Attracting Talent to Increase Interest for Engineering among Secondary School Students

Team-based building of a Remotely Operated Underwater Robot

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Abstract—**This paper reports our experience in developing a team-based project activity to promote engineering programs among secondary school students. The aim of the activity is to increase the interest of students for science and technology in general, but also to promote engineering skills, capabilities and values, leading to attract more secondary school students to enrollment for engineering programs. Simple theoretical concepts are illustrated through hands-on experimentation. To achieve this goal, the students build a Remotely Operated Underwater Robot in a 2½-day workshop. The robot is built using low-cost materials and the students customize their own design over the different phases of the workshop. Once the activity is completed, every team understands that with teamwork, effort and a good working strategy, every problem can be overcome. At the end of the activity, a survey is conducted through an assessment survey questionnaire which reflects different aspects related with the development of the activity and the degree to which learning of its different facets has been achieved. The responses and feedback from students serve not only to evaluate the workshop, but also as feedback for future fine-tuning of the different phases as pedagogical learning tools.**

Keywords: Increasing Interest for Engineering; Attracting Talent; Secondary School Student; Hands-on Experiments; Project-based Learning

I. INTRODUCTION

Project based activities are a good way to expose secondary school students to more science and math at earlier grades. Children are naturally curious about the world around them. Science is the perfect vehicle to answer many of their questions when they try to solve a problem. Unfortunately, as children grow older, they may perceive engineering as a difficult and unknown subject, and this perception has derived in the last few years in a decrease of enrollment for engineering programs in Spain. For this reason, the University of Girona (UdG), the Social Council of UdG and the Catalan Government started an initiative called *EnginyCAT*, with the aim of increasing the interest of students for technology and promote engineering skills, capabilities and values. These institutions support and promote scientific and technological activities of recreational nature that are attractive for students.

The advantages of such an activity are numerous. Working directly with experts at their laboratories makes really a difference in terms of student motivation and eagerness to learn. Our research group has conditioned a fully equipped experimentation lab where secondary school students and senior researchers cohabitate for some time in a learning experience. Through creating this atmosphere that makes the students feel determined to learn, engineering questions are better answered if the student directly puts his hands into the problem [1, 2]. This interaction with senior faculty members makes engineering concepts more tangible, more understandable and more related to applications [3].

The activity presented in this paper, inspired on the ideas of MIT *SeaPearch* [4], has been designed for students from 14- to 16-year-old, and its aim is to increase the demand for engineering degrees. The report presented here shows the first results of a workshop to build a remotely-operated underwater robot. The robot is fully built by a team of 5-6 secondary school students[1] during a 2½-day workshop, which ends with the students showing their ability to teleoperate it and to execute underwater challenging operations that are realistic approaches to real missions developed by the real Remotely Operated Underwater Robots (ROVs). These operations consist in collecting metallic parts from the bottom of the pool and placing them into a cargo (cleaning operations), launching and releasing objects using different techniques (as if they were scientific instrumentation moored on the seabed to collect data), etc . Some of these missions can only be accomplished

Figure 1. CIRS facility at the Technological Park of the University of Girona. This facility has a 18-meter long and 8-meter wide tank test, and a submerged lab with a window to observe the robots over the 5-meter deep central part of the water test tank.

[1] The maximum number of participants is 30 students, which would build 5 underwater robot prototypes.

by following collaborative strategies using more than one vehicle.

The robot prototype is built using low-cost materials, with a total cost not exceeding 60 €. Another important purpose of this activity is to introduce the students into the correct and safe utilization of standard tools.

The paper is organized as follows. The activity carried out by the students is described in Section II. Next, the assessment survey and the survey results are presented in Section III. Then, conclusions on the overall results are provided in Section IV.

II. Development of the Activity

The workshop is supervised by three faculty members. It takes place in the Underwater Robotics Research Facility (CIRS) at the University of Girona, a new modern laboratory provided with all the necessary equipments to supply such an activity (see Figures 1 and 2).

A. *Welcome presentations*

The workshop starts with three short presentations (see Figure 2). In the first one, the professors welcome the students and introduce themselves. Some instructions are given and the group starts familiarizing with the environment and the tools. In most cases, this will be the first contact of secondary school students with the university and, therefore, kindness and closeness are a must to minimize their fears while keeping the appropriate levels of respect. Professors try to encourage motivation and provide positive feedback to the students to create a positive atmosphere, which always helps when starting to work with an unknown group of pupils. As stated in [6], every learning process concerns with an emotional domain where the pupils play a fundamental role. The objective of these minutes is to make the pupils feel comfortable and confident, establishing a bidirectional communication loop among all them. This first presentation should not last more than 10 minutes.

Figure 2. Students at CIRS during a presentation.

A multimedia presentation is given next, accompanied with individual documentation of the whole activity. The length of this activity presentation should not exceed 20 minutes. An accurate temporization of the workshop and the planning strategy are described, showing the different parts of the submarine and the tools used to build them. Safety advices about tools and their correct utilization receive a special attention during all the presentation. The students are going to start a serious project, and for that purpose they need real, professional tools. It is important to remark that the safety elements (protective goggles, gloves, aprons, etc.) are as important as the tools. Moreover, students are also instructed to follow adequate security protocols and behave accordingly.

On the other hand, and as stated at the beginning of this section, the students are divided into groups of 6 pupils. In order to build a balanced teamwork, the students are accurately grouped. For this purpose, an individual questionnaire is filled in by every student [7]. This questionnaire describes their working profiles and capabilities, providing the basis to group balanced working teams and, thus, avoiding conflicting members within the same team. The first duty of the new groups is to choose a name for the team. This name will identify them and their work along the whole workshop development.

The final presentation aims to promote the research done at the Computer Vision and Robotics Group (VICOROB). The objective is to awake the student's interest in the engineering field. The numerous industrial applications around underwater technology, such as environmental monitoring, oceanographic research or maintenance/monitoring of underwater structures are presented to the pupils. The duration of this presentation should not exceed 25 minutes.

B. *First Day of the Workshop*

The first task of the students is to build the teleoperation unit illustrated in Figure 3(left). The console is made out of wood. Students must assemble the spare parts using wood glue and nails. It requires about 1 hour to cut the spare wood parts, make the needed holes on it and assemble the whole console. While the pupils wait for the glue to dry, they can start constructing the vehicle's chassis (see Figure 3-right). The structure is made of PVC pipes of different lengths linked together by means of T's, 90º and 45º elbows. Students measure and cut all the pipes using the appropriate tools. The chassis, once finished, is used as a starting point to explain and

(a) (b)

Figure 3. (a) Teleoperation unit or control console. (b) PVC chassis of a finished underwater robot.

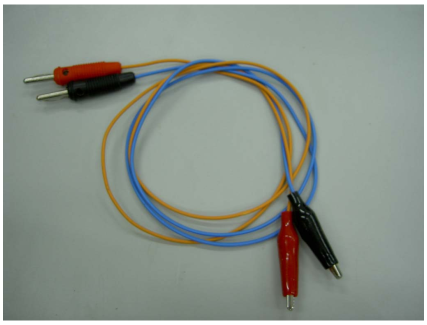
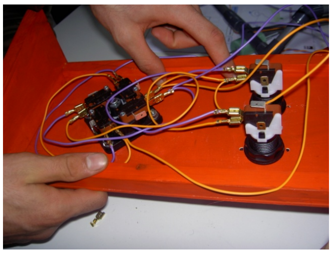
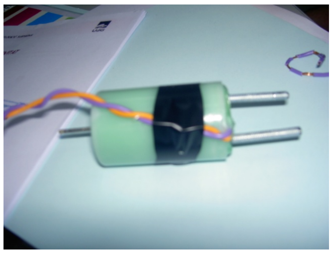


Figure 4. Testing wires equipped with alligator clips used to verify partial electric subsystems.



(a)



(b)

Figure 5. (a) Back side of the console: assembly of wire connections. (b) Wax sealed DC motor.

understand the dynamics and force-torque vectors acting on an underwater vehicle. The chassis construction takes around 1 hour.

The next step would be to start with the electrical connections. Before introducing the pupils to soldering and connectivity issues, they expend some time learning and training some electrical principles. To do so, they build a couple of "test wires", as illustrated in Figure 4. This simple tool will be used during all the electrical design and construction phases of the robot to check connections, polarities and switches. By this time, the wooded console is ready to be polished and painted. The students can feel free to decorate and customize their teleoperation units as they like, since design skills and artistic creativity are 100% compatible with engineering. Customizing the console should not last more than 30 minutes while building the test wires takes around 25 minutes.

Once the electric issues are clear, the pupils complete the first day task plan by mounting all the connection wires that will be needed for the console. The students must attach fast-on connectors to each cable edge, leaving the wire set ready for the next day. In order to level the progression of the teams, the most advanced groups can help the delayed ones with the wiring.

C. *Second Day of the Workshop*

The second day starts wiring the console up. With all the right wires prepared from the previous day, the students must assemble three DC motor polarity invertion circuits. The correct interpretation of the circuit schematics is crucial to succeed. This phase is closely guided by the teachers, since the students initiate themselves experiencing with electric components. In order to understand that a motor can rotate clockwise or counter clockwise depending on how we polarize it, the student uses the test wires to connect the DC motor to a power supply and makes it rotate in both senses. As soon as the circuit schematics have been empirically derived, the next step is to transfer the assembly to the teleoperation console, as shown in Figure 5(left). Each motor circuit is verified independently. With the installation of the push-buttons and the joystick, the teleoperation unit is finally completed.

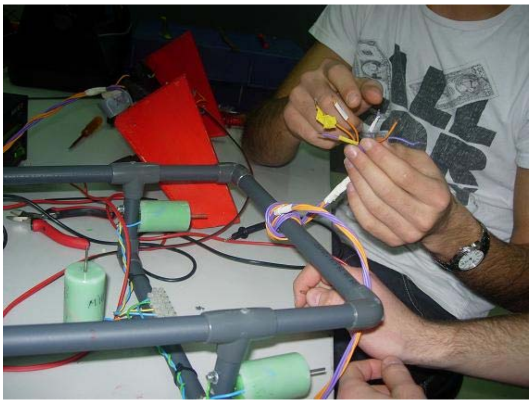
In order to prepare the motors to be submerged, the next step is to seal them with standard wax to make them watertight. For that purpose, the delicate parts of the motors are first covered with electric tape and thermal adhesive. Also, the motor shaft and the frontal plane of the motor are generously covered with petroleum jelly to prevent water coming inside the motor through the shaft. Then, the motor is introduced into a photo roll plastic case. Students have to drill a small hole at the bottom of the case for the motor shaft (see Figure 5b). Subsequently, the case is filled with melted wax. After a short period of time, when the wax hardens, we obtain a solid sealed motor with only a shaft and 2 wires coming out.

As illustrated in Figure 6(top), the final task of the second day is to fix the sealed motors to the chassis of the vehicle and connect them -by means of an umbilical tether- to the teleoperation console. With all the connections between the robot and the console established, every team must verify the correct operation of the robot. To do so, pupils must connect the console to the power supply and test the response of the vehicle's motors to the different commands given by the teleoperation console. If everything is correctly working, the vehicle is ready to face the final assembly phases to be carried out along the last day of this workshop (see Figure 6b).

D. *Third Day of the Workshop*

On the last day of the proposed activity, students only have until noon to finish their vehicles and test them in the water test tank. The adjustment of the robot's buoyancy is the last step prior to real experimentation. To be efficient, the stability and density of the vehicle is a key factor. The robot's stability and density are the result of an accurate distribution of the heavier elements at the lower part of the chassis combined with the effect of *technical foam* placed in the top, which should provide a slightly positive buoyancy to the robot, assuring that it will surface automatically in case of motor failure. For these reasons, the students must adjust the buoyancy and the stability by combining technical foam located at the top of the robot and small weights strategically placed at the bottom of the chassis. To do so, the laboratory is equipped with a small (portable) water tank, illustrated in Figure 7.

At this point, the robot is ready to begin the final experiments at the CIRS water tank. If all the previous steps have been accomplished with no delays, pupils should have



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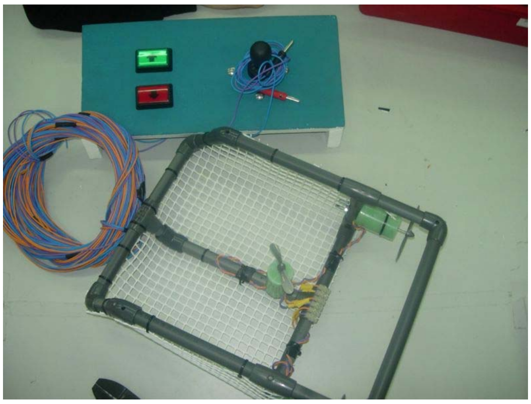


(b)

Figure 6. (a) Sealed motors and umbilical cable are fixed to the chassis. (b) Finished chassis, umbilical and teleoperation console.

around 2 hours to test, play and enjoy with their robots (see Figure 8a). At this stage, different obstacles are artificially introduced in the pool to make the students test their skills and fully experiment the performance capabilities of their robots (see Figure 8b). While playing, the robot goes through various stages of testing and final adjustments. Also, as illustrated in Figure 9a, the vehicles can be equipped with a small watertight camera which allows them to watch the underwater scene and experience navigation as professional pilots do.

Finally, students are requested to complete an assessment survey questionnaire which is used to evaluate the workshop. The results of this survey are presented in the next section. At the end of the activity, the pupils can take their robots with them and they usually like to show them in their schools (see Figure 9b).

III. ASSESSMENT SURVEY AND EVALUATION

A. *Assessment Survey*

Asking the students to fill in a survey questionnaire is a good way to evaluate activities [8]. For this reason, we have designed an assessment survey questionnaire which reflects different aspects related to the development of the activity and the degree to which learning is achieved. The responses and feedback from students served not only to evaluate the performance of the result of the activity (to have the possibility to use the underwater vehicle) in adding to the students learning process, but also as feedback for future fine-tuning of the different phases as pedagogical learning tools.

The questions asked on the corresponding assessment survey are:

Q1 What's your opinion about the availability to reach the research centre CIRS-UdG using public transportation?
Q2 What's your opinion about the scheduling of the activity?
Q3 Setting-up of the Research Centre CIRS-UdG and the Classroom
Q4 Overall setting-up of the Scientific and Technological Park – UdG
Q5 Availability of resources to do properly the activity (equipments, tools, computers ...)?
Q6 In your opinion, is it interesting/appropriate for the secondary school students to work in topics related to Underwater Robotics?
Q7 Has been difficult to you to build the remote operating vehicle (ROV)?
Q8 Has been interesting to you the introductory talk related to the presentation of the whole activity?
Q9 Did you like the activity for building working groups related to your personal skills?
Q10 What is your opinion about the efficiency of the working groups we did?
Q11 Did you feel comfortable working with the colleagues of your working group?
Q12 Has been interesting for you the talk about underwater robotics?
Q13 Do you thing that the theoretical concepts studied during the activity have been adequate (Control of DC motors, buoyancy concept, Archimedes Law ...)?
Q14 Do you consider that the underwater robotics basics are difficult?
Q15 Has been interesting to you to work with the tools and materials available to build the underwater vehicle?
Q16 Did you feel safe and comfortable using the tools and materials available?

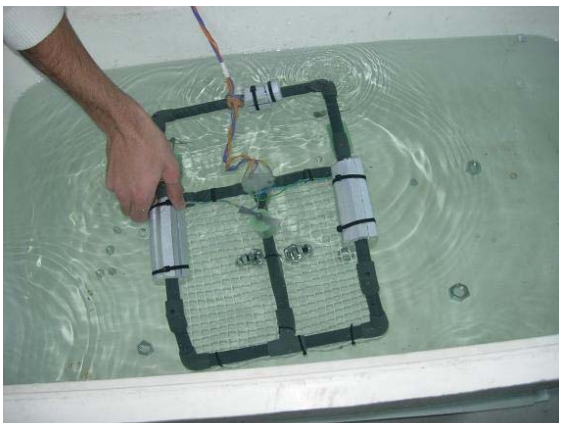
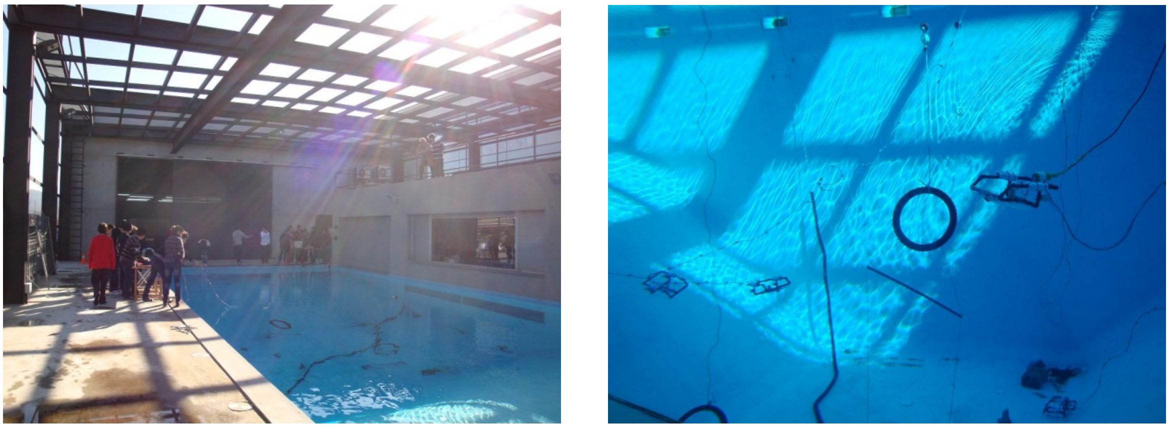


Figure 7. Small water tank for performing buoyancy and stability tests.



(a) (b)

Figure 8. (a) Students playing in the water tank with their vehicles. (b) Artificial underwater scenario .

Q17 Do you thing that the level of the teachers was adequate?
Q18 Do you thing that the relationship with the teachers during the activity was adequate enough?
Q19 Has been interesting to you the visit you did to the underwater research centre?
Q20 Do you consider that the documentation delivered to you is adequate and useful?
Q21 Do you consider that the activity has helped to introduce to you new technical and scientific concepts?
Q22 What is your GENERAL judgement about the activity (Good / Fair / Poor)?

The answer choices ranging from a score of 1 to 5 were: 1: none /very bad; 2: very little / bad; 3: average; 4: good; 5: excellent.

Moreover, there are also three open questions that the students may answer:

- *Please, state your comments about the activity (the best, the worst, what you liked and what you did not like)*
- *Would you encourage a colleague or a friend to carry out this activity (YES/NO)?*
- *Additional comments.*

B. *Results of the Survey*

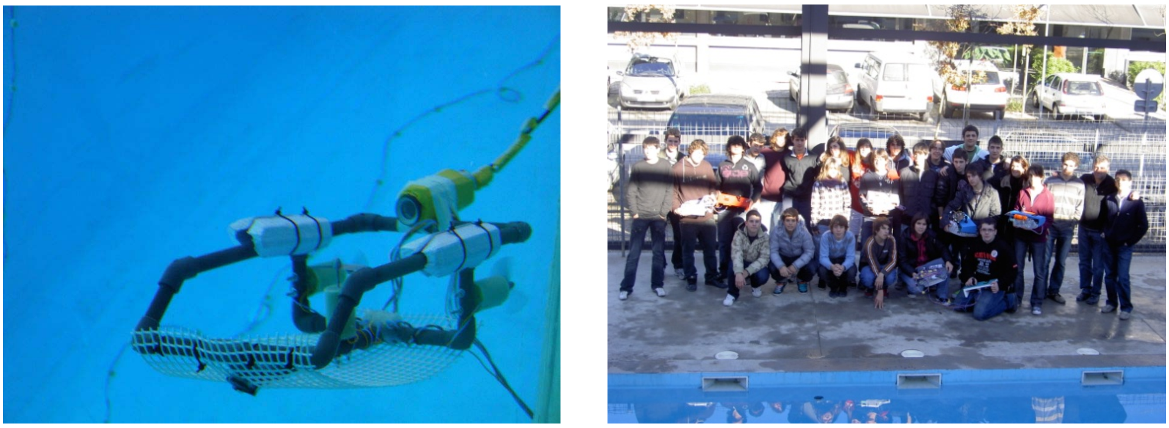
Up to date, the whole activity has been carried out by four different groups of students. Three of these groups (with 25, 27 and 18 students respectively) were students of 4th level of Compulsory Secondary School (*4º curso de ESO*, in Spanish). This course corresponds to the last year of compulsory education in Spain, and the students are normally 16 years old. These three groups belonged to three different secondary schools and all the students had almost similar (and standard) social and cultural qualities. The fourth group (with 10 students) was a special group of students that came from a Specific Labour Market Preparation School addressed to students with some specific needs. This school is part of the efforts of the Labour Department to ensure that students that have abandoned either the standard or professional education can obtain a professional training. They taught a module of Computer Networks for one scholar course. These students were 16-18 years old, and they presented different kind of social and behavioural problems because their social procedure or unstructured families (among other problems): lack of interest about scholar matters, difficulty to hold attention in theoretical explanations, impolite behaviour during specific periods of time, etc.

The statistics (mean and standard deviation) of the scores for each question for each group are illustrated in Table I. On the other hand, Table II summarizes the scores obtained for the general question about the activity (Q22).

Regarding the three open questions of the questionnaire, students were asked to comment on them, if they wished. The answers of the students are described below for each of the groups:

<u>Secondary School Students</u> (some comments collected from 70 students)

- Positive comments about: tools and materials (6 students), circuit analysis (3 students), teaching staff (3 students), to experiment with an underwater vehicle (6 students), “it is a different activity” (3 students), and the whole activity (27 students).
- Negative comments about: introductory talk (6 students), lunch not included (3 students), some spare time (2 students), to much people on the working group (2 students), to make the umbilical tether (3 students), don’t have the possibility to work on the design (8 students), scheduling of the activity (4 students), don’t have the possibility to choose the colleagues of the working group (3 students), disposition of some colleagues of the working group (2 students), theoretical explanations (0 students), and the lack of possibility to innovate on the vehicle (3 students).
- No special comments (9 students).
- Specific comments: gratitude to organisers and teachers (19 comments), positive comments about the whole activity (10 students), “it has been a nice experience” (9 students), “the



(a) (b)

Figure 9. (a) Underwater vehicle equipped with a watertight camera. (b) Teams at the closing ceremony.

job of the teachers has been very good" (5 students) and, "more time could be convenient" (2 students).

- The answer to the question "*Would you encourage a colleague or a friend to carry out this activity (YES/NO)?*" has been YES in all the cases (100% of the students).

TABLE I. STATISTICS OF STUDENT ANSWER SCORES

SURVEY	Secondary School Students		Labour Market Preparation School Students	
Question #	*Mean*	*Std. dev.*	*Mean*	*Std. dev.*
Q1	4.11	0.79	-	-
Q2	3.33	0.70	4.11	0.99
Q3	4.17	0.55	4.44	0.74
Q4	4.50	0.61	4.60	0.56
Q5	4.72	0.46	4.70	0.48
Q6	4.70	0.42	4.90	0.18
Q7 (difficulty)	2.12	0.83	1.40	0.56
Q8	3.35	0.69	3.70	1.22
Q9	3.00	0.89	-	-
Q10	2.94	1.12	4.00	0.80
Q11	3.50	1.00	4.10	0.72
Q12	3.47	0.73	4.40	0.60
Q13	3.83	0.78	4.50	0.60
Q14 (difficulty)	1.72	0.72	1.80	0.80
Q15	4.11	0.99	4.70	0.42
Q16	4.33	0.81	4.67	0.44
Q17	4.61	0.60	4.70	0.48
Q18	4.89	0.20	4.78	0.35
Q19	4.33	0.59	4.33	0.59
Q20	4.33	0.59	4.78	0.35
Q21	4.17	0.74	4.50	0.63

Specific Labour Market Preparation School Students (some comments collected from 10 students)

- Positive comments about: tools and materials (3 students), circuit analysis (0 students), teaching staff (0 students), to experiment with an underwater vehicle (3 students), "it is a different activity" (0 students), and the whole activity (4 students).

- Negative comments about: introductory talk (0 students), lunch not included (0 students), some spare time (0 students), to much people on the working group (0 students), to make the umbilical tether (2 students), don't have the possibility to work on the design (1 students), scheduling of the activity (0 students), don't have the possibility to choose the colleagues of the working group (0 students), disposition of some colleagues of the working group (0 students), theoretical explanations (1 student), and the lack of possibility to innovate on the vehicle (0 students).

- No special comments (1 student).

- Specific comments: gratitude to organizers and teachers (2 comments), positive comments about the whole activity (1 students), "it has been a nice experience" (1 students), "the job of the teachers has been very good" (1 students) and, "more time could be convenient" (0 students).

- The answer to the question "*Would you encourage a colleague or a friend to carry out this activity (YES/NO)?*" has been YES in almost all the cases (88.9%).

TABLE II. RESULTS OF THE 22TH QUESTION

Secondary School Students			Labour Market Preparation School Students		
Better than expected	***Almost expected***	***Worse than expected***	***Better than expected***	***Almost expected***	***Worse than expected***
72.22%	27.78%	0 %	90 %	10 %	0 %

IV. CONCLUSIONS

Taking secondary school students to the university to interact with senior researchers is a key factor to motivate them, increasing their interest for science and technology. In this paper we have presented a project based activity that allows students to build their own teleoperated robot. After some brief presentations, students get hands-on experiments to validate the illustrated concepts in the fields of physics, electronics and mechanics. During the activity, special effort is carried out to work the abstraction skills of the students. Every team studies the possible robot designs, which include alternative chassis configurations, motor arrangements, location of buoyancy elements, etc. Beyond the design of the robot, teams are encouraged to customize their prototypes in accord with their creativity and likings. Once the construction process is over, students enjoy performing different challenging real missions at the CIRS underwater facility.

At the end of the activity, students fill in an assessment questionnaire. The results of this survey have been discussed in this paper, showing an increased interest of students in the different engineering aspects of the activity.

Several workshops have been carried out along the past months, obtaining satisfactory results. The comments and impressions provided by the involved students are very rewarding and, more importantly, the workshop has proved to promote engineering skills and scientific methodologies among young students.

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