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Article

An Innovative Low Cost Educational Underwater Robotics Platform for Promoting Engineering Interest among Secondary School Students

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Abstract: The presented article describes the design features of an educational robotics project addressed for secondary school students and carried out at the University of Girona (UdG). The project, called Underwater Robotics Workshop, is about the students building an underwater exploration robotic vehicle using low-cost materials. Its ultimate objective is to promote engineering interest among students and motivate them to direct their future studies towards engineering degrees. The main purpose of this article is to describe this activity and to promote it. Versatility and adaptation are key values as the activity has been designed to be adapted to convenience or replicated. It is a continuation work of a previously published articles, now describing different technological adaptations related to the design of the vehicle's controller, and the gathered experiences from added workshop celebrations in the recent years. The workshop has been defined as a project-based learning approach where the students learn about physics, engineering, electronics, programming, and robotics, as well as to use all kinds of working tools, according to the maker philosophy. To date, the opinions collected from the participants encourage continuation of the activity and, at the same time, ask for the introduction of novelties to keep the workshop updated with the contents of the subjects related to technology and sciences. This project is being held for more than 13 years in the UdG. More than 800 secondary school students have participated in the activity, building about 200 underwater vehicles in more than 50 editions of the workshop.

Keywords: increasing interest for engineering; hands-on experimentation; project-based learning; underwater robots

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1. Introduction

The lack of interest of students in Europe and the United States for science, technology, engineering and math (STEM) studies seems not to have changed much in the last ten years. On average, the number of science and engineering students has fallen by about 29% in Europe [1]. The situation is worse in the case of women, with very low representation in engineering studies. This under-representation is also true for minority groups. As early as middle school, these groups start losing interest in STEM fields [2,3]. On the other hand, the labor market demand for engineering related jobs is currently increasing and the ratio of graduated student does not cover that increase. The descending numbers tendency is also confirmed at the local level. Figure 1 shows the engineering students registration numbers recorded at the University of Girona (UdG) over the past years. As can be seen in the graphic, the total number of students registered for engineering studies plots a clearly descending line.

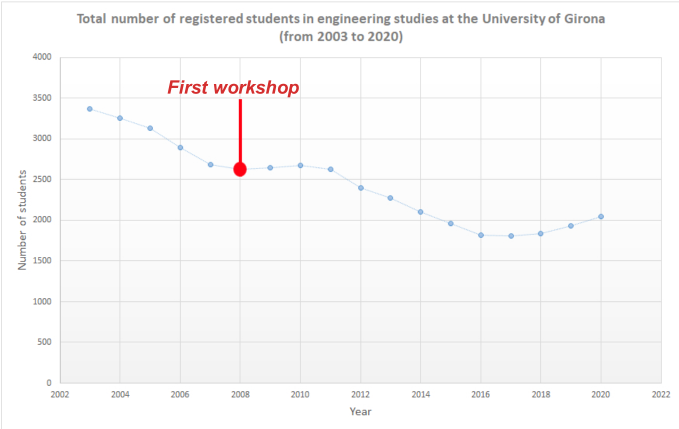

Figure 1. Engineering student annual registration at the University of Girona from 2003 to 2020.

As a general rule, in the initial educational stages of STEM training, each subject is studied separately, as if they were isolated fields and alien to each other, and traditional methodologies based on expository strategies are still the most frequently used activities in learning processes, as opposed to other, more innovative activities. This model does not really fit this teaching, because to be considered as such it is necessary to be accompanied by an integration of these contents, going beyond the concept of subject and proposing an integrative approach, as well as the interactive acquisition of the skills required in that teaching. In addition, the subjects arouse more interest if they present a higher percentage of practical activities, which implies more involvement and a better understanding of these contents. This fact is especially relevant in STEM subjects [4]. The need to adapt compulsory secondary education to the characteristics and demands of a society ruled by the rapid development of technologies, the availability of a vast amount of information and the requirement to increase the population's scientific literacy are generating new training requirements that education systems must meet. Accordingly, the adaptation of teaching practices to learning paradigms that are better suited to the learning of STEM disciplines is one of the most urgent needs, because of the vocational implications for the future generation of scientists, and the danger of them losing interest in these areas during their academic life. It is during Secondary School when students begin to move away from scientific-technical subjects, hence it is necessary to intervene in this educational stage and apply the necessary resources to avoid this distancing. From the age of 12 to 14, most professional vocations are created, orienting the trajectories of the following educational levels accordingly. Students and teachers seem to agree that STEM disciplines are interesting, but do not perceive them as fun but instead as hard and requiring the investment of effort, training methodologies should focus on holding student interest in science and technology by making it accessible and applying it to societal issues. Knowledge related to STEM is crucial to respond to the challenges the society is facing. It is often overlooked that these disciplines have played a key role in addressing some of humanity's greatest challenges in areas such as health, communications, food, and energy.

In 2008, the Polytechnic School of the University of Girona considered early interventions to improve interest and encourage pursuit of STEM areas as a priority and greatly needed. As a result, the workshop presented in this article was born. Similar activities with interesting results can be found in [5,6], where the realization of parallel events or activities to teach engineering principles demonstrate the potential for hands-on, biomechanics-based activities to engage students. Also, Ref. [7] shows a designed activity for secondary students focused on engineering and programming which uses app design concepts to build software applications. Deep analysis on the results obtained on those activities demonstrates a general interest increase in engineering, regardless of initial interest, even to the point of positively impacting students' consideration of careers in engineering. The workshop activity described in this article is oriented towards robotics. Real robotics is a highly interdisciplinary field with ties to engineering, programming, and physics. More precisely, in order to take advantage of an expertise contained inside the Computer Vision and Robotics Group (VICOROB) of the UdG, which is focused on underwater robotics. Underwater environments has always been a very important challenge for humanity. Exploring unknown environments using new challenging technological devices has become a compelling necessity, and it is also a very attractive field, especially for young people. The study, development and use of these devices can be a stimulus for their vocation to technological and scientific disciplines. Motivation activities for engaging young students with knowledge and education has always been a major concern for the teaching community. Among state of the art learning possibilities, authors have designed a workshop which explores constructionist learning [8]. Constructionist learning is a student-centered, discovery learning technique based on the creation by learners of mental models to understand the world around them. Students learn through participation in project-based learning where they make connections between different ideas and areas of knowledge facilitated by the teacher through coaching rather than using lectures or direct step-by-step guidance [9]. Constructionist learning holds that learning can happen most effectively when learners are active in making tangible and shareable objects in the real world, which generates an emotional link with them.

There are a lot of mobile robotics activities of many different natures and they use all sorts of terrestrial mobile robots. Most of them are very interesting and are perfectly aligned with the constructionist approaches mentioned above. The peculiarity of our project is to create small-scale, simple, but functional low-cost remote operated underwater prototypes using everyday materials whenever possible. A Remote Operated Vehicle (ROV) is an unmanned submarine vehicle controlled by a command console attached to the vehicle by an umbilical cord. These ROVs are equipped with engines for propulsion, and can be equipped with sensors of different characteristics, underwater cameras and various intervention widgets. Our project is inspired mainly by the Sea Pearch Program of the Massachusetts Institute of Technology (MIT) [10], and the MATE ROV competition from MATE Inspiration for Innovation [11], an annual underwater robotics competition with different amazing challenges that engages a lot of learners and volunteers. Our project seeks to attract and motivate students (and the general public) to technology through the construction and the operation of these underwater vehicles [12–14]. It is also intended to encourage the imagination of students participating in different parts of the design, obviously prioritizing engineering aspects and that the resulting vehicles must respect the underwater environment. These kind of project-based activities are considered highly relevant for exposing students to the fields of Science, Technology, Engineering, and Mathematics (STEM) [15]. The MIT SeaPerch Program was created by the MIT Sea Grant College Program in 2003. Now, SeaPerch program is an initiative from RoboNation [16] that introduces students to basic engineering, design, and science concepts [17], engaging students and fostering skills as for instance, critical thinking, collaboration, and creativity. Also, an interesting approach is presented in the OpenROV open-source hardware project [18] which makes available to the general public a teleoperated submarine robot at a very reasonable cost. In this case the developers provide a list of the submarine parts and instructions on how to assemble them, with the aim to democratize underwater exploration. As far as we know, there are no references to other low-cost underwater robot construction activities such as the one proposed in this article, especially in Europe, and this is something that makes this activity very special and unique.

The presented project is completely in accordance with the maker and do-it-yourself philosophy that is being promoted around the world. The result of the activity is an underwater device made by the participants, using low-cost materials, which reinforces the emotional link of them with the whole activity. The underwater vehicle is very attractive and it navigates underwater graciously and softness, which is very surprising, in the best sense, for all the participants [19]. In some specific cases, when these workshops have been held in the Underwater Robotics Research Center (CIRS) [20] of the UdG, they have been an appropriate way to explain the research in underwater robotics that is carried out there. The close interaction of students with senior researchers at the University can also be a very motivating factor in increasing their interest in science and technology. The activity is a very useful tool to explain and discuss with the participating students about the different research projects and underwater vehicles developed in this research center, where it is shown that these devices are a key to developing underwater technology projects, related to different fields such as marine biology, geology, archaeology projects, which makes the workshop even more transversal. Technology, and especially robotics, is something that is very attractive to young people. Unfortunately, as they grow older, they tend to perceive technology and engineering as difficult and unknown, which causes them to stop considering degrees in technology and engineering. Within the framework of the development of the activity, different types of concepts are considered and worked on, according to the curriculum of technology and science subjects studied in secondary education: Newton's Laws, the Archimedes Principle, control of DC motors, engineering aspects related to the design of the structure and chassis of the vehicle and the location of the engines, the operation of a joystick, the study of different types of sensors, design and construction of different types of actuators with different technologies, use of open-source microcontrolled boards, programming, etc. Not to mention other competences that are very interesting such as teamwork, the correct and safe use of professional tools, the handling of different types of materials, work in a real professional environment, contact with a university research center, compliance with safety regulations, regular use of the English language, etc.

Recently, more advanced concepts have begun to be introduced in the project addressed to students with a higher degree of maturity. These concepts are focused on Autonomous Underwater Vehicles (AUVs) instead of working with ROVs. The students launch a programmable submarine vehicle, which emulates the behavior of the AUVs used in real exploration and research missions. For this purpose, students work with open source electronic platforms based on the use of low-cost and easy-to-use hardware and software, such as Arduino boards [21]. The students program the vehicles in open loop or closed loop (if there is the possibility of incorporating low-cost sensors) and study and program different types of missions to perform trajectories that are tested in the pool. In this case, the students have to adapt the programs they are coding so that the vehicles behave properly as expected. The goal is to discover the difference between the behaviors of real vehicles and those of *ideal* vehicles.

The article is organized as follows. Section 2 gives details about the vehicle and the different teleoperation modes. The workshop carried out by the students is described in Section 3. Finally, the results, conclusions and future sights are discussed in Section 4.

2. The Robot

The main idea is to create prototypes of small-scale ROVs, simple but functional, using everyday materials. By definition, a ROV is an unmanned submarine vehicle, controlled through a command console attached to the vehicle by a tether. A significant example of a vehicle that is built throughout the activity is the one shown in Figure 2.

The control console can be of different types, depending on the technological level of the students who carry out the activity. The console must allow for control of the 3 DC motors that are on board, and it can be made of any material. The basic console holds a frontal panel with a joystick and two buttons to control the 3 motors that propel the vehicle. For students of advanced level, this console can be designed using low cost programmable hardware and DC motor control modules. Also, they can use a mobile device and an app designed by the students themselves as a submarine vehicle control console.

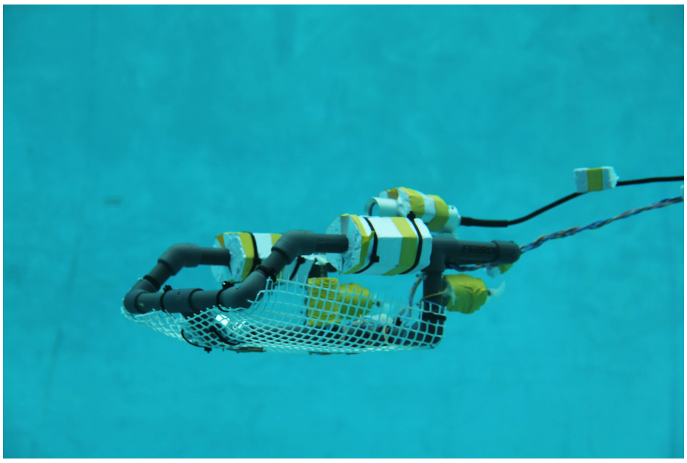

Figure 2. Example of vehicle built at the workshop.

2.1. The Structure of the Vehicle

In Figure 2 details of the low-cost underwater vehicle can be observed. The chassis of the vehicle is very light and robust, built with pipes and joints of PVC of 20 mm in diameter, a material that can be easily manipulated by the students. The structure of the vehicle must be able to accommodate all the components that form part of the vehicle, and which allow it to carry out the mission or missions for which it has been designed (propulsion, buoyancy, sensors, actuators, or cameras). The chassis should house the engines that allow for propulsion and the buoyancy elements. Two horizontal motors and one vertical motor must allow the movement of the vehicle in three dimensions within the underwater environment. The activity allows participating students to propose different chassis models for the submarine vehicle. Students, working in group, make design proposals about possible feature designs. The proposals are made with the missions as the final objective, so students' proposals must be directed to vehicle optimization and mission fulfillment. The final design must be extracted by consensus of the whole group and on the basis of specific advantages for mission success that will be accepted or rejected by workshop supervisors. Figure 3 depicts some suitable design examples for the vehicle chassis.

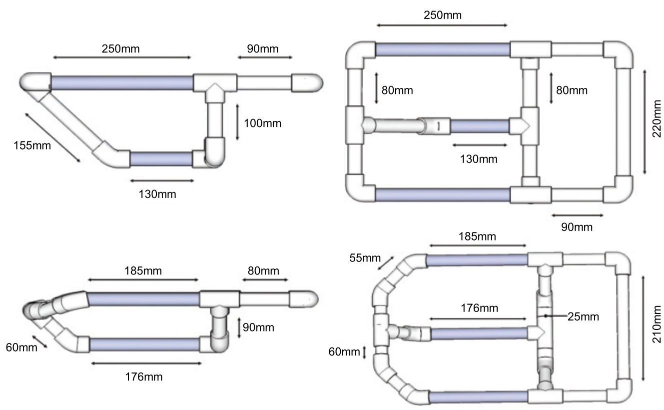

Figure 3. Examples of two possible chassis designs.

The final design must be extracted by consensus of the whole group and on the basis of specific advantages for mission success that will be accepted or rejected by workshop supervisors.

2.2. The Basic Command Console

The most basic control console is a structure built with any type of material, which must be able to house a joystick, two push-buttons and the control circuits of the three

DC motors that equip the underwater robots. Two of these engines are the horizontal motors, which are responsible for the steering movements of the submarine vehicle. These horizontal motors are controlled by the joystick. The third one is the vertical motor, responsible for the ascending and descending movements of the underwater vehicle. This motor is controlled by the two push-buttons provided by the control console.

The push-buttons have a movable mechanical pivot (red in Figure 4) that allows the change in the connections of the terminals: terminals C and NC (Normally Closed) are connected if the pivot is not pressed, and C and NO (Normally Open) are connected if the pivot is pressed. The circuit that controls the movement of each of the DC motors is a standard inverted polarity circuit, governed by two push-buttons, named A and B, as shown in Figure 5. In the case of the two horizontal motors, the two push-buttons on each of the motors are the ones located on the joystick (which has four push-buttons in total). In the case of the vertical motor, the two push-buttons are the ones located on the console near the joystick.

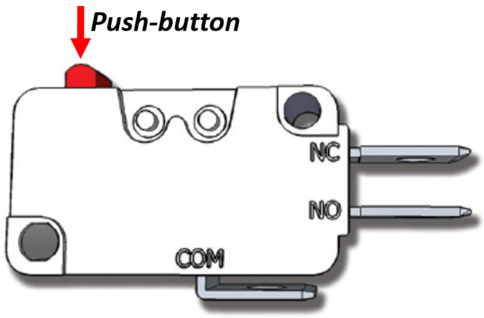

Figure 4. Push-button for DC motor control. Red-dotted line shows the two possible circuit positions depending on the pivot position.

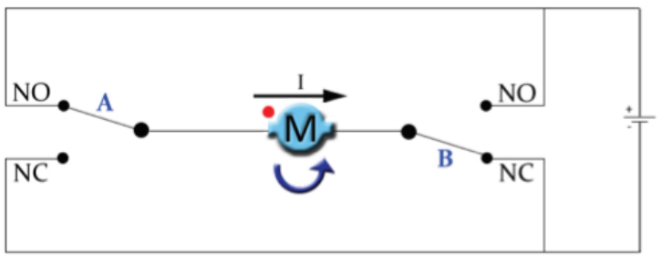

Figure 5. Inverted polarity circuit.

The joystick is basically made up of a handle and four push-buttons placed strategically (see Figure 6). It is crucial that the joystick is placed on the console with a rhomboidal distribution as shown in the figure and not in another distribution, as that fact will be decisive for its correct operation. The joystick should help drive the vehicle in a reasonable and intuitive way. The following Table 1 shows the four possible configurations that this circuit can have:

Table 1. Possible circuit configurations. NO is Connected to +, NC is Connected to −.

Pushbutton A		Pushbutton B		Motor Turning
Pressed	COM A is +	No pressed	COM B is −	Counterclockwise
Pressed	COM A is +	Pressed	COM B is +	No turn
Not pressed	COM A is −	No pressed	COM B is −	No turn
Not pressed	COM A is −	Pressed	COM B is +	Clockwise

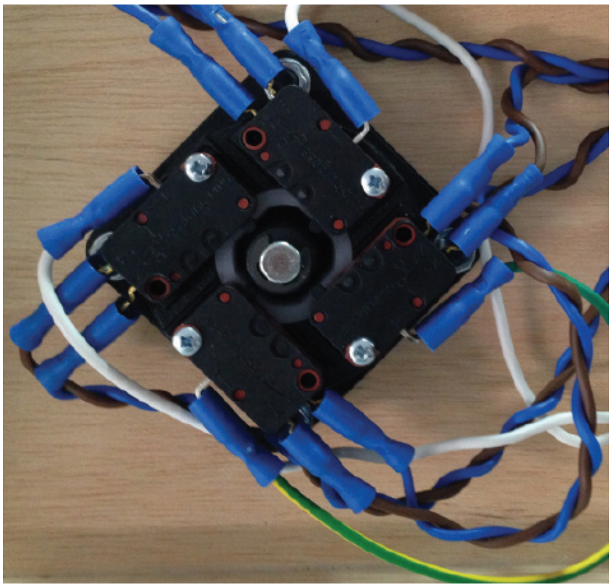

Figure 6. 4 push-buttons of joystick seen from below.

If, for example, we want the vehicle to move forward, the user will push the joystick handle forward, and this gesture should cause the two buttons corresponding to the two horizontal motors to operate simultaneously to move the water both backwards, thus pushing the vehicle forward. This is not possible if the joystick mounting is arranged in a different geometric arrangement.

2.3. The Advanced Programmable Command Console

Considering the educational needs of secondary schools, and with the contents of the curricula of technology subjects in mind, the activity has been adapted from a technological point of view. The new version of the control console incorporates the use of low-cost programmable hardware (mainly based on Arduino UNO boards) and also the possibility to program apps for smart mobile devices. This feature allows for covering a wide range of technology content, and ostensibly increase the overall interest of the activity. Coding is also incorporated into the activity at this level, which gives it a very important added value. It is possible to develop a simple app using programming tools like Appinventor [22], a programming language based on blocks, developed by researchers of MIT, which helps students to build functional apps for Android and IOS smartphones and tablets. Also, Scratch4Arduino-S4A [23], a similar block-based software, can be used if deemed appropriate. Concepts of submarine mission programming, sensor integration, Bluetooth communications, power electronics, and even autonomous behaviors can be also introduced into coding.

Figure 7 shows the complete diagram of the connection of the three DC motors of a submarine vehicle to the power control boards (H-bridges) and to a programmable low-cost hardware. Through the programming cable, the programmable board is connected to a laptop. Some specific keys of the keyboard can be used as buttons to control the movements of the ROV. A mobile device can also be used as a control console using an app developed by the students. From the app, the user can send control commands to the programmable hardware using a Bluetooth link. A specific low-cost Bluetooth module must be connected to the programmable hardware. The development of an app that allows the use of a mobile device as a control console is something that young students value a lot, establishing a powerful link between the student and the project.

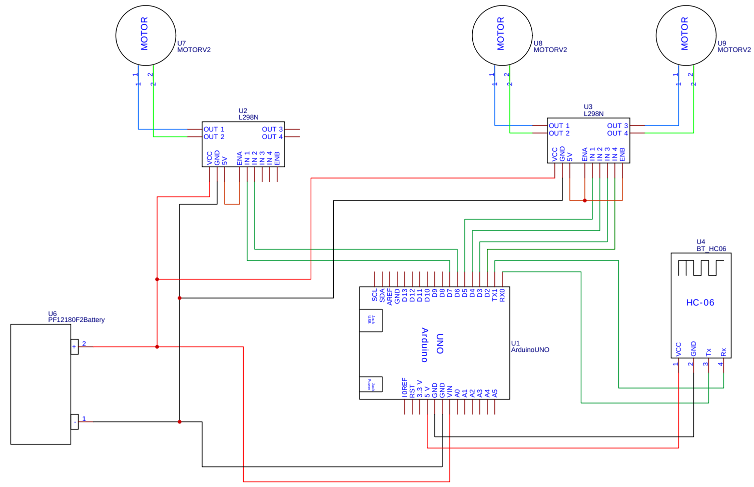

Figure 7. Advanced console connection schematic.

Figure 8 shows an example of the screen of an app that controls the underwater vehicle and a program developed with Appinventor that allows the user to control the underwater vehicle sending control commands to the programmable hardware through a Bluetooth link.

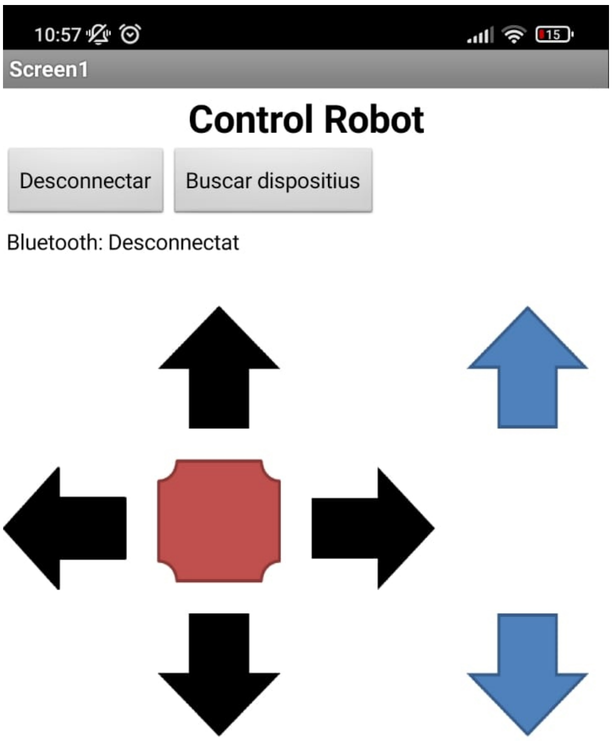

Figure 8. Example of app screen for vehicle control designed with Appinventor.

3. The Workshop Development

The workshop can be carried out in any swimming pool that has minimum dimensions that allow the navigation of the underwater robot. To the date, it has been developed a few times in the CIRS facility at the UdG. This laboratory is one of the most advanced facilities for underwater research built in Spain, it has plenty of space available and all needed machinery and tools for the activity development. In order to fit secondary school requirements, budget and schedules, the workshop has been designed to be developed in two different formats: Standard three-day format and compressed one-day format. The standard three-day format lasts for two and a half days, 20 h approximately. The one-day format divides the workshop in two steps, one at their own school where the students do part of the workshop with their teachers and a second step where they come to the research lab, or a pool for one day. In this compressed format, activities to be done at school or at the lab are studied depending on school equipment. As can be appreciated in Table 2, the standard three-day format is divided into three modules. One module for the teleoperation console and the vehicle chassis, a second module for the motors and console wiring and, finally, a last module for assembling, buoyancy adjustment and mission development.

Table 2. Standard three-day format modules.

Module One	Module Two	Module Three
Presentation	Console wiring	Buoyancy adjustment
Console construction	Motor sealing	Connection check
Chassis construction	Propellers attachment	Final missions
Wires preparation	Umbilical attachment	
Umbilical preparation	Connection check	

The one-day format experience did not exist at the beginning of this project. It was later created as a request from schools demanding for a shorter format, more aligned with their course schedules and economic budgets. Nowadays, the one-day format is the most demanded one among schools. Table 3 shows only the final activities performed during the last part of the workshop, where the pool is needed, while the previous tasks are carried out by the students at their schools and remotely supervised by faculty supervisors. This short format also includes a training session at the school where students' teachers receive all the information and necessary materials to develop the school work. Two weeks before the workshop, school teachers must report supervisors in order to check robot development. School visits by supervisors is an option in case of troubles or delays related with the normal development of the planned activities.

Table 3. One-day format module.

Final Module
Presentation
Buoyancy adjustment
Connection check
Final missions

As can be noted, the tasks contained in the one-day format are almost the same as the ones in the module three of the three-day format. The presentation contains all the information needed by the students about how to operate: mechanical tool usage, safety instructions, and recommendations for quality assurance of the whole experience are given. The last part of the presentation is related with engineering, underwater robotics and research. The numerous industrial applications around underwater technology, such as environmental monitoring, oceanographic research or maintenance/monitoring of underwater structures are presented to the students with the aim of awaking the student's interest in the field. The next sections detail all the tasks listed for every module.

3.1. Module One

The students start the workshop with the design and the construction of its two main elements: the control unit and the vehicle's chassis. As explained in Section 2, the control unit can be implemented using different technology, wired or wireless. Figure 9a shows a finished control unit in the case of a wired selection. In this case, the console is made of wood and the students must combine nails and glue to fix it. The wired control console contains the joystick and the up-down push-buttons for the robot control. Once the glue is dry, students can paint and decorate the console according to their preferences. The vehicle's chassis, shown in (Figure 9b), is made of assembled tubes and joints made of PVC (T, 90° and 45° PVC connectors). Initially, the students propose and discuss several designs on paper. The commencement of the chassis assembly cannot be done without the supervisors approval on the final paper design.

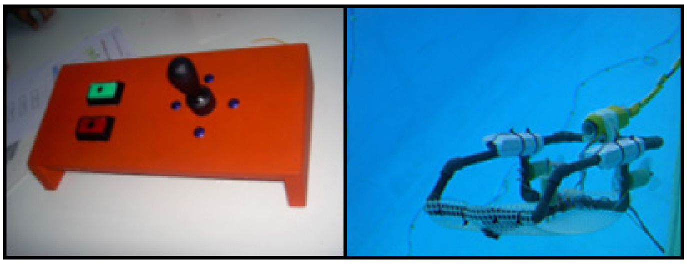

Figure 9. (**Left**) Control unit. (**Right**) Finished chassis.

With the two main frames of the design built, the students must now prepare all the needed wires and connectors that will be used the next day for the console and chassis wiring. A fixed number of cables must be prepared, with a defined color, length and connection type. All wires must be welded with a tin solder in order to facilitate the connection to the console the day after. Also, some extra wires are prepared for motor tests performed during the second module.

3.2. Module Two

As can be seen in Table 2, the second module is related with the assembly of the elements prepared during the first module. Thus, this module is about the console wiring, the motor sealing, and propeller and umbilical assembly. Before the module starts, the students first attend to a lecture session about the electric schematic of the whole design. Here, the student learns the basics about electricity and circuits. The final objective is to apply the acquired knowledge on the proposed schematic. Its is very important to understand the electrical behavior of the design as the success of the final vehicle depends on it. Final assembly of the console wires can be seen in Figure 10.

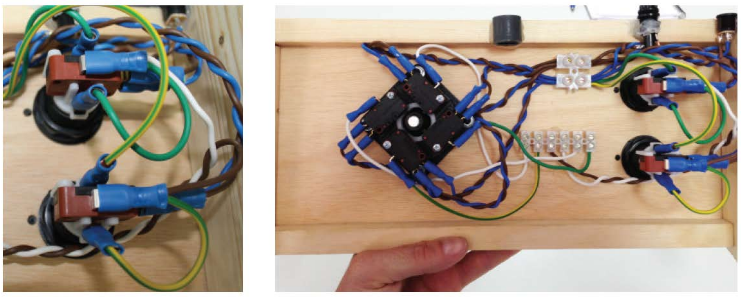

Figure 10. Assembly of wire connections to the back side of the console.

The chosen vehicle propellers are common 12 V DC motors. They are not specially designed to operate in underwater domains and, therefore, an encapsulation work must be done with them in order to safely use them underwater. To do so, the current design uses a mixture of petroleum jelly and thermal adhesive. The delicate parts of the motors are first covered with electric tape. 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 cylindrical plastic canister. Students have to drill a small hole at the bottom of the case for the motor shaft. Subsequently, the case is filled with thermal adhesive. After a short period of time, when the thermal adhesive hardens, we obtain a solid sealed motor with only a shaft and two wires coming out. The final task of this module is to fix the sealed motors to the chassis of the vehicle and connect them -by means of an Ethernet cable- to the teleoperation console. With respect to the umbilical cable, for this workshop design, an Ethernet cable is used. The advantages of using Ethernet cable are numerous. First of all, the resultant umbilical is thin, flexible and quite light, eliminating drag problems resultant from using heavy and more rigid cabling. An Ethernet cable has four cable pairs, which fit perfectly in our design, which uses three pairs for the motors and leaves an extra unused pair for added gadgets, such as an underwater light, or a grabbing device. The last task of this module is to check all the electrical connections and test the vehicle outside the water to verify its correct behavior.

3.3. Module Three

According to Table 2, the tasks contained in the last module are: buoyancy adjustment, connection check and final mission tests. The one-day format workshop also contains a presentation and a facility visit as, in this format, students do not know the CIRS laboratory and must receive this introductory content as their colleagues from the three-day format did. The last step to be done before performing the real experimental missions in the CIRS pool is to adjust the vehicle's buoyancy. This step is about using a modeled block of foam to be attached to the vehicle in order to compensate for its weight when submerged. The objective of this step is to have a close-to-neutral underwater vehicle in terms of density. Acting this way, the maneuverability and efficiency of the submarine will be close to optimal as its neutral buoyancy helps it to maintain desired depths without spending energy or generating momentum in unnecessarily. Figure 11 illustrates the process.

Figure 11. (**Left**) Buoyancy adjustment step. (**Right)** CIRS experimental pool.

Once the buoyancy has been correctly adjusted and verified, one last electric check is carried out with the objective of validating the prototype for navigation and mission development. The final objectives of the designed missions pursue two main goals: first, to exploit the capabilities of the designed vehicles so the students can appreciate the results of their efforts and, secondly, to show the students what real missions with AUVs look like in the real world. Most of the missions have been designed starting from similar real missions performed by our vehicles at CIRS in open sea conditions and by doing them, the students get the touch of the requirements and performance expected from a real vehicle designed to perform specific tasks.

Figure 12 shows an example vehicle inside the water pool surrounded by a mission set. The designed missions are mostly involved with different recuperation tasks, maneuver the vehicle through complex underwater structures or collaborative tasks where the participation of two or more vehicles is needed to complete the mission. While performing the missions, installed cameras and the installed underwater window allow for recording of the different team's performance in order to evaluate their projects at school.

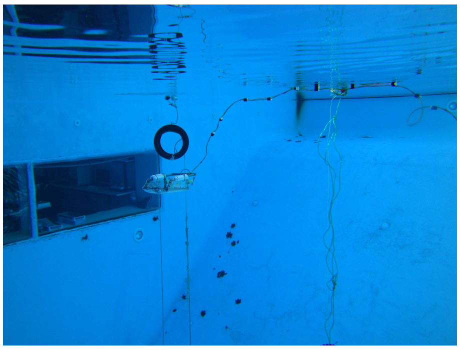

Figure 12. The vehicle and the mission set.

4. Results and Conclusions of the Workshop

Nowadays, there are very few known experiences where secondary students participate in an exciting project-based workshop of building their own underwater vehicle. This fact makes the presented activity very special and characteristic. We have examples of similar activities in the United States, such as the Seaperch project which is a very important national project supported by RoboNation. The activity presented in this article is inspired in the Seaperch project and it has been conveniently adapted to local circumstances. Initiatives like the OpenROV project present a teleoperated submarine robot for a price of approximately $900, nine times the cost of the proposal presented in this article. The activity can be easily adapted to different environments and situations. It can be carried out in a swimming pool, or in other simpler facilities with a minimum amount of water. The workshop has been designed with a series of proposed build materials for its realization but this is just a proposal. Everyone should feel free to try other different approaches that may be as good or even better than the one used here. The use of low cost materials should be a priority and, from this concept in mind, there is always the possibility of incorporating new elements, new aspects, new blocks, and new concepts. For example, it is possible to investigate the incorporation of sensor blocks into the vehicle (sensor blocks that must be isolated from the water) that may be related to parameters of interest that you want to investigate (such as the water quality), or incorporate elements that allow for the cleaning of the water sheet of contaminants (using for example materials based on cellulose nanofibers). The experience gained during all editions of the underwater robotics workshops has determined a number of engineering needs in the design of the chassis of the underwater vehicle:

- The proper location of the two horizontal motors and the vertical motor necessary for the movements of the vehicle. Pieces of vertical PVC pipe are needed to accommodate the two horizontal motors, and a piece of horizontal PVC pipe, at the bottom of the vehicle, to fit the vertical motor.
- The structure of the vehicle chassis must not impede the operation of the propellers when they expel water to provide propulsion.
- The structure of the vehicle chassis must protect the engine-propeller assembly from possible collisions, housing it inside the body of the vehicle.
- The structure of the chassis must allow the buoyancy elements to be located at the top of the vehicle so that it is properly balanced.
- It is necessary to drill the PVC pipes so that the water can flood them, thus preventing possible water bubbles from unbalancing it when it is sailing.
- It is necessary to have a piece of PVC pipe in the back of the vehicle to be able to fix the tether, thus avoiding stresses on the welds of the terminals of the motors, when it is necessary to pick-up it from the water.
- The size of the vehicle should be approximately the size of a shoe box. This is due to the power of the motors used in the activity. With these dimensions, vehicles move underwater with astonishing agility and grace.

The presented activity is completely linked to new ways of learning such as learning based on transversal projects, considering creativity, teamwork, and focusing on different skills, and completely in accordance with the philosophy maker and do it yourself and sometimes related to certain very interesting counterculture movements. The end result of the activity is an artifact made by the students with their own hands, which extraordinarily strengthens the link between them and the theoretical concepts needed to build it. The activity is easily carried out by technology and science teachers in secondary schools. It is considered that after few hours of training and a little practice and audacity, teachers can carry out the activity with complete independence.

Table 4 sums up the total number of editions of the workshop performed to date. As can be appreciated, 53 editions of the workshop have been held, and there are at least three more editions scheduled for 2022. More than 800 students have participated in the activity and more than 200 underwater vehicles have been built. Also, Table 4 describes the format used for the workshops: three-day format or one-day format.

Table 4. Workshops done since November 2008.

Year	Students	ROVs	3-Day Format	1-Day Format
2008	20 (Inaugural Demo Edition)	2	0	0
2009	26	5	1	0
2010	61	11	3	0
2011	85	20	3	2
2012	73	21	2	4
2013	78	19	4	1
2014	78	20	2	2
2015	54	15	3	1
2016	70	20	3	3
2017	80	22	4	1
2018	72	23	4	2
2019	72	21	3	2
2020	All activities cancelled (COV19)	0	0	0
2021	32	8	2	0
2022	3 workshops scheduled	-	-	-
TOTAL	**801**	**207**	**34**	**19**

To the date, the number of experiences that have been carried out is numerous. The last pandemic year asked for a sudden stop in our workshop activities, but we hope to restore pre-pandemic student volumes soon. The participation comes mainly from secondary and high schools inside the Girona area, our territory of influence, and we plan to continue inside this range of reach. Exceptionally, groups of students from other places may be invited to participate in the activity. In all cases, experience feedback from participating students and teachers has been very positive [14,19]. The degree of satisfaction is very high, and the activity covers the learning objectives previously considered. The development of the workshop is associated with a series of strongly related activities that are considered as collateral results of the continued celebration of the event since its beginnings:

- Technology outreach books.
- Scientific publications in national and international journals and conferences.
- Outreach talks addressed to students of different levels and the general public.
- Participation in projects for the dissemination of scientific and technological culture.
- Participation in international cooperation and solidarity projects.
- Participation in national and international science fairs.
- Secondary and high school teacher training activities.
- Distinctions and awards that provide prestige to the project.
- Proposals for research work and practical work in companies for high school students

- Proposals for practical work, final degree and master's thesis in companies for university students.

Authors believe that the presented activity is a successful way to promote research in underwater robotics carried out by VICOROB research group of the University of Girona and, at the same time, encourage engineering studies among secondary school students. Currently, most research projects must be accompanied by appropriate outreach activities, and this activity is a clear example of it. The incidence of this kind of activities in the students decision to carry on with engineering studies has to be deeply analyzed with statistical data. This is one of the most serious aspects we are currently pointing out as our future work, together with improving the design of the workshop, the materials used for construction and the total cost of the activity.

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Abbreviations

The following abbreviations are used in this manuscript:

STEM	Science, Technology, Engineering and Math
UdG	University of Girona
VICOROB	Computer Vision and Robotics Group
ROV	Remotely Operated Vehicle
MIT	Massachusetts Institute of Technology
CIRS	Underwater Robotics Research Facility
AUV	Autonomous Underwater Vehicle

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