Cooperative Problem Solving: an experience of high-school teaching updating

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Abstract

We present the results of an experience of teaching updating dispensed to Italian high school physics teachers to promote the application of the cooperative problem solving method as an useful strategy to improve physics learning at high-school level and to foster the development of problem solving skills. Beside analysing the method and discussing the ways to propose and apply it in a high school context, the teachers experienced the method acting both as learners and as tutors of student group learners. Students and teachers evaluated the experience as positive, mainly focusing on cooperation within the group by information exchange and the application of a solution scheme. The ex-post analysis of the students' performances in applying the method to solve some rich context text showed the need of improving their critical thinking attitude with respect to achieved results to fully exploit the strategy and develop their problem solving skills. Finally, an analysis on gender differences of students is presented.

Keywords: cooperative problem solving, gender analysis, high-school physics teachers, teaching physics

1. Introduction

As many other countries all around the world experienced in the last decades [1,2], Italy faced reduced enrolment in STEM (Science, Technology, Engineering and Mathematics) studies and, mainly, in hard natural sciences such as physics among the others. Since 2004, the Italian Ministry of University and Research promoted a national project (PLS, Piano Lauree Scientifiche [3]) aimed to increase the number of high school students pursuing enrolments and graduation in physics by means of a series of actions devoted to both students and teachers. Among the others, the promotion of courses aimed to promote and diffuse the use of problem solving is gaining a lot of interest in the field of education. Indeed, it is well known that problem solving is a skill strongly requested in the whole STEM courses and increasingly appreciated in professional and social world [4-8], being recognized as a habitus useful to manage new situations and contexts. Problem solving can be in general defined as the ability of one person to cope with a problem, the latter being a new situation which requires elaborating previous knowledge and experience to achieve the solution [9,10].

Physicists always valued problem solving as one of the most peculiar features of their discipline and spent a lot of efforts to analyse how to teach it and how to use it for teaching physics [11-17]. Teaching problem solving strategies to students was demonstrated as very effective in improving their performances in problem solving and their ability, in general, to use structured strategies to deal with professional issues [18-20]. Among the numerous methods to teach problem solving, in his classic text, "How to Solve It", Pólya [21] espoused a four-step problem-solving process: 1. Understand the problem, 2. Make a plan, 3. Carry out the plan, and 4. Look back on your work. While Pólya did recommend some reflection at the end to help the solver understand what worked and what did not, his suggested process does not emphasize the necessary monitoring that must occur throughout the process in order to successfully solve a problem. Bransford and Stein developed the IDEAL method of problem-solving, which includes the step "Explore Alternative Approaches" [22]. While this does encourage students to do some monitoring, it does not strongly encourage different ways of monitoring throughout the solution process. There are other models of problem-solving that include monitoring and other components such as confidence and creativity, but these are likely too complex for teachers and students to use as a tool in the classroom. Heller proposed to implement the Polya's solving strategy in cooperative grouping focusing on cooperation as a key feature in the learning process. Cooperative learning was indeed proven successful at high school and college level in improving students' achievements and teaching approach [23-25]. This is also confirmed by cognitive studies in the field, showing how to share different points of view to solve a common problem involves cognitive development and a more effective learning [28]. Cooperative learning and problem solving methodologies are certainly realized in the so-called Cooperative Problem Solving (CPS) method. The CPS is a social interaction of multiple entities working together for achieve a common goal. It is based on the pedagogical model developed at the School of Physics and Astronomy - University of Minnesota [12-13] and on the model of Peer Instruction developed at Harvard [29]. The application of the CPS in physics involves the use of a shared framework for the solution of complex problems with a rich context useful for stimulating the interaction of group to achieve a common goal useful for both students and teachers in their facing with the structure of physics problem [30].

The CPS method is based on 5 iterative steps: focus the problem; description of the problem; plan of a solution; execution of the plan; evaluation of the solution. Its implementation passes through the formation of cooperative groups with an optimal number of components of three. Every member of the group has a specific pre-assigned role with specific tasks [CIT]: mentor (responsible for coordination of members and managing of their activities), secretary (responsible for validation and verification of adopted procedures), sceptic (responsible for checking all the possible choices in solving a problem and evaluation of group's proposals). Teachers assumes the roles of tutors or coaches with the aim to guide students in applying the method and solving problems [CIT]. By means of CPS method, group members can improve their capabilities in solving complex problems and experience interaction and confrontation among peers. The method also helps in developing both individual and group consciousness and related responsibilities [CIT]. While students experience the method, teachers act as tutors or coaches, guiding the class in the learning process.

Inspired by Heller's proposal of cooperative problem solving strategy, in the present work we present the results of an experience of teaching updating dispensed to Italian high school physics teachers to promote the application of the CPS method as a useful strategy to improve physics learning at high school level and to foster the development of problem solving skills. We also experimented with a group of teachers and one of students the approach to evaluate their willingness towards the method.

The structure of the paper is as follows: in section 2 we present the methodology we used during CPS activities with teachers and students. We also report questionnaires we presented to teachers and students to evaluate their experience. In section 3 we show results about questionnaires and students' elaborates. We also show statistical results on gender differences about students' performances in the cooperative problem experience. In section 4 we discuss our results. Finally, in section 5 we draw our conclusions. The list of tables, figures and the supplementary material are showed at the end of the paper.

2. Methodology

We promoted a course on cooperative problem solving to update knowledge of physics teachers and promote the diffusion of the method to teach physics in the high school. The research has been conducted between December 2017 and January 2018 at the Physics Department of University of Cagliari (Italy) with a sample of teachers and students coming from scientific and classical high schools of the metropolitan area of Cagliari. To promote the application of CPS approach in high school, we firstly organized a four days course for teachers where the approach was explained and tested. Beside receiving the instruction of the approach (12 hours), teachers were also involved in direct CPS experience. Divided in 3-member groups, they discussed motivations and ways to apply CPS in a high school classes and evaluated the different aspects of the distinction in roles within the group. They also participated to few hours (6) of exercitation to product and examine enriched problems of physics achieving a common and shared database of problems. Finally, the approach was tested with two mixed large classes of high school students, teachers being involved as active coaches or as passive scouts (4 hours).

Students faced up with the solution of physics text-enriched problems based on arguments they studied during their high-school physics classes (mechanics and thermodynamics). Due to the large number of participants, students participated at the laboratory in two different days divided in two large groups (to which we refer to as "G1" - first day group - and "G2" – second day one). G1 and G2 groups were divided in small subgroups, each member having a specific role (mentor, secretary, sceptic). During this experience, teachers acted as tutor or coach.

We proposed three different physical problems, named "A", "B" and "C" (see the supplementary material SF1). Students in group G1 faced up with problems "A" and "C", whereas students in G2 solved problem "B". G1 group was composed by 19 subgroups (indicated as A/1, A/2, …, C/1, C/2, …), G2 by 13 subgroups (indicated as B/1, B/2, …), as reported in Table 1. Students used a 5-steps CPS method to analyse and find the solution of the problem as follows (see the supplementary file SF2 for the complete form):

1. *Focus the problem*
   To read out and individuate the physical quantities and to draw what happens in the proposed problem. To report the question asked in the problem and describe the approach to solve it.
2. *Description of the Physics*
   To draw a physical diagram to describe the physical problem. To find and define the physical variables, pointing those involved in the final question out. To write down the useful equations to arrive at the solution.
3. *Plan a solution strategy*
   The solution strategy is represented by the set of equations to describe the phenomenon and to find the solution. To verify the internal consistency of the adopted scheme and indicate the decisive steps.
4. *Execution of the solution strategy*
   To apply the solution strategy to find the physical quantities requested in the problem. To verify the consistency of the result through dimensional analysis.
5. *Evaluation of the final solution*
   Three questions to answer: "Does the mathematical result correspond to the problem question?"; "Is the result expressed in the right units?"; "Is the result reasonable?"

We analysed the elaborates of the students by ranking each step of the implemented solution scheme in a 0 - 1 rank. The results are collected in graphs by grouping as insufficient (0.0 - 0.4 range), sufficient (0.5 - 0.7 range) and good (0.8 - 1.0 range).

To analyse the experience, we questioned the appeal of the approach and its applicability as foreseen by the teachers and we asked the students to evaluate their experience in solving some text-enriched problems. In both cases we proposed an online questionnaire. Finally, we performed a gender analysis based on results coming from students' elaborates.

2.1 Composition of the sample

There were 36 teachers attending the course (22 females, 14 males), 32 (88.9%) of them coming from scientific high schools, 3 (8.3%) from technical schools, 1 teacher (2.7%) from classical one. Teachers selected and recruited students who attained the CPS laboratory among different classes of their institutes. The students' sample was composed by 98 high-school students, 82 (83.7%) coming from different scientific high schools and 16 (16.3%) from classical ones. Considering the entire sample, 10 students were attending the third-year class (10^{th} grade in US scale, 16 years old in average), 25 the fourth-year class (11^{th} grade in US scale, 17 years old in average) and 63 the fifth-year class (12^{th} grade in US scale, 18 years old in average). Among the scientific high school students, 10 were attending the third-year class, 14 the fourth-year class and 58 the fifth-year one (see Table 2). For what concerns classical high-school students, 11 were attending the fourth-year class and 5 the fifth year (see Table 3). The sample was composed by 34 female (34.7%) and 64 male (65.3%) with an avarage age of 17.5 years. The "G1" group was composed by 59 students (60.2%) with 18 teachers acting as tutors; the "G2" group was composed by 39 (39.8%) students, with 18 teachers acting as tutors.

2.3 Teachers' questionnaire

We asked the teachers to answer 9 questions regarding their activities at CPS laboratory. Different ranking scales have been used according to the topic in order to differentiate the evaluation from one aspect to the other. Teachers' questionnaire and suitable ranking scales are schematically reported in Table 4.

In section 1, three questions devoted to investigate teachers' feelings on the peculiarities of CPS approach were proposed: "*What do you think about the distinction in roles?*"; *"What do you think about the distinction in steps?"; "What do you think about the use of text-enriched problems?"*. Teachers could use a 3-steps ranking scale, from 1 (not effective) to 3 (effective) to evaluate their perceptions on these topics which, in turns, allowed us to obtain a precise and direct estimation of these issues from them.

As part of teacher's experience with CPS laboratory, the section 2 of the questionnaire explored their perception about students' activities. This part was addressed only to teachers participating as tutors/coaches at students' laboratory. Teachers evaluated students' *engagement* in CPS method, students' *comprehension* of the problem and students' *capability to apply the solving method*. They used a 4-steps evaluation scale, from 1 (insufficient) to 4 (excellent). This choice was aimed to give us a complete and reliable data distribution concerning teachers evaluations. In this section, they also evaluated the *difficulty of the problems presented to students* by means of a 4-step ranking scale, from 1 (very low) to 4 (very high).

Finally, in section 3 teachers evaluated their *interest* in CPS method by using 5 steps ranking scale, from 1 (very low) to 5 (very high). They also evaluated the *replicability of the method* in high school classes by using 3 steps ranking scale, "no", "partly" and "yes", respectively.

2.4 Students' questionnaire

As in the case of teachers, students answered to a questionnaire about their participation to the CPS laboratory. The evaluation was accomplished through a set of questions aimed to appraise the difficulty level, their comprehension of the method and level of cooperation. Finally, they were asked to self-judge their contribution and success. We also asked the students to express their comments on the experience, evidencing which were the aspects helping most to find the solution.

We elaborated 21 questions divided in five independent sections, each of them characterized by a proper evaluation scheme. Students' questionnaire and suitable ranking scales are schematically reported in Table 4.

In section 1, we proposed 4 general questions about the CPS activity and the preparation they received from their teachers to participate at the laboratory: 1) *"Do you have understood the text of the problem?";* 2) *"Do you have understood the step-division typical of CPS activity?";* 3) *"Do you have understood the division in roles in your group?"*; 4) *"Have you been prepared to participate to the activity?"*. Students could answer by using a 3-steps ranking scale, 1 (No), 2 (Partly), 3 (Yes).

In section 2, we asked them to evaluate 5 aspects about the CPS method they used to solve problems during the laboratory: *"Evaluate if your group was able to successfully carry out each CPS step to face up with the problem: 1) Focus the problem; 2) Describe the physics behind the problem; 3) Plan a solution strategy; 4) Execution of the solution strategy; 5) Evaluation of the final solution"*. Students could answer by using a 3-steps ranking scale, from 1 (unsolved) to 3 (solved).

In section 3, students evaluated specific aspects regarding their contribution as single and the contribution as a group in planning and finding the solution of the problem using CPS steps. Four questions were asked to them (8 questions in total): 1) *"Evaluate your/the group contribution in finding the solution of the problem"*; 2) *"Evaluate your/the group contribution in finding ideas to analyse the solution strategy before writing down the equations"*; 3) *"Evaluate your/the group contribution in finding ideas to plan a mathematical solution of the problem"*; 4) *"Evaluate your/the group contribution in using a logic and organized approach to find the solution of the problem".* Students could answer by using a five-steps ranking scale, from 1 (irrelevant) to 5 (essential).

Section 4 and 5 was devoted to resume students' feelings and capabilities regarding the CPS laboratory. In section 4 we asked two questions, students could rate them from 1 (No) to 3 (Yes): 1) *"Do you think that your*

Physics knowledges have been sufficient in facing up the presented problem?"; 2) *"Do you think that this activity can be used in your Physics class?"*. In section 5 we asked two questions about the difficulty level of the activity and their interest in the CPS laboratory. Students could vote by using a 5-steps ranking scale, from 1 (very low) to 5 (very high): 1) *"Evaluate the difficulty level of the activity"*; 2) *"Evaluate your interest in the activity"*.

3. Results

In this section, we firstly report teachers' results on the evaluation of their questionnaire. Secondly, we show results on students' questionnaire and on the evaluation of their elaborates. We show a gender analysis on results coming from students elaborates at the end of the section.

3.1 Teachers

Among the 36 teachers participating at the course, we collected 28 answers (77.8%). Not all teachers participated at students' activity so the number of answers we obtained is variable within the questionnaire. The list of questions and corresponding results is shown in Table 4.

In section 1, teachers answered to three questions about the distinction in roles during the activities, the resolutive scheme (the distinction in steps) and the use of text-enriched problems (Fig. 1). We obtained 28 answers in total. For what concerns the distinction in roles, 5 (17.9%) teachers found the approach not effective, 16 (57.1%) of them found it quite effective and 7 (25%) found it effective. For what concerns the division in steps, 1 teacher (3.6%) found the approach not very effective, 7 (25%) teachers found it quite effective and 20 (71.4%) found it very effective. Finally, 1 (3.6%) teacher found the use of text-enriched problems not very effective, 13 (46.4%) found it quite effective and 14 (50%) very effective.

In section 2, teachers evaluated four aspects regarding their tutoring/coaching activity during students CPS laboratory. We obtained 23 answers in three items regarding students' engagement, comprehension of the problem and capability to apply the solving method (Fig. 2). Students' engagement was rated as sufficient by 3 teachers (13.1%), good by 13 teachers (56.6%) and very good by 7 teachers (30.4%). Students' comprehension was rated as sufficient by 8 teachers (34.8%), good by 8 teachers (34.8%) and very good by 7 teachers (30.4%). Students' capability to apply and implement the CPS method was rated as sufficient by 11 teachers (47.8%), good by 11 teachers (47.8%) and very good by 1 teacher (4.4%). Finally, teachers rated the difficulty level of problems presented to students. We obtained 22 evaluations: 3 teachers (13.6%) rated it as low, 15 teachers (68.2%) as medium and 4 (18.2%) as high.

In the last section, teachers rated their interest in CPS method. They also evaluated the replicability of the experience in high school classes (see Table 4). In the case of their interest, we obtained 27 answers distributed as follows: 1 teacher (3.7%) found the activity as interesting, 6 (22.3%) teachers found it as quite interesting, 8 (29.6%) found it interesting, and 12 (44.4%) reputed it very interesting. Concerning the replicability of the method in class, we obtained 28 answers: 3 (10.7%) teachers rated it as not replicable ("No"), 14 (50%) as partly replicable ("Partly") and 11 (39.3%) as replicable ("Yes").

3.2 Students

We report results on students' questionnaire and elaborates. The list of questions and corresponding results is shown in Table 4.

Among the 98 students participating at the CPS laboratory, only 79 (80.6%) of them decided to fill the questionnaire. In the first section, students answered to 4 general questions about the CPS activity and the preparation they had to participate at the laboratory (Fig. 3). For what concerns understanding the problem, 6 students (7.6%) declared to have partly understood the text, whereas the rest (73, 92.4%) declared to have completely understood the text. Regarding the step-division typical of CPS method, 3 students (3.8%) did not understand the procedure, 21 students (26.6%) declared to have partly understood it and 55 (69.6%) to have completely understood it. In the case of the division in roles within the group, 9 students (11.4%) declared to have partly understood the procedure, the rest (70, 88.6%) to have completely understood it. Finally, when we asked if they have been prepared by their teachers to participate to the activity, 23 students (29,1%) answered “yes”, whereas 56 (70,9%) answered “no”.

In section 2, students self-evaluate their experience in solving a problem by means of CPS methodology (Fig. 4). For what concerns focusing the problem, 3 students (3.8%) rated the experience as partly solved, whereas the rest (76 students, 96,2%) rated as solved. In the case of describing the physics behind the problem, 1 student (1.3%) rated the activity as unsolved, 25 students (31.6%) as partly solved, 53 students (67.1%) as solved. For what concerns the students’ evaluation in planning a solution strategy, 11 students (13.9%) rated the activity as partly solved, whereas the rest (68 students, 86.1%) as solved. The execution of the solution strategy has been evaluated as unsolved by 2 students (2.5%), as partly solved by 18 students (22.8%) and as solved by 59 students (74.7%). Finally, the final CPS step (evaluation of the final solution) has been evaluated as unsolved by 7 students (7.6%), as partly solved by 25 students (31.6%) and as solved by 50 students (61.7%).

In section 3, students went deeper in the self-evaluation of their contribution in specific aspects of CPS laboratory as single and as a group. For convenience, we firstly report students’ evaluation on their single contributions (Fig. 5). For what concerns to find a solution of the problem, 2 students (2.5%) evaluated their single contribution as irrelevant, 4 (5.1%) as minimal, 23 (29.1%) as discrete, 40 (50.6%) as important and 10 (12.7%) as essential. For what concerns the single contribution in analysing the solution strategy, 1 student (1.2%) evaluated it as irrelevant, 3 (3.8%) as minimal, 23 students (29.1%) as discrete, 31 (39.2%) as important and 21 students (26.6%) as essential. The single contribution in planning a mathematical solution has been evaluated as irrelevant by 1 student (1.3%), as minimal by 4 students (5.1%), as discrete by 24 students (30.3%), as important by 32 students (40.5%) and as essential by 18 students (22.8%). Finally, students evaluated their single contribution in using a logic and organized approach to find the solution of the problem as follows: 1 student (1.3%) rated it as irrelevant, 4 (5.1%) as minimal, 20 (25.3%) as discrete, 37 (46.8%) as important, 17 (21.5%) as essential.

When students have been asked to evaluate the group contribution we obtained the following results (Fig. 6): in the item “to find a solution”, 1 student (1.3%) evaluated the group contribution as irrelevant, 3 students (3.8%) as minimal, 23 (29.1%) as discrete, 31 (39.2%) as important and 21 (26.6%) as essential. For what concerns the group contribution in analysing the solution strategy, 1 student (1.3%) evaluated it as irrelevant, 1 (1.3%) as minimal, 22 students (27.8%) as discrete, 34 (43.0%) as important and 21 (26.6%) as essential. The group contribution in planning a mathematical solution has been evaluated as irrelevant by 2 students (2.5%), as minimal by 1 student (1.3%), as discrete by 22 students (27.8%), as important by 28 students (35.4%) and as essential by 26 students (33.0%). Finally, the group contribution in using a logic and organized approach to find a solution has been evaluated as irrelevant by 2 students (2.5%), as minimal by 3 students (3.8%), as discrete by 17 students (21.5%), as important by 29 students (36.8%) and as essential by 28 students (35.4%).

In section 4, students evaluated if their level of physics knowledge was adequate or not to face up with the presented problem and, according to them, the enforceability (replicability) of the CPS method in class (Fig. 7). In the former case, 5 students (6.3%) rated as inadequate (“no”) their level of physics knowledge, 24 students (30.4%) rated it as “partly” adequate and 50 students (63.3%) rated it as adequate (“yes”). In the latter case, 9 students (11.4%) rated the activity as not enforceable (“no”), 37 students (46.8%) as “partly” enforceable and 33 students (41.8%) as enforceable (“yes”).

In the final section, students rated the difficulty level of the presented problem and their interest in the CPS activity (Fig. 8). For what concerns the difficulty level, 7 students (8.9%) rated it as very low, 22 (27.8%) as low, 36 (45.6%) as medium, 14 (17.7%) as high, and none (0.0%) as very high. In the case of their interest in CPS activity, 2 students (2.5%) rated it as very low, 3 (3.8%) as low, 16 (20.3%) as medium, 42 (53.1%) as high, 16 (20.3%) as very high.

3.3 Analysis of students elaborates

As mentioned in the previous section, we analysed the 98 elaborates of the students participating at CPS laboratory by ranking each step of the implemented solution scheme in a 0-1 rank (see Table 6). The results are collected in Fig. 10 by grouping as insufficient (0.0 – 0.4 range), sufficient (0.5 – 0.7 range) and good (0.8 – 10.0 range).

For what concerns the "focusing" item, 3 students (3.0%) reported an insufficient vote, 27 students (27.3) reported a sufficient vote and 68 students (69.7%) reported a good vote. Students reporting an insufficient vote in the "description" item were 18 (18.2%), the ones with a sufficient vote were 39 (39.4%) whereas the ones reporting a good vote were 41 (42.4%). For what concerns the "planning" step, 27 students (27.3%) reported an insufficient vote, 27 students (27.3%) a sufficient vote and 44 students (45.5%) a good vote. 30 students (30.3%) reported an insufficient vote in the "execution" step, whereas 15 (15.2%) and 53 (54.5%) students reported sufficient and good votes, respectively. Finally, concerning the "evaluation" step, 65 students (66.7%) reported an insufficient vote, 15 students (15.2%) reported a sufficient vote and 18 (18.2%) reported a good vote.

3.4 Analysis on gender and schools' distribution

It is interesting to infer something about gender performances obtained by students during the results. The cooperative problem-solving course we proposed was not focused in obtaining results from single students in a group. Moreover, as shown in Table 1, groups are mixed with males and females randomly distributed among groups. These two aspects make more involved any analysis on this topic. Nevertheless, here we propose statistical results based on gender analysis of students elaborates (see Table 7).

Considering every CPS step, we firstly decided to attribute to each student the vote reported by his group (see Table 1). This choice is certainly not unique; however, it is the most conservative and reliable one for our purposes, at least from a statistical point of view. We will further discuss this point in the next section. Then, we considered the sum of males and females votes separately and divided them for the total number of students for a given gender. According to our analysis, these are the results: concerning the "focusing" step, females and male obtained both good votes, 0.8 and 0.7 points, respectively (both "good"). Concerning the "description" step, females obtained 0.7 points ("good") and males 0.6 points ("good"). In the "planning" step, females reported 0.6 points ("good"), whereas males 0.7 ("good"). Finally, in the evaluation "step" females reported 0.4 points and males 0.3 (both "insufficient").

4. Discussion

In this section we discuss results obtained from teachers and students in CPS activities.

4.1 Teachers

As mentioned in section 2 and 3, teachers' questionnaire was composed by three different sections. Section 1 and 3 were addressed to all teachers, whereas section 2 was only for those of them who participated at students' laboratory. Among the entire sample participating at the course (36 teachers), only 28 (77.8%) answered to the questionnaire. Moreover, we noticed that some teacher did not answer to some question in the common part of the questionnaire. This happened twice, in the evaluation of the difficulty of the problems presents to students and in the evaluation of their interest of CPS activities. We do not know the reason why we lack of such a data, probably it is due to some technical problem encountered by the teachers in filling the online form.

Teachers results on their experience in CPS laboratory are shown in Table 4. In general, the overall evaluation was positive, being the different aspects of CPS rated quite or very efficient by most of the teachers (Figs. 1 and 2). The majority of them gave also a positive evaluation on the replicability of the activity in high school classes, thus confirming the usefulness of the methodology with high school students.

What emerges from our analysis is that this experience allowed them to better understand the method and to evaluate its reliability in a class contest, suggesting an easier implementation in the final classes of the high school where the age and expected ripeness of students could make easier management and supervision of student groups. It should be noted that, when privately interviewed about their roles as coachers during students CPS laboratory, teachers declared a minimal coaching activity, mainly devoted to simplifying understanding and separating the different steps of the method. Coaching was evaluated positively to ignite the discussion.

The division in steps was found complex and somehow artificial, being not perfectly clear the separation among too much steps perceived as redundant. In general, the experience was evaluated as interesting (96.3% rated it >3 in a 1 – 5 scale).

4.2 Students

Students' results on their CPS experience are shown in Figs. 3 – 10. In general, students feel confident with their comprehension of the problem and their capability to apply the solution method ("steps"), even though the matter was not prepared in class before attending the laboratory (Figs. 3 and 4). Students also felt positive when appraising their contribution as a single or within the group cooperation (both rated at least discrete in general, see Figs. 5 and 6) and estimated as successful their results in each step of the method, being their physics knowledge evaluated as suitable for the proposed problem (Fig 7). The most appreciated aspect was the discussion within the group and the sharing of knowledge. Other beneficial aspects were the splitting in roles and the resolving scheme.

The major part of students (73.4%) rated the difficulty of presented problem as low (27.8%) and medium (45.6%), respectively (Fig. 8). This has not affected their interest in the CPS activity, rated as as interesting (20.3%) and very interesting (53.1%) by the majority of them (73.4%).

As reported in Table 6 and Fig. 9, students experienced increasing difficulties in the different steps of the solution scheme. More than 80% of them were able to successfully complete the first two steps (focusing and description) and up to 70% the plan and execution steps. The percentages are totally reversed in the last step (evaluation) where the students should evaluate their results and give reasons if they found them reasonable or not. The most part of the groups did not understand the request of evaluation and at most gave the easy answer as yes or no, despite they were advised that any results should be examined in a rational basis. It should be noted that this is in contrast with the student feeling of successfully reaching the solution. It indicates, in our opinion, that the general approach of the students to solve a problem is to find a number, with no further speculation on the reliability and soundness of the found number, evidencing a general lack of the capacity of abstraction and generalization. This was already reported in previous studies [4] and in general refers to the different approach of expert and novice to problem solving [12-14,30]. Improving their critical sense is a crucial aspect to increase their problem-solving ability, allowing conversion of novices into experts and helping the students in developing a more objective self-analysis of their performances.

The gender analysis confirms what emerges from results about students' elaborates. As mentioned in the previous section, the cooperative problem-solving course we proposed was not focused in obtaining results from single students in a group. However, due to the composition of the sample we reputed as interesting to explore whether there were or not any gender differences in students' performances during CPS activities. One limit of our approach is that we cannot perform any statistical correlation between groups' results on their elaborates and, possibly, gender ones. Our analysis is merely based on simple statistical considerations about gender distribution in the sample and what follows is the result coming from it. As show in Table 7 and Fig. 10, female students obtained better results than male schoolmates in focusing and describing the problem they were looking at. Male students were more efficient than females' colleagues in planning strategies and executing calculation to find solutions to problems. For what concerns the last step, evaluation, the results are comparable for the twos. However, in females it emerges a slight increased capability to evaluate the goodness of the obtained results with respect to male students. The results of our analysis confirm what is well known in literature about gender differences in physics problem solving [6,26,27].

5. Conclusions

We proposed the cooperative problem-solving technique (CPS) to high-school physics teacher and discussed its applicability to Italian high-school classes by performing an experience of CPS where the teachers acted as solvers. We also simulated an application of the method to students from final years of high schools (10^{th} to 12^{th} grades) to verify how the students evaluate the new technique (in this case the teachers acted as tutors or coaches). Teachers appreciated the method and suggested that classes in final years of high schools could be the proper ones where the method could be introduced because of the need of abstraction and speculation. The most appreciated aspects were the group working and text rich context, evaluated as really positive in stimulating student engagement, even though preparation of rich context problems requires lot of effort. The students appreciated the same aspects but perceived the problem division in different steps and somehow the role splitting as a compelling over structure. The analysis of their performance displayed a quite good success, considering that there was not, in general, previous preparation and it was their first attempt in CPS. However, the analysis displayed also some difficulties in separating the different steps of the methods, despite the use of a solution scheme, and, above all, showed a large fault in the self-evaluation process and in the evaluation of the reached results. These findings show that there is a large need to develop critical sense and abstraction abilities of students to improve their problem solving skills, results which could be achieved by CPS implementation in high school classes.

Finally, we have examined results on students' elaborates from a gender perspective. We have found a confirmation of previous analysis about gender differences in physics problem solving [6,26,27]. The analysis have shown that females students are more capable than male ones in focusing and describing the problem they are looking at. On the contrary, male students have been more efficient than females' colleagues in planning strategies and executing calculation to find solutions to problems. For what concerns the CPS step called "evaluation", the results are comparable for the twos. However, a slight increased capability to evaluate the goodness of the obtained results appears in females' data with respect to males' ones

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List of Tables

Table 1. In column 1, the list of CPS groups with related working problems; in column 2, the indication of typology of schools and the number of students per group (in parentheses). Column 3 shows the gender distribution of students per group. Column 4 shows groups results in CPS steps: letter “F” stays for “Focusing”, letter “D” for “Description”, letter “P” for Planning, letters “Ex” for “Execution”, letters “Ev” for “Evaluation”. Ranges of votes spans from insufficient (0.0 – 0.4) to sufficient (0.5 – 0.7) and good (0.8 – 1.0).

Problem/Group	***School (N of students)***	***N of students per gender***	***Results in CPS steps***				
			F	***D***	***P***	***Ex***	***Ev***
A/1	Scientific (3)	1 F, 2 M	0.8	0.5	0.9	1.0	0.0
A/2	Scientific (3)	3 M	0.6	0.5	0.5	0.5	0.5
A/3	Scientific (3)	1 F, 2 M	1.0	0.8	0.0	0.3	0.3
A/4	Scientific (3)	2 F, 1 M	0.7	0.7	0.7	0.3	0.4
A/5	Scientific (3)	3 F	1.0	0.5	0.7	0.8	0.2
B/1	Classical (3)	3 F	0.8	0.8	0.2	0.0	0.0
B/2	Scientific (3)	3 M	0.8	0.7	0.4	0.7	0.0
B/3	Classical (3)	1 F, 2 M	0.7	0.4	0.4	0.3	0.0
B/4	Classical (3)	1 F, 2 M	0.8	0.5	0.3	0.2	0.0
B/5	Classical (3)	2 F, 1 M	0.3	0.0	0.5	0.5	0.0
B/6	Scientific (3)	3 F	0.6	0.3	1.0	0.5	0.0
B/7	Scientific (2), Classical (1)	3 M	0.5	0.5	0.8	0.7	0.0
B/8	Scientific (3)	3 M	0.7	0.6	0.3	0.0	0.0
B/9	Scientific (3)	2 F, 1 M	0.8	0.8	1.0	0.8	0.6
B/10	Classical (3)	2 F, 1 M	0.8	0.7	0.4	0.4	0.0
B/11	Scientific (3)	1 F, 2 M	0.7	1.0	0.7	0.8	0.9
B/12	Scientific (3)	3 M	0.8	0.6	1.0	0.9	0.8
B/13	Scientific (3)	3 M	0.5	0.2	0.7	0.8	0.0
C/1	Scientific (3)	3 M	0.7	0.8	0.9	1.0	0.9
C/2	Scientific (3)	2 F, 1 M	0.8	0.8	0.8	1.0	0.7
C/3	Scientific (3)	1 F, 2 M	0.8	0.8	1.0	1.0	0.0
C/4	Scientific (4)	1 F, 3 M	0.8	0.8	0.9	1.0	0.0
C/5	Scientific (3)	3 M	0.8	1.0	1.0	0.8	0.7
C/6	Scientific (3)	3 M	1.0	1.0	0.9	1.0	0.9
C/7	Scientific (3)	1 F, 2 M	0.8	0.9	1.0	1.0	0.9
C/8	Scientific (3)	3 M	0.8	0.8	0.8	1.0	0.7
C/9	Scientific (3)	1 F, 2 M	0.8	1.0	0.5	0.5	0.0
C/10	Scientific (3)	1 F, 2 M	0.9	0.3	0.4	0.3	0.0
C/11	Scientific (4)	4 F	1.0	0.7	1.0	0.8	0.0
C/12	Scientific (3)	3 M	0.9	0.7	1.0	1.0	0.9
C/13	Scientific (3)	1 F, 2 M	0.9	1.0	0.7	1.0	0.0
C/14	Scientific (3)	3 M	0.8	0.5	0.7	0.8	0.0

Table 2. Composition and ages (in average) of the students' sample coming from scientific high schools

	Third Year (10th grade)	*Fourth Year (11th grade)*	*Fifth Year (12th grade)*	*Mean Age (years old)*
Females	3	3	19	17.6
Males	7	11	39	17.6
Total	10	14	58	17.6

Table 3. Composition and ages (in average) of the students' sample coming from classical high schools

	Fourth Year (11th grade)	*Fifth Year (12th grade)*	*Mean age (years old)*
Females	7	2	17.2
Males	4	3	17.4
Total	11	5	17.3

Table 4. Schematic list of questions posed to teachers to evaluate the CPS activity (left column) and related results (right column). On the left column, we specify the number of answers we received per item from teachers. On the right, we also indicate the specific ranking scale for each section.

Questions (Number of answers)	*Results*				
Section 1	***Ranking scale: 1 (not effective) – 3 (effective)***				
	1	**2**	**3**		
1. Distinction in roles (28)	17.9%	57.1%	25.0%		
2. Distinction in steps (28)	3.6%	25.0%	71.4%		
3. Text-enriched problems (28)	3.6%	46.4%	50.0%		
Section 2	***Ranking scale: 1 (insufficient) – 4 (excellent)*** ***Ranking scale for question 7: 1 (very low) – 4 (very high)***				
	1	**2**	**3**	**4**	
4. Engagement (23)	0.0%	13.1%	56.5%	30.4%	
5. Comprehension of the problem (23)	0.0%	34.8%	34.8%	30.4%	
6. Implementation of the method (23)	0.0%	47.8%	47.8%	4.4%	
7. Difficulty level of the problem (22)	0.0%	13.6%	68.2%	18.2%	
Section 3	***Ranking scale for question 8: 1 (very low) – 5 (very high)*** ***Ranking scale for question 9: 1 (no), 2 (parly), 3 (yes)***				
	1	**2**	**3**	**4**	**5**
8. Interest (27)	0.0%	3.7%	22.3%	29.6%	44.4%
	No	**Partly**	**Yes**		
9. Replicability in class (28)	10.7%	50.0%	39.3%		

Table 5: Schematic list of questions posed to students to evaluate the CPS activity and related results. On the left column we indicate the number of answers we received from students (79). On the right we show the results, indicating the specific ranking scale for each section of the questionnaire.

Questions (79 answers)	***Results***				
Section 1	***Ranking scale: 1 (no), 2 (partly), 3 (yes)***				
	1	**2**	**3**		
1. Comprehension of the problem	0.0%	7.6%	92.4%		
2. Comprehension of the step division	3.8%	26.6%	69.6%		
3. Comprehension of roles	0.0%	11.4%	88.6%		
4. Preparatory School activity on CPS	70.9%	0.0%	29.1%		
Section 2	***Ranking scale: 1 (unsolved) – 3 (solved)***				
	1	**2**	**3**		
5. Evaluate step 1 (Focusing)	0.0%	3.8%	96.2%		
6. Evaluate step 2 (Description)	1.3%	31.6%	67.1%		
7. Evaluate step 3 (Planning)	0.0%	13.9%	86.1%		
8. Evaluate step 4 (Execution)	2.5%	22.8%	74.7%		
9. Evaluate step 5 (Evaluation)	8.9%	31.6%	59.5%		
Section 3	***Ranking scale: 1 (irrelevant) – 5 (essential)***				
Evaluate your contribution as a single to	**1**	**2**	**3**	**4**	**5**
10. find a solution of the problem	2.5%	5.1%	29.1%	50.6%	12.7%
11. analyse the solution strategy	1.3%	3.8%	29.1%	39.2%	26.6%
12. plan a mathematical solution	1.3%	5.1%	30.3%	40.5%	22.8%
13. find/solve the proper equations	1.3%	5.1%	25.3%	46.8%	21.5%
Evaluate the group contribution to	**1**	**2**	**3**	**4**	**5**
14. find a solution of the problem	1.3%	3.8%	29.1%	39.2%	26.6%
15. analyse the solution strategy	1.3%	1.3%	27.8%	43.0%	26.6%
16. plan a mathematical solution	2.5%	1.3%	27.8%	35.4%	33.0%
17. find/solve the proper equations	2.5%	3.8%	21.5%	36.8%	35.4%
Section 4	***Ranking scale: 1 (no), 2 (partly), 3 (yes)***				
	1	**2**	**3**		
18. Adequate level of knowledge	6.2%	29.6%	64.2%		
19. Enforceability of CPS method	11.1%	45.7%	43.2%		
Section 5	***Ranking scale: 1 (very low) – 5 (very high)***				
	1	**2**	**3**	**4**	**5**
20. Difficulty of the problem	8.9%	27.8%	45.6%	17.7%	0.0%
21. Interest	2.5%	3.8%	20.3%	53.1%	20.3%

Table 6. Analysis of students' elaborates and related votes they obtained in every CPS step. We show the percentage of students with insufficient results (0.0 – 0.4 range), sufficient (0.5 – 0.7 range) and good results (0.8 – 1.0 range). The number of elaborates was 98.

Range of votes	Focusing	Description	Planning	Execution	Evaluation
0 – 0.4	3.0%	18.2%	27.3%	30.3%	66.7%
0.5 – 0.7	27.3%	39.4%	27.3%	15.2%	15.2%
0.8 – 1.0	69.7%	42.4%	45.5%	54.5%	18.2%

Table 7. Votes reported by students in CPS steps divided per gender. The sample was composed by 98 students, 64 males (65.3%) and 34 (34.7%) females.

CPS Steps	Females	Males
Focusing	0.8	0.7
Description	0.7	0.6
Planning	0.6	0.7
Execution	0.6	0.7
Evaluation	0.4	0.3

List of Figures

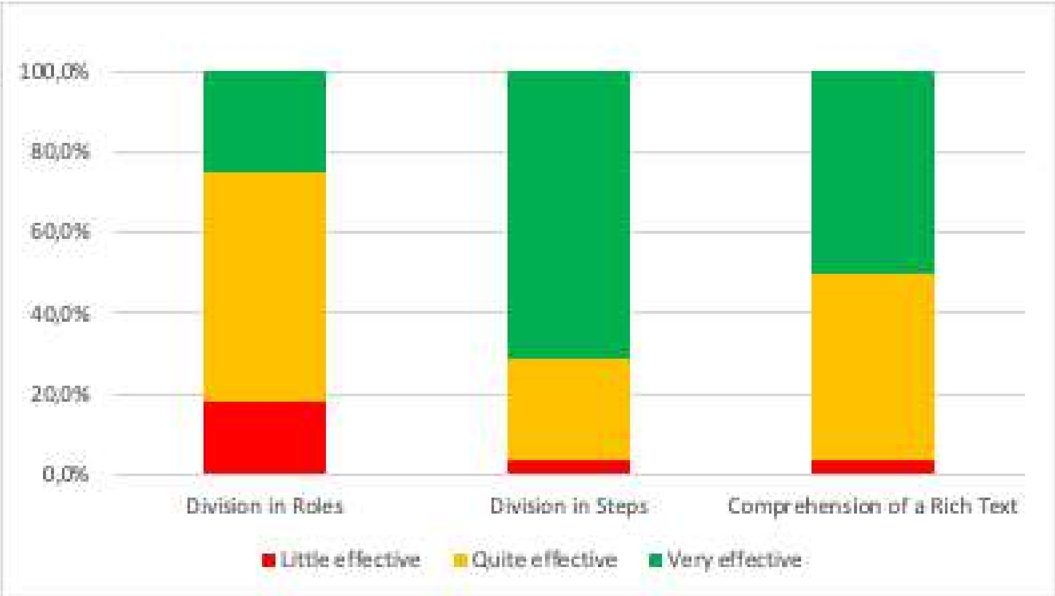

Fig. 1: How teachers evaluated different elements of CPS: from left to right, the distinction in roles, the distinction in steps and the use of text-enriched problems. The rank scale is 1 (little effective), 2 (quite effective) and 3 (very effective).

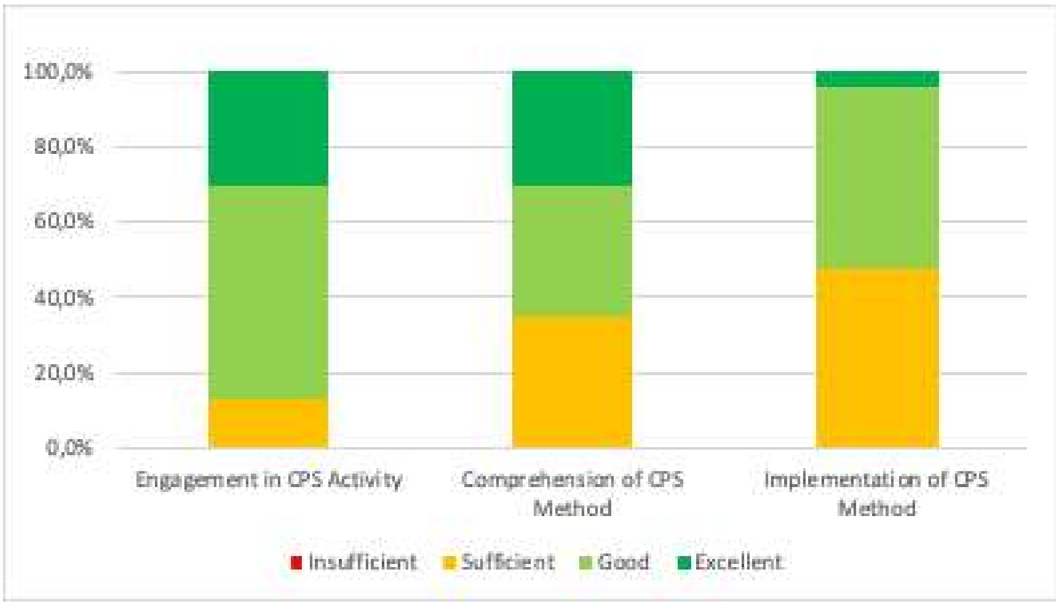

Fig. 2: Teachers evaluation of CPS experience with students: from left to right, students' engagement in CPS activity, comprehension of CPS method and capability to implement the CPS method during the problem solving activity. The ranking scale is 1 (insufficient), 2 (sufficient), 3 (good), 4 (excellent

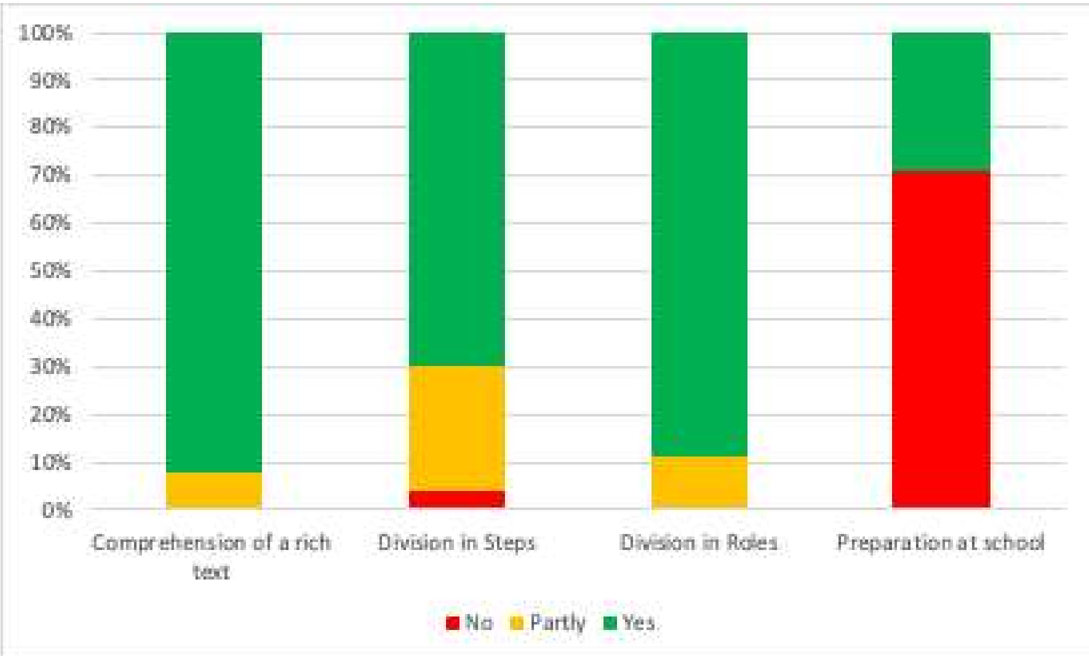

Fig. 3: Students evaluation of CPS experience in 4 different aspects: from left to right, comprehension of the text-enriched problem, comprehension of division in steps, comprehension of division in roles and preparation to the activity at school. The ranking scale is 1 (no), 2 (partly), 3 (yes).

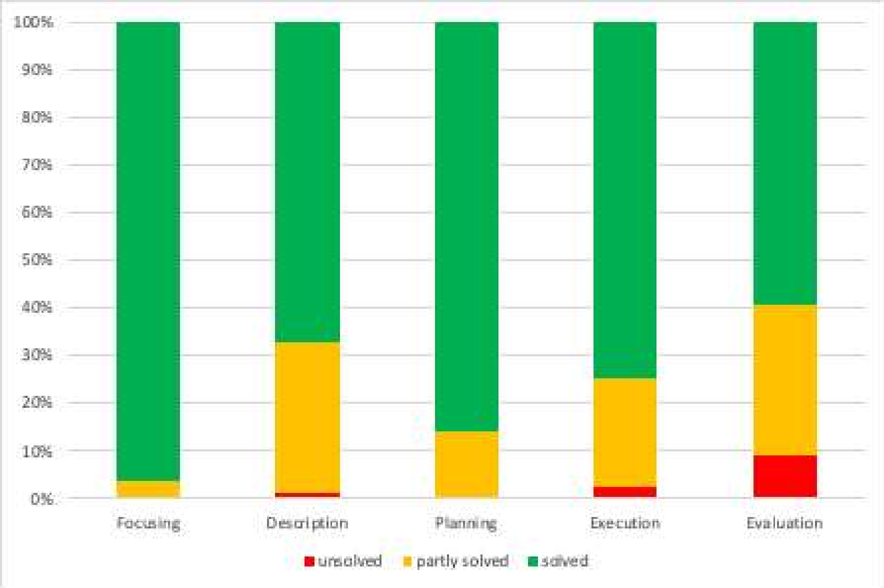

Fig. 4: Students self-evaluation of their success in CPS steps (from left to right): focusing the problem, description of the physics, planning the solution strategy, execution of the strategy, evaluation of the solution.

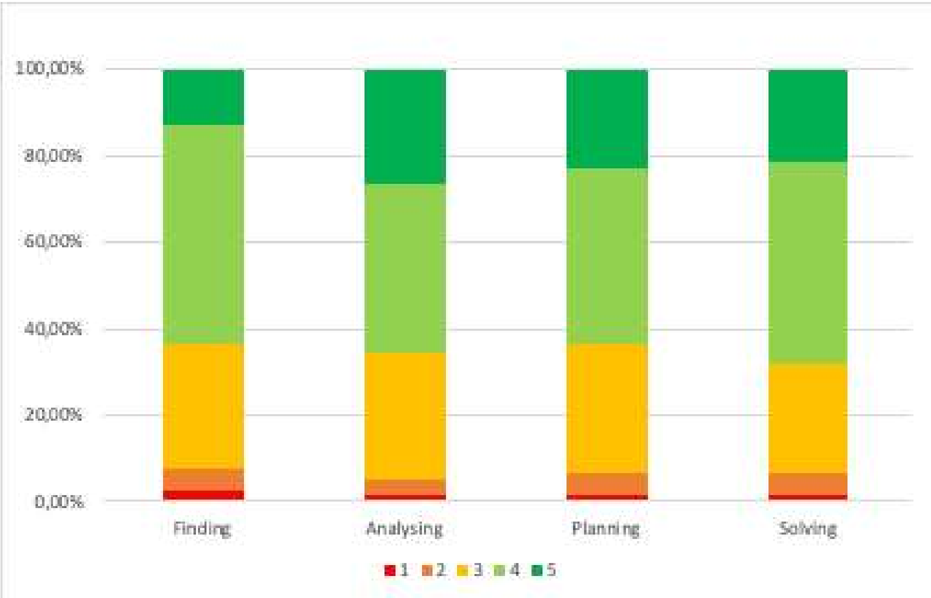

Fig. 5: Students self-evaluation of their single contributions in 4 specific aspects of CPS activities (from left to right): finding the solution of the problem, analysing the solution strategy, planning a mathematical solution, using a logic and organized approach to find a solution.

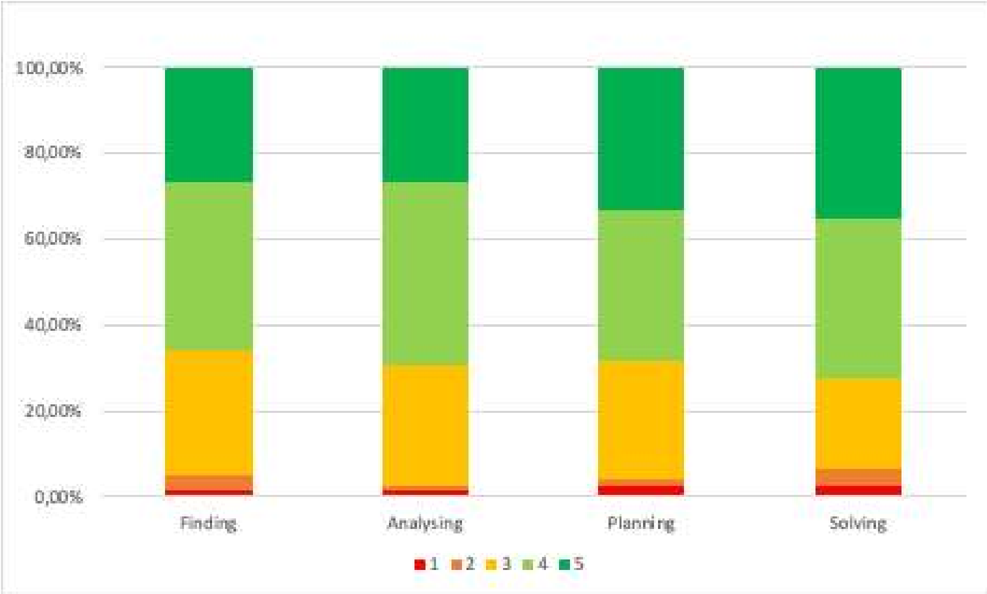

Fig. 6: Students self-evaluation of group contribution in 4 specific aspects of CPS activities (from left to right): finding the solution of the problem, analysing the solution strategy, planning a mathematical solution, using a logic and organized approach to find a solution.

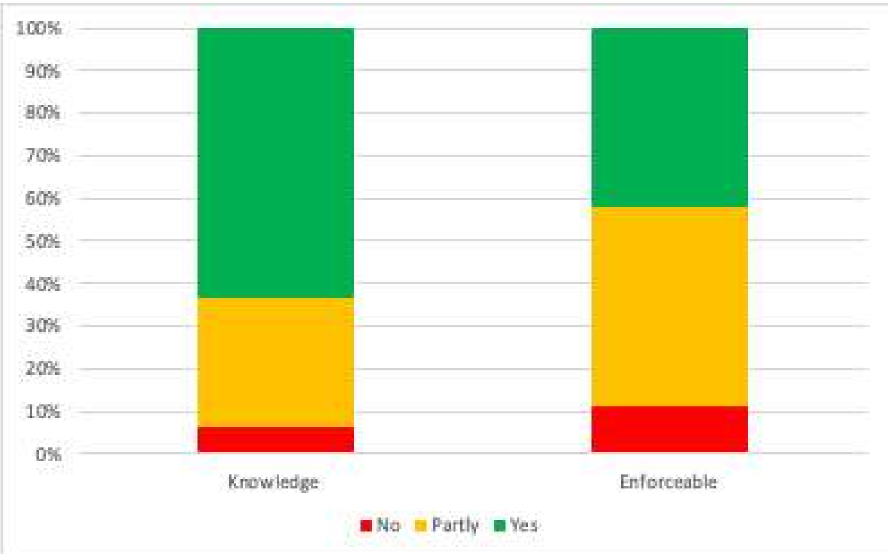

Fig. 7: Students' evaluations on the adequateness of their physics knowledge to face up with the presented problems (on the left) and on the enforceability of the activity in class (on the right)

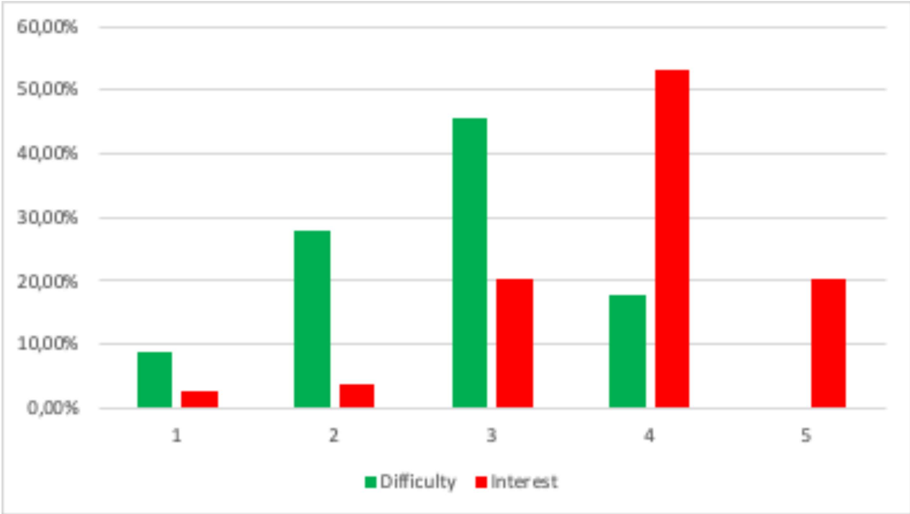

Fig. 8: Students' rates on the difficulty of the presented problems (on the left) and on their interest in the CPS activity (on the right). In both cases, the ranking scale goes from 1 (very low) to 5 (very high).

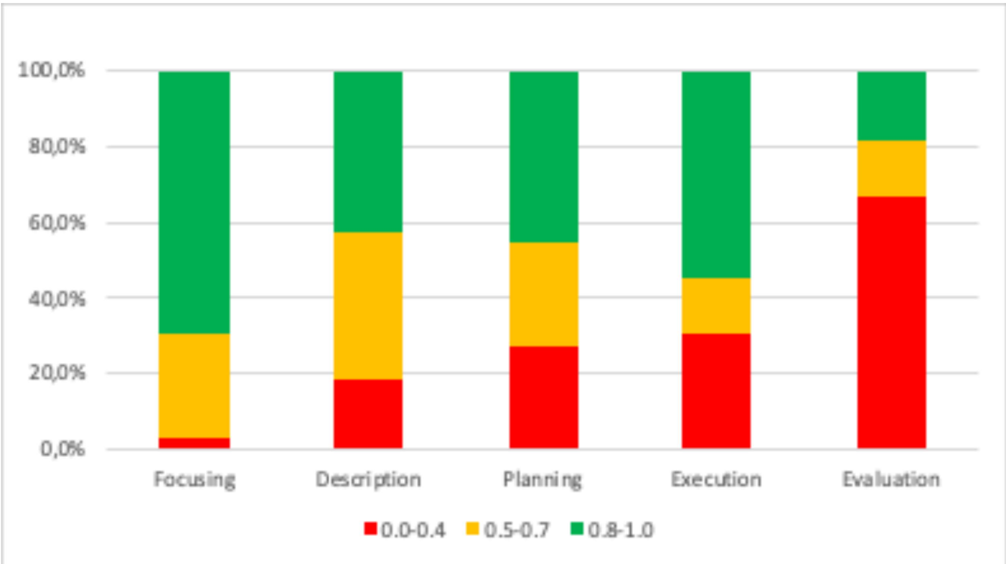

Fig. 9: Analysis of the students elaborates. In red the percentage of students with insufficient results (0.0 – 0.4 range); in yellow, the percentage of students with sufficient results (0.5 – 0.7 range); in green, the percentage of students with good results (0.8 – 1.0 range).

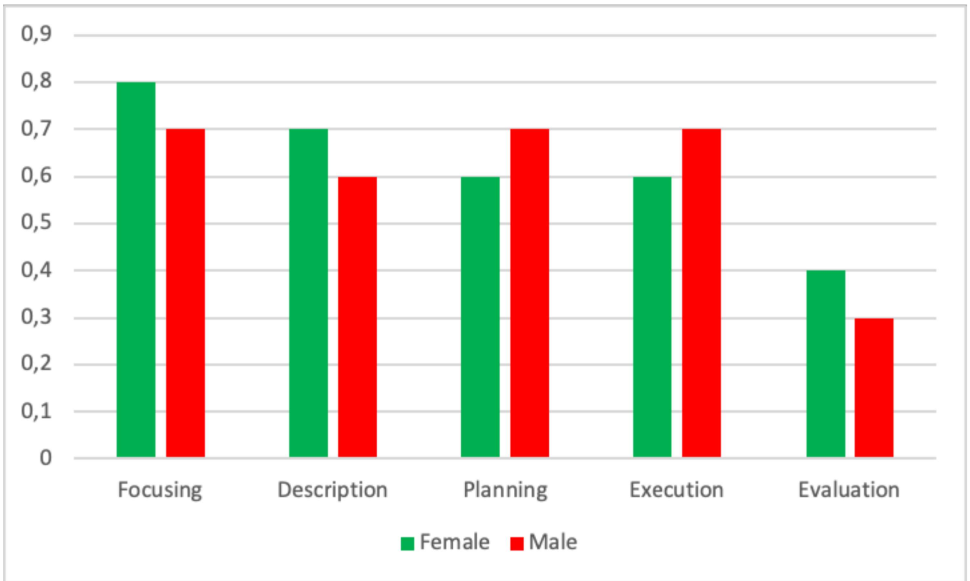

Fig 10: Votes Distribution per Gender. In green, female results; in red male results. The votes scale is insufficient (0.0 – 0.4), sufficient (0.5 – 0.7), good (0.8 – 1.0).

Supplementary Files

SF1: List of text-enriched problems presented to students (in Italian).

Problem A: Gettando al vento ogni prudenza non hai retto alla tentazione della torta gelato alla festa di compleanno di un tuo amico. Preso dai rimorsi, dopo guardi il retro della confezione e scopri che una porzione di torta ha un contenuto di 400 Calorie. Poiché non vuoi vanificare la dieta fatta degli ultimi tre mesi, decidi di andare in palestra a fare un po' di sollevamento pesi per bruciare queste calorie. Prima di uscire di casa però ci pensi su e calcoli quante volte dovresti sollevare un peso di 10 kg ad un'altezza di 1 m. Ti chiedi quindi se per il futuro sia più saggio resistere alla tentazione.

Problem B: Mentre sei al ristorante un tuo amico ti parla delle ricerche della cosiddetta materia oscura. Ha letto che, secondo la teoria della gravitazione di Newton, i pianeti orbitano attorno a una stella o le stelle attorno al centro galattico con velocità che decrescono in funzione della distanza dal centro. Numerose osservazioni hanno evidenziato come nelle zone più esterne della galassia, la velocità smette di decrescere e una possibile interpretazione è la presenza di ulteriore materia "oscura" non visibile (perché non emette luce) oltre a quella ipotizzata nelle zone più centrali. Affascinato dall'idea, poiché hai appena studiato i moti planetari, decidi di calcolare la velocità e l'energia cinetica di un pianeta in orbita attorno a una stella in funzione del raggio dell'orbita e delle masse del pianeta e della stella. Confronti quindi le velocità di rotazione e le energie cinetiche della Terra e di Giove, i cui raggi orbitali sono 150 x 10^6 km e 778 x 10^6 km. La massa del Sole è circa 2 x 10^{20} kg, quella della Terra 2 x 10^{24} kg. Giove è 318 volte più massiccio della Terra.

Problem C: Mentre sei al ristorante un tuo amico ti parla di un libro sulla struttura degli atomi. Ha letto che secondo la teoria di Bohr, gli elettroni sono in moto circolare uniforme attorno al nucleo. Immaginando che l'atomo sia un microscopico sistema planetario, decidi di calcolare l'energia cinetica di un elettrone in orbita attorno a un protone in un atomo di idrogeno in funzione del raggio dell'orbita e delle proprietà dell'elettrone e del protone. Calcoli quindi quanto vale l'energia cinetica per il raggio dell'orbita più piccola, che è 0.5 x 10^{-10} metri.

SF2: Scheme of CPS activity for students (in Italian).

FOCALIZZARE IL PROBLEMA

A. **Figura e quantità utili (informazioni date):**

B. **Domanda:**

C. **Approccio:**

DESCRIVERE LA FISICA

A. **Diagrammi della situazione e definizione delle variabili**

B. **Quantità bersaglio:**

C. **Possibili equazioni utili:**

PIANIFICARE LA SOLUZIONE A. Catena di equazioni per ottenere una soluzione	ESEGUIRE IL PIANO A. Seguire lo schema del piano
B. Verifica della sufficienza:	B. Verifica delle unità:
C. Delineare i passaggi risolutivi:	C. Calcolo del valore della quantità bersaglio:

VALUTARE LA SOLUZIONE
Il risultato matematico risponde alla domanda posta? Il risultato è nelle unità corrette Il risultato è ragionevole?