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Hydrobots, an Underwater Robotics STEM Project: Introduction of Engineering Design Process in Secondary Education

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ABSTRACT

This paper presents the project Hydrobots, which the Eugenides Foundation has run in Greek secondary education schools since 2012. It is based on the MIT's Sea Perch project and more than 300 student teams got involved and built successfully an underwater remotely operated vehicle. The formal Greek education system lacks large-scale STEM-related activities, despite the growing demand for qualified scientists and engineers. The project serves as a great introduction to STEM disciplines through robotics, by applying the Engineering Design Process (EDP). It creates a friendly learning environment, students learn important issues of school curriculum, develop STEM skills and competences as well as transversal skills. The project continues after the vehicle construction. Teams from vocational high schools are more focused on modifying it, while the rest teams usually use the robot for scientific experimentation in marine environments. A large number of the teams upgrade the vehicle by adding a sensor module, the Hydrosensor, provided by the Foundation too, and in some cases they improve this prototype even more. The teams, which conduct experiments with their robot, follow a specific procedure.

We also present the results of a large survey among the participants, students and teachers, who evaluated the achievement of project learning objectives. The majority of the teams reported that the project has contributed to their positive attitude towards Science and Technology, improved their performance and developed their transversal skills. Almost all the responders illustrate an enthusiastic reception of the project from the students and the school community that affected the students career perspective.

The project Hydrobots seems an ideal STEM tool for those teachers in Greece who desire to be more effective through innovation, while the involved students become familiar with STEM key aspects and the engineering thinking.

Key words: STEM, secondary education, engineering design process.

INTRODUCTION

Modern Labor Market Demands And STEM Skills Acquisition

The impact of Science and Technology in modern society is remarkable. Numerous smart devices and a wide range of innovative applications are worldwide available to everyone. These technology advents have created a need for a future workforce that today's Europe youth is unable to fulfill, since a significant decline in STEM specialists has been recorded. European Commission (2015) reports that the STEM professional and associate occupations' growth in Europe is assumed to be at 13% and 7% respectively until 2025. The number of STEM graduates has declined within a few years' period. In 2012, only 23% of graduates who held STEM qualifications came from all Union's members, while in 2007 the STEM qualified graduates were at about 22% (EC 2015). Additionally only a short part of future job offers will be covered by today's students (Cedefop 2018). The US National Academy of Sciences, the National Academy of Engineering, and the Institute of Medicine describe a similar situation in the United States (2010).

Nesbit et al. (2005) present some major constraints to explain why middle school students lack interest in following a STEM-related career. One reason is that high school students do not interact in real life with STEM professionals and their work. They usually communicate with medical experts, teachers and lawyers and meet their way of thinking. Students rarely interact with engineers and the engineering design process (EDP). A second reason rises from the learning content of current formal education curricula. The presented problems are well-defined and expected to be solved by one single correct solution. Students' experience in problem solving is usually based on memorization and focused on how to pass their exams successfully (Kimmel et al. 2003). Additionally, formal science curricula give limited space to students for expanding their creativity (Donelly 2010).

The STEM framework (Science, Technology, Engineering and Mathematics) in secondary education pursues to engage more students in scientific and engineering thinking, as well as the problem solving procedures, by working on real world problems. The report from the US National Academy of Engineering and the National Research Council also emphasizes the importance of introducing engineering in secondary education (2009).

The Greek Secondary Education System – The Greek Student Profile

The formal educational system in Greece consists of three types of schools in secondary education. From ages 12 to 15 years old, all the Greek students attend the compulsory Junior High School (Gymnasio). After completing their Gymnasio studies, the students (ages 15 to 18) choose between two major types of schools: the General High School (Lykeio) or the Vocational High School (Epaggelmatiko Lykeio). No matter the school type, the whole Greek secondary education system is exam-focused and the achievement of high grades in examinations is widely considered very important (Kampourakis 2017). Additionally, the country's public tertiary education entry is highly competitive through national examinations (Psacharopoulos & Tassoulas 2004). Secondary Science lessons are also exam-driven and have become unpopular among students (Hadzigeorgiou & Schulz 2017). There is little educational time devoted to laboratory exercise and hands-on activities as well.

Therefore, the students in Greek schools have little chance to work on real engineering projects and their laboratory practice on STEM disciplines is quite limited. During their formal education and due to the examination-based teaching, Greek students face only well-structured problems with all the resources available. From their elementary education years, they have not learned working on non-structured issues. But what happens when they have to deal with ill-defined problems and without the necessary resources? In such a case, any possible solutions have serious limitations. Although STEM skills are necessary for the citizens of the 21th Century, the Greek national curriculum lacks STEM activities.

The Project Hydrobots, The Greek Version Of The Sea Perch Project

The Eugenides Foundation runs the project "Hydrobots" in Greece, a Sea Perch underwater vehicle clone from 2012 up to date (2019). The project is based on the Sea Perch, an innovative marine robotic project that has been developed in the USA from MIT's Sea Grant College initially as an introductory course (Bohm and Jensen 1997, Techet et al. 2006). It has also been offered as a pre-orientation program for incoming college students in Engineering since 1998 (Thompson and Consi 2007). Due to its high educational value and impact, the project has expanded to high schools. The United States Office for Naval Research (ONR) and the Society of Naval Architects and Marine Engineers (SNAME) have turned it into a national K-12 STEM outreach program (Nelson et al. 2015). Since 2003, the Sea Perch project has been widely applied in the USA and worldwide. The educational value of the Sea Perch related projects is well described in literature (e.g. Techet et al. 2006, Nelson et al. 2015).

The Hydrobot (Figure 1-left) is a remotely operated vehicle, designed for natural marine environments. There are two kinds of underwater robots depending on the way the user controls them: the

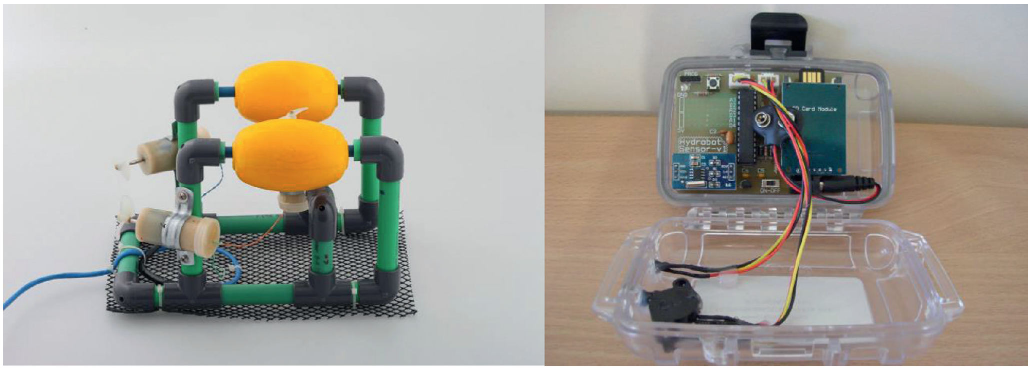

Figure 1. (left) The underwater remotely operated vehicle (ROV), the Hydrobot. Its dimensions are: Length: 28 cm, Width: 16 cm, Height: 19 cm. The construction steps of Hydrobot are described in full details at https://olcms.stem4youth.pl/content_item/detail/12. (right) The Hydrosensor circuit unit in its waterproof case. Several teams upgrade their ROV by using this sensor kit. The Eugenides Foundation provides this equipment to all the Greek school teams that express their interest. The basic kit consists of the vehicle frame fragments, the motors and the electronic parts for the remote control.

Remote Operated Vehicle (ROV) and the Autonomous Underwater Vehicle (AUV). The user controls directly the former via a wireless connection or a wire, while the latter operates autonomously through a programmed mission (Beaudoin et al. 2012). Although there are limitations of distance and duration during its operation, the basic concept of Hydrobots interacts directly with the user (the student) and this is its main pedagogical advantage in the Greek case. Despite the fact that the ROV function resembles a drone or a toy car, it is a ready to use vehicle when students assemble its frame and motors. As mentioned above, students in Greek schools lack engineering projects and the basic concept of the construction emphasizes the engineering simplicity. The educational value of AUV is undoubtable, since it engages the users to computational thinking. However, students in Greek schools have short time limitations, due to the exam-based educational system, and most of them lack proper mentoring in order to construct autonomous vehicles. Therefore, the familiar function of drone or toy car engages young Greek students more easily in the engineering design process. The basic outcome of the project is shown in the video: https://www.youtube.com/watch?v=uKflNtTrZ20. We have to mention that the teams can upgrade their ROV to a AUV through a guided procedure, which is described in detail in the project's platform (http://hydrobots.gr/index/?page_id=2624 - in Greek). The teams, except for the basic concept of a Hydrobot, can also get the Hydrosensor (Figure 1-right), a kit of sensors based on the popular open-source electronic platform Arduino (http://www.arduino.cc/). This circuit is easy to be built and gives the students the opportunity to measure *in situ* water pressure, temperature and luminosity versus depth in marine environments in real time. They have in hands a powerful scientific instrument made by them. These measurements are recorded in a SD card, which is embedded in the module. The kit is stored in a waterproof shield box and operates independently from the main ROV electronics. The sensor circuit is upgradable with more sensors, cameras or other electronic or mechanical equipment.

This paper presents one of the largest STEM projects in Greece, concerning its duration and the huge number of participating students, teachers and schools. Almost all the involved Greek students completed the project tasks, despite their demanding exam-oriented educational environment within a school year. We illustrate the modifications that some teams applied in their ROV and the results of a large-scale survey conducted by the Eugenides Foundation. The participating students and teachers were asked to (a) evaluate the project and its impact, (b) report about the project's contribution to the student's attitude and STEM and transversal skills development and (c) describe their experience and mention any influence in their future career decisions.

METHODOLOGY

The Project Hydrobots Learning Objectives

Eugenides Foundation has applied the Hydrobots project in Greek Schools since 2012, as an in-school or out-of-school activity. The project is offered for all the types of secondary schools in Greece. The Hydrobots project goal is to engage students in a real STEM - mostly engineering activity.

By the end of the project, the participants will be able to explore and experiment in various subjects, directly related to their Science curriculum, such as the laws of motion, electrical circuits and buoyancy. Through their engagement, students are also expected to develop their STEM and transversal skills, such as work in teams and train in problem solving, while they explore certain professional options.

Each educational level has its own specific learning objectives. The project focuses on inspiring the younger students of Gymnasio to participate in STEM-related activities and meet the engineering methodology. This outcome is also expected for the majority of the involved students of Lykeio. The students of vocational education have also the opportunity to work on real conditions and face real engineering constraints.

The Hydrobots Project Requirements

At the beginning of each school year, the Eugenides Foundation invited public school teachers to submit an application in order to be considered for one of the 100 Hydrobot kits that were distributed by the Foundation annually. In this application, the teachers should also describe the way they were planning to use the kit as part of their lessons. The Eugenides Foundation's committee reviewed the applications and decisions were primarily based on the submitted lesson plans and the demographics. The selected proposals received the kit at no cost.

The project has been designed for a team consisting of 4 or 6 students and one or two mentors (teachers). The net time for the basic ROV construction is estimated from 1.5 up to 8 hours. Teams who decide to upgrade their ROV with a Hydrosensor kit need about 10 to 15 hours to build the circuit. No prerequisite knowledge in Engineering is needed and the necessary equipment is internet connection, a computer or a tablet and some hand and electrical tools, which are very easy to find. The project's advantage is the low cost, which has been estimated at about 80 euros per module (the basic kit). The Hydrosensor kit's cost was 260 euros per unit, including the waterproof box and all the electronic parts in 2013 pricing. All the project material is reusable. The project tutors are the Eugenides Foundation team consisted of Vassilis Papakonstantinou (Mechanical Engineer, MIT), Dimitris Piperidis (Electrical Engineer, National Technical University of Athens) and Dimitris Stathopoulos (Physics, National & Kapodistrian University of Athens).

The project's online platform (www.hydrobots.gr) hosts all the latest versions of the hardware manuals, software files and updates for download, active blog, the measurements' database and the users' forum. The teams were fully supported throughout the project from the Foundation team and the Hydrobots web forum. The latter was set up by Eugenides Foundation in order to encourage direct interaction among the participants. The participants can have their own account to participate actively in the forum. There is no specific course dedicated for the teachers. Every year, the Foundation organizes online meetings to communicate with the teachers, mostly via Google Hangouts, an easy to use web platform.

The Engineering Design Process (EDP) in Hydrobots

Hydrobots, as a Sea Perch clone project, is a true engineering experience and it focuses on introducing the Greek students to the Engineering, since related tasks are missing in their national curriculum.

Before beginning the main construction of the ROV, the Foundation proposes a preparatory activity called "*What is Engineering? -Discover the differences between Engineering and Technology*". Although this module is optional, it gives the opportunity to strengthen the team bonds and meet the engineering thinking. In this activity, students are asked to build a construction from raw materials like a table from newspaper that can afford the weight of a laptop.

Then the students start to work on the Main Project Activity "Building the Hydrobot". Students apply the Engineering Design Process (EDP) in every step of the project. The EDP approach (Ertas and Jones 1996) is a cyclical design sequence that engineers follow to discover a solution for a real problem and it has many versions depending on the situation (Tayal 2013). Importing EDP in the learning procedure is not a new idea. Large-scale robotic-based projects as the FIRST robotics competition have influenced the participants towards Science and Engineering thinking since 1989 (e.g. Melchior et al. 2005). Similar to the Sea Perch, the aquatic project ROAVEE has been used to successfully introduce the involved students in EDP to marine environments (Hartigan and Hademenos 2019). Thematic competitions, using humanoid robots like either the RoboCup (Asada and Kaminka 2002) or the TCFFHRC (Trinity College Fire-Fighting Home Robot Contest – Pack et al. 2004), had also significant impact to enhancing children engineering skills and outreaching robotic projects respectively. Soft robotics projects also introduce students to EDP, although they are still piloted and the results have been derived from a small sized group (Jackson et al. 2018). The projects BEST Robotics (Shannon 2015) and botball (Miller et al. 2015) also emphasize the EDP implementation by young students as one of their major scope.

The Hydrobots teams divide the main task (the ROV construction) into three subtasks:

1. Construction of the main frame of the ROV;
2. Construction of the ROV's propulsion system;
3. Construction of the ROV's console.

In each subtask, the teams try to understand the problem and its parameters and discover possible solutions. For example, they define the materials they have to use or discuss relative scientific topics like buoyancy. Figure 2 below depicts the six-step sequence, which students follow to develop and build a solution to each specific problem.

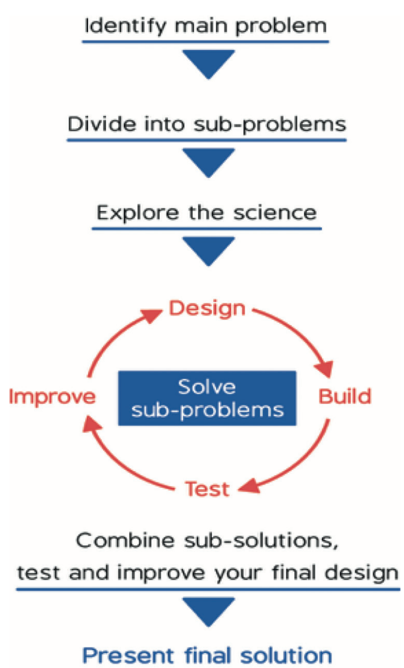

Figure 2. The simplified six-step Engineering Design Process (EDP) as suggested by the Eugenides Foundation team for its engineering educational projects and activities.

EDP application derives several uncertainties that challenge the students. McCormick and Hammer (2016) have observed that usually teachers limit the openness of the procedure. And this is the case in Greece, where most of the teachers lack engineering background. This six-step simplified EDP has many similarities with the scientific method. For this reason it seems familiar enough to the Greek students and teachers, who easily adopted it.

The Hydrosensor Module

Coding is also a major concern of the project. The students use the open source Arduino software to work on the Hydrosensor platform. Arduino's main advantage is its simplicity in programming and its low cost boards and peripherals. It is suitable for beginners and is appropriate to the project tasks. The Foundation offers a simple code that operates the sensors kit simultaneously. Teams can manipulate the code to function with their add-ons. While the code is running, it measures the environmental conditions and records the data in a mounted SD card. The teams can process their measurements with common spreadsheet software and conclude about the physical parameters of the water. Through this procedure, the teams can study the variation of the temperature and the luminosity versus the depth, the contribution of the distance from the shore and the relation with the atmospheric temperature and weather conditions. They can also study if the position of the sensors on the ROV affects significantly the measurements.

Teams have also the chance to share their data in a specific online repository. In this case they are advised to take 15 to 20 measurements on different dates at the same location and follow the specific data collection protocol, which has been designed by the Foundation (Table 1).

Table 1. The protocol for collecting and uploading data with the Hydrosensor module.

Step	Description
1	Define exactly the location of the measurement
2	Record the timestamp of each measurement.
3	Record the atmospheric temperature and report the weather conditions at the time of the experiment.
4	Reset the sensor kit (Hydrosensor).
5	Dive the Hydrobot with the sensor kit onboard in about 2 meters depth.
6	Move the ROV horizontally for 1 meter in a vertical direction to the shore.
7	Almost surface the ROV, just to be covered from the water.
8	Move the Hydrobot for 1 meter towards the same direction as in step 6.
9	Change the position of Hydrosensor on the ROV. Repeat the steps 5 to 8 once.
10	Upload collected data to the online repository: http://hydrobots.gr/index/hydrosensor.php

Table 2. The project Hydrobots participants in Greece from 2012 to 2018.

School year	Number of schools	Students involved
2012–2013	67	1024
2013–2014	98	1211
2014–2015	43	569
2015–2016	40	467
2016–2017	40	164
2017–2018	28	214
TOTAL	**316**	**3,649**

This data collection introduces the teams to the crowd sourcing process. The crowd sourcing process permits society to save resources and also has a great educational value, since it motivates the students to follow scientific research patterns. This online cloud database is available to everyone and especially to researchers.

Project Hydrobot Application In Greek Secondary Schools

From 2012 to 2018, 316 public schools, more than 320 teachers and 3,649 students across Greece have participated voluntarily (Table 2). According to the teachers' responses, 51 of the student teams consisted of four to six members. The typical team had 10 members and the largest team had 37 members. The number of the team members ended up larger than initially designed. This was due to the fact that the interest rate from the students was higher than anticipated. Team members are mostly male. However, a significant number of girls participated, but we do not have specific numbers to report.

The project could be divided into three distinct phases: (1) The basic concept of the project, which is to construct an operating vehicle that floats and dives in the water, by putting together the framework parts, its motors and the control console. (2) Adding the Hydrosensor kit is the second phase of the project, which is optional. (3) The third phase of the project is an upgrade that some teams perform and it depends on their time availability and creativity.

We have asked the involved students and teachers to participate in a survey in order to evaluate the project and describe their experience. Two types of questionnaires – one for the students and one for the teachers – were uploaded to Google Forms, because it is a convenient format for the students. The questionnaires were selected to offer simple and few items, in order to be convenient for the responders who filled them voluntarily. Most of the questions are similar in both types of questionnaires and the teachers were responsible for one submission per student. All the questionnaires are structured and all the fields have required answers to avoid missing values on the survey and facilitate data analysis. They have open-ended and closed-ended questions in several ordinal scales. In particular, the close-ended question types are dichotomous and multiple-choice items that investigate the project's tasks completion. Additionally, five level Likert-type scale items are offered for measuring attitudes, skill development and project's impact. The open-ended questions search for demographic data and suggestions about project applications.

This project was conducted in large numbers of students, teachers and schools across Greece (Table 2). However, the lack of a comparison group with students who did not engage in the project is a limitation of the survey. Such surveys also face the issue of the student's tendency to exaggerate about their results (Kirkman et al. 2017). Since the participation was voluntary and the students were already interested in robotics and STEM before getting involved in the project, we cannot adjust the results to the general student population in Greece.

The most significant improvement was performed by the team of the 1st Technical Vocational High School of Salamis island. The students and the teachers of this school upgraded their Hydrobot three times within a two-year period (2012–2014). Ten students under the supervision of two teachers (Mr. Petros Poutos and Mr. Paraskevas Andrianos) worked during the first year, while 16 students worked during the second year with the same teachers. In their first upgrade, a camera with servo motors and a simple robotic arm (gripper) were attached on the vehicle (Figure 3 – the ROV in the center). The second upgrade was a construction of a new ROV with different materials but based on the same idea (Figure 3 – the ROV on the left). It is made of aluminum and acrylic glass sheets

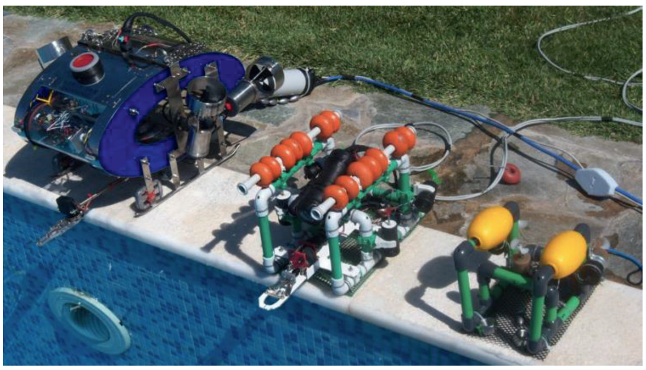

Figure 3. Two of the three upgrades that the team of the 1st Technical Vocational High School of Salamis island made in Hydrobots. The original vehicle is on the right side of the image. The ROV in the center of the figure has a camera and a gripper. A major upgrade of the initial plan is the vehicle showed on the left side of the figure with four motors and one-degree of freedom gripper. The reader can find more details about the latter at https://www.youtube.com/watch?v=hRsbDD39tik.

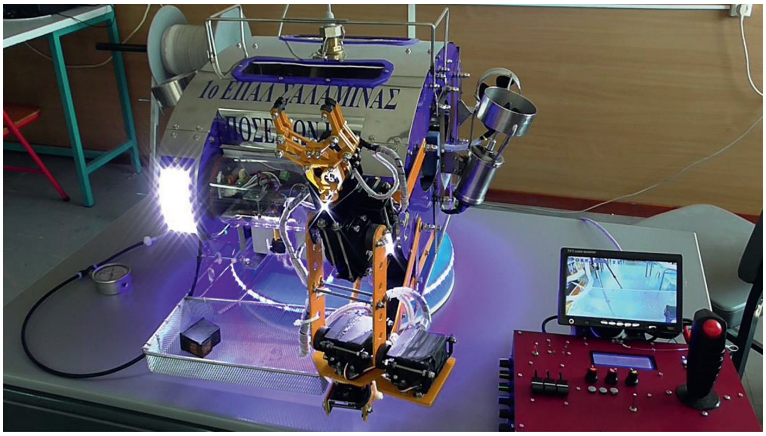

Figure 4. The most significant upgrade of the Hydrobots project by the 1st Technical Vocational High School of Salamis. The design of the ROV has improved significantly. The reader can find the block diagrams of this ROV in the Appendix. More about its design and construction at https://www.youtube.com/watch?v=1ogouxh5-8M and https://www.youtube.com/watch?v=RadnMvMxcJc

and, except for the camera with servo motors and the gripper, it has also a bunch of sensors that could detect changes on light, temperature, pressure and magnetic field.

Figure 4 shows the most significant upgrade of the Salamis team. This version has two cameras, one for navigation and one for video panorama, and a 4-degree of freedom robotic arm with a gripper. The vehicle's batteries are onboard and the team used a 230-meter long cable for communication with the shore. Data collected were processed with the LabView software. This version was constructed by 15 students and the previously mentioned two teachers.

This team has observed that the long length of power supply cable as well as the high motor loads produce a voltage drop and asymmetrical currents that affected the sensor circuit. As a result, erroneous measurements have been recorded in some experiments. The block diagrams of this most advanced modification are shown in Appendix A (Figures 5 and 6).

Presentation Of The Survey- Project Evaluation

In this section, we present the results of the survey concerning the project. The Eugenides Foundation team conducts an online survey after each school year, in order to record the learning objectives achievement, the impact of the project and other administration issues. All the participating students and teachers are asked to respond to a specific questionnaire. The students are asked also for a self-efficiency assessment.

We miss data from the school year 2015–2016 because, due to technical reasons, the answer sheets were not saved. We have also omitted teachers' questionnaires from 2012–2013 for analysing the constructs below, since their questionnaires did not contain all the items as the following years do. One teacher from each engaged school responded to the survey, while 17% of the participating students submitted their forms. In total numbers, we have analysed 209 teacher and 547 student questionnaires by using SPSS v25. We present the results of students' and teachers' responses on the following three constructs:

- Evaluate the project outcome and impact
- Report the students' attitude and skills development due to the project and mention any influence in future career choice
- Describe the students' satisfaction from their participation in the project.

First, we have to ensure the reliability of each construct by applying the most used measure of reliability, the Cronbach's alpha. In our case, the Cronbach's alpha indicates optimal results and high correlations between the items of each construct (Table 3).

Students Survey Questions

The items that the participating students were asked to respond as well as the results for each construct are listed in Tables 4, 5 and 6 below.

Table 3. Cronbach's alpha reliability test results for students' constructs, which show high internal consistency for each construct for both student and teacher questionnaires.

Construct	Cronbach's alpha (students)	Cronbach's alpha (teachers)
Evaluate the project outcome and impact	0.801	0.800
Report about the students' attitude and skills development due to the project and mention any influence in future career choice	0.794	0.792
Describe the students' satisfaction from their participation in the project	0.830	0.751

Table 4. Students responses on the project outcome and impact.

Item	Not at all (%)	Very little (%)	Average (%)	Above average (%)	Very much (%)	Not answer (%)
A1	2.4	3.5	8.6	20.1	63.8	1.6
A2	1.8	6.0	17.7	28.2	41.9	4.4
A3	2.4	4.4	13.3	24.3	46.6	9.0
A4	2.4	5.1	14.6	28.3	47.2	2.4
A5	2.0	7.3	16.5	30.0	36.7	7.5

Table 5. Student responses on their attitude and skills development due to the project.

Item	Not at all (%)	Very little (%)	Average (%)	Above average (%)	Very much (%)	Not answer (%)
B1	1.5	5.7	19.0	30.7	41.9	1.3
B2	4.6	7.5	19.0	32.9	34.6	1.5
B3	8.8	10.8	21.4	29.1	26.7	3.3
B4	8.2	10.6	23.8	26.7	28.3	2.4
B5	10.8	13.9	21.6	22.7	20.5	10.6

Evaluate the project outcome and impact

A1. How interesting was the construction for you?

A2. How interesting was the construction for your non-participating classmates?

A3. How interesting was the construction for the non-participating teachers?

A4. Estimate the project's originality to you.

A5. Estimate the project's originality for your non-participating classmates.

Report the students' attitude and skills development due to the project and mention any influence in future career choice

B1. Which was the level of cooperation with your teammates?

B2. How much did the cooperation among the team members improve due to the project?

B3. How much did the project contribute to your school performance?

B4. How much did the project contribute to your interest in school?

B5. Did the project influence the career perspective of the participating students?

Satisfaction from the students' participation in the project

C1. What is your degree of satisfaction concerning the project's creativeness?

C2. What is your degree of satisfaction concerning the educational value of the project?

C3. What is your degree of satisfaction concerning the opportunity for cooperation among students?

C4. What is your degree of satisfaction concerning the development of student skills?

C5. What is your degree of satisfaction concerning the opportunity for cooperation among students and teachers?

C6. What is your degree of satisfaction concerning the achieved result?

C7. What is your degree of satisfaction concerning the achieved result comparing to the initially designed one?

C8. How difficult was the construction?

Table 6. Student responses on their satisfaction from their participation in Hydrobots.

Item	Not at all (%)	Very little (%)	Average (%)	Above average (%)	Very much (%)	Not answer (%)
C1	1.3	4.9	17.9	29.6	45.3	0.9
C2	1.1	7.3	18.6	35.3	36.7	0.9
C3	1.6	4.8	11.9	28.7	51.6	1.5
C4	1.3	9.1	16.1	33.5	38.9	1.1
C5	1.5	4.2	14.6	30.2	47.7	1.8
C6	1.1	4.6	12.4	33.1	47.3	1.5
C7	2.2	1.8	5.5	16.8	29.6	44.1
C8	15.9	27.2	27.6	16.5	11.0	1.8

Students' responses show high percentages in project interest and impact in their schools (items A1 to A5 in Table 4). More than 50% of the responders reported that their involvement help them develop their skills significantly (items B1 to B4 in Table 5). About half of the students mentioned that their involvement in the project had influenced their future career perspective (item B5 in Table 5). More than half of the students enjoyed their participation and completed the project's tasks without difficulty (items C1 to C8 in Table 6).

Teachers Questionnaires

The following Tables 7, 8 and 9 contain the teachers' responses on each construct.

Evaluate the project outcome and impact

D1. How interesting was the construction for you?

D2. How interesting was the construction for your students?

D3. How interesting was the construction for the non-participating students?

D4. How interesting was the construction for the non-participating teachers?

D5. Estimate the project's originality to you.

D6. Estimate the project's originality for the participating students.

Table 7. Teachers' responses on the project outcome and impact.

Item	Not at all (%)	Very little (%)	Average (%)	Above average (%)	Very much (%)	Not answer (%)
D1	0.0	0.5	3.8	12.9	82.3	0.5
D2	0.0	0.5	5.7	15.8	77.5	0.5
D3	0.0	1.4	7.2	27.8	58.9	4.8
D4	1.0	5.7	11.5	30.6	48.3	2.9
D5	0.5	1.9	6.7	29.2	61.2	0.5
D6	0.0	1.9	3.8	23.4	67.9	2.9

Table 8. Teacher responses on the attitude and skills development of their students due to the project and influence in future career choice.

Item	Not at all (%)	Very little (%)	Average (%)	Above average (%)	Very much (%)	Not answer (%)
E1	0.0	2.4	11.0	36.8	49.3	0.5
E2	0.0	2.9	15.3	34.9	44.0	2.9
E3	0.0	7.7	25.5	33.2	26.4	7.2
E4	0.0	5.8	20.7	37.0	30.8	5.8
E5	1.9	9.6	25.4	31.1	17.2	14.8
E6	1.9	5.8	21.6	31.7	32.7	6.3

Report about student's attitude and skills development due to the project and mention any influence in future career choice

E1. Which was the level of students' cooperation?
E2. To what extent did the cooperation among the team members improve due to the project?
E3. To what extent did the project contribute to your students' school performance?
E4. To what extent did the project contribute to your students' interest in school?
E5. Did the project influence the career perspective of the participating students?
E6. To what extent did the project help you improve the lessons you teach?

Satisfaction from their participation in the project

F1. What is your degree of satisfaction concerning the project's creativeness?
F2. What is your degree of satisfaction concerning the educational value of the project?
F3. What is your degree of satisfaction concerning the opportunity for cooperation among students?

Table 9. Teacher responses on their students' satisfaction from their participation in the project.

Item	Not at all (%)	Very little (%)	Average (%)	Above average (%)	Very much (%)	Not answer (%)
F1	0.0	1.4	4.3	16.3	78.0	0.0
F2	0.0	1.0	7.2	27.3	64.1	0.5
F3	0.0	1.4	1.9	19.6	76.6	0.5
F4	0.0	1.0	6.7	24.4	67.5	0.5
F5	1.0	4.8	15.8	36.4	42.1	0.0
F6	3.3	10.5	13.4	32.1	40.7	0.0
F7	5.3	6.7	21.1	36.4	30.1	0.5
F8	2.9	22.0	37.8	29.7	7.2	0.5

F4. What is your degree of satisfaction concerning the development of student skills?

F5. What is your degree of satisfaction concerning the achieved result?

F6. What is your degree of satisfaction concerning the achieved result comparing to the initially designed one?

F7. Was the construction easy for the teacher?

F8. Was the construction easy for the students?

Teachers' responses show high percentages of project interest of their students and the project impact in their schools (items D1 to D5 in Table 7). The majority of the teachers answered that the project helped their students develop their STEM and transversal skills significantly (items E1 to E4 in Table 8). Half of them reported that the ROV construction had influenced the career perspective of their students (item E5 in Table 8). About two thirds of the involved teachers mentioned that they had upgraded their lessons due to the project (item E6 in Table 8). Almost all the teachers enjoyed their participation and their teams completed the project's tasks with moderate difficulty. Indeed, more than 90% of the teachers are satisfied with the educational potential of Hydrobots, the outcome of students' cooperation and skills development (items F1 to F8 in Table 9).

DISCUSSION AND CONCLUSIONS

One of the major goals of the Eugenides Foundation is to promote both scientific and engineering education in Greece. Due to the geographical position of Greece, many Greek schools are located close to the Mediterranean and the Hydrobots project helps students interact with their natural environment, even in highly populated cities like Athens. The statistical analysis of the survey confirmed that Hydrobots had a great reception from the students and the teachers who participated. The survey results about students' reception are suggestive but not definitive, as they rely on low response rates from the students. Teachers reported that the project helped the involved students develop significantly their STEM and transversal skills, such as team working. Their students are able to build the ROV, since almost all the teams have completed the basic construction successfully without any difficulties. The teachers were more enthusiastic compared to their students about the interest of the latter for the project and its impact in the school community. Students and teachers agreed on the degree of the positive project's contribution to students' performance in school. They also agreed on the project's positive impact in students' career perspective as depicted in items B5 and E5 (Tables 5 and 8 respectively). On these items, almost one to ten of all the survey participants responded that they did not know about the project's influence on students' future professions. This can be explained by the fact that the participants were involved voluntarily and they usually had already expressed their interest in Science, Engineering or robotics before the project call.

Almost half of the students avoid answering the item C7, about their satisfaction from the achieved result compared to the initially designed. It is possible that these students were not aware of the initial workflow and the schedule of the team. On the other hand, about 60% of the teachers reported in the same question that they completed the tasks as they had planned them (item F6). This discrepancy confirms the fact that the Greek educational system is still teacher-centered and it derives that more work should be done for a more student oriented learning environment.

Although the questionnaire results cannot be expanded for the majority of the Greek students, the huge number of the participants indicates the urgent need for similar projects in Greece, due to the curriculum deficiency in STEM education. Hydrobots is an innovative STEM school activity for Greek students and beneficiary for all the participants. Through Hydrobots, students can learn effectively difficult topics of their school curricula and become familiar with mechanical tools, electronics and procedures that enhance their engineering skills (Techet et al. 2006). On the other hand, students meet the engineering way of thinking, which is missing from the formal Greek education and the exam-driven system. By applying EDP during the project tasks, students discover their skills' limitations and are motivated to work on Science and Mathematics (Nesbit et al. 2005). In fact, building and operating a Hydrobot is a true engineering experience for the involved students and this project leaves the participants with a memorable and enjoyable impression (Thompson and Consi, 2007). Additionally, content knowledge is only one factor of developing scientific and engineering thinking. Students have to understand the meaning and the scope of learning in order to construct the proper conceptual framework for their future career paths (Peters–Burton 2014). The ROV with its sensors and any possible modifications can be also used as a tool for scientific school experimentation in real environments. Teachers have expanded the educational potential of the ROV and conduct small scale research projects. The teams can collect environmental data and commute their results to the local community.

Since future workers in contemporary technology-rich environments are expected to possess sophisticated technology skills and attitudes (Lee and Spires 2009), students should be prepared accordingly. Towards this scope, educators have to reform their teaching in order to fill the gap between the modern students that are digitally natives (Prensky 2006) and the 20th century-based educational curricula. Students and teachers' feedback shows that it is possible to introduce STEM effectively in this age group by educational robotics. Students become creative, feel productive and develop a positive attitude to formal education and especially to STEM fields.

During the project, students and teachers also develop useful educational material, pictures, videos and web sites and announce the events in local media, in social media and school journals. The project improves not only the engineering skills of the participants, but also their communication skills. Teamwork contributes significantly to social behavior and students give away the rough competitiveness that stresses them during their school years. Through Hydrobots, students are able to interact with the learning procedure, to evaluate the results of their work and to develop critical thinking and positive attitude to school. Like similar STEM projects (e.g. Spencer et al. 2009, Beaudoin et al. 2012, Cross et al. 2016, Ziaeefard and Mahmoudian 2018), it motivates students to express their interest in Science or their engineering talent.

The project is beneficiary for the teachers too. Most of the teachers, who need to strengthen their teaching skills, seek for innovative projects. As they are self-motivated to participate in such projects, they become more satisfied with their work (Huberman 1995) and improve their teaching effectiveness (Guskey 2002) and learning results (Emo 2015). Moreover, this project could be a useful introductory course to students who decide to get involved professionally in Engineering. Through Hydrobots, the future engineers will learn some important professional skills that Shuman et al. (2005) describe as process skills, like communication and teamwork.

SUMMARY AND FUTURE WORK

The project Hydrobots is an engineering experience, especially designed for schools in Greece, based on the MIT Sea Perch project, where the students construct a fully remotely operational underwater vehicle by dealing with problems completely foreign to them. The application of the sequential process of EDP fulfills the needs of a modern educational environment, focuses on the students' needs and helps them to decide for their future professional steps. The results of its application in Greek secondary education are remarkable and show significant improvement in involved students' attitude as well as STEM and transversal skills development.

Due to its high impact, engagement and acceptance from the Greek education community, the Hydrobot project was decided to be updated and incorporated as an engineering challenge suited in European education environments in the framework of the European Community funded STEM4you(th) project. The enthusiastic reception of this project encourages the Eugenides Foundation to continue offering innovative STEM-related projects.

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Dimitris Piperidis holds a degree in Electrical and Computer Engineering from National Technical University (NTUA) and a degree in Medical Instrument Technology of the former University of Applied Sciences of Athens (now Department of Biomedical Engineering of the University of West Attica). His fields of research are robotics, automation systems and computer programming. Since 2012, he works in the Science and Technology Center of the Eugenides Foundation on designing and developing educational activities in Robotics, Information Technology and Electronics and the maintenance of Foundation's exhibits, and engaging in, science and technology.

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APPENDIX A

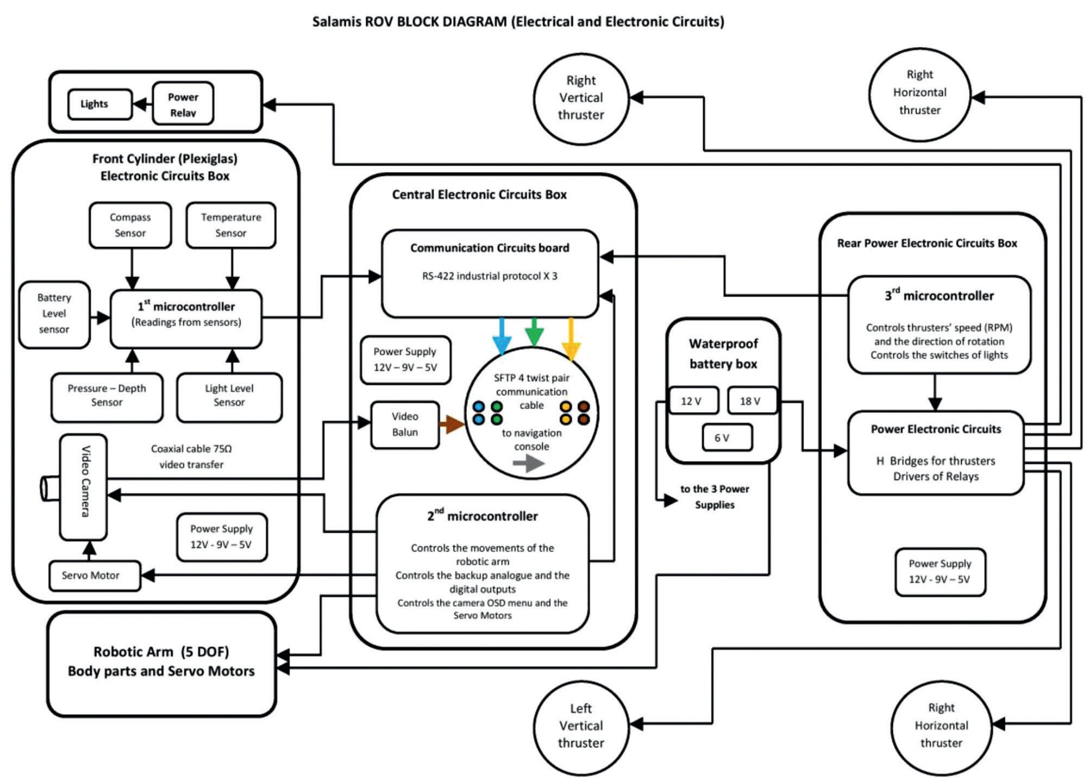

Figure 5. Block diagram of the most significant modified Salamis ROV part A – the main framework.

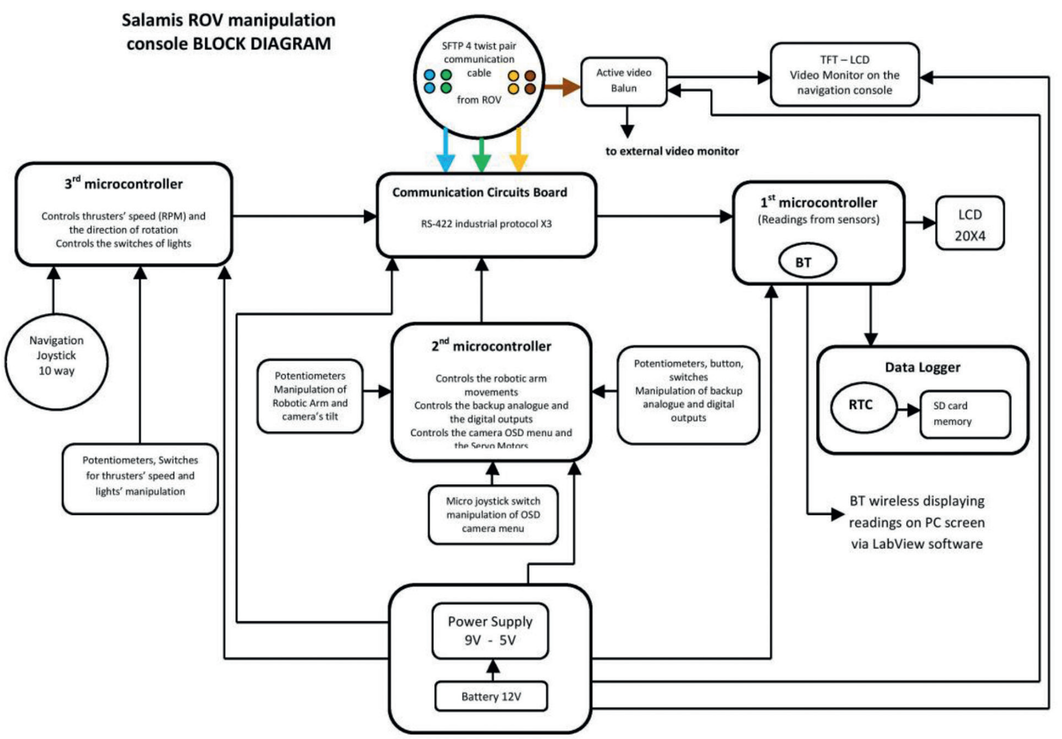

Figure 6. Block diagram of the most significant modified Salamis ROV part B – the manipulation console.