitions in Education, by Tom Verhoeff, 1977. In *Proceedings of the Future World Educating for the 21st Century Conference and Exhibition*.
http://olympiads.win.tue.nl/ioi/ioi97/ffutwrld/competit.html

[2] Is Competition Ever Appropriate in a Cooperative Classroom?, by Alfie Kohn, 1993. In *Cooperative Learning Magazine* 1993 – vol. 13, no. 3.
http://www.alfiekohn.org/teaching/compinCL.htm

[3] Effects Of Competition In Education: A Case Study in an e-Learning Environment, by Iván Cantador, José M. Conde, 2010. In *Proceedings of IADIS International Conference e-Learning 2010*.

[4] Competitions and mathematics education, by Petar S. Kenderov, 2006. In *Proceedings of the International Congress of Mathematicians*, Madrid, Spain, 2006 European Mathematical Society.

[5] Motivating Students through On-Line Competition: an Analysis of Satisfaction and Learning Styles by Regueras, L. M., Verdú, E., Verdú, M. J., Pérez, M. Á., de Castro, J. P., Muñoz, M. F., 2008. *In Proceedings of the 7th International Conference on Web-based Learning (ICWL 2008).*

[6] Cooperative Learning in a Competitive Environment: Classroom Applications, by Simon Attle and Bob Baker, 2007. In *International Journal of Teaching and Learning in Higher Education*, vol. 19, no. 1.
http://www.isetl.org/ijtlhe/

See also the previous section on *Curricula materials available to the teaching community*.

6. Letters of Support

Two letters of support, from school principals participating to OPS, are provided as attachment to this submission.