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A Professional Project Based Learning Method in Mobile Robotics*

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***Abstract*—Due to its high potential and encouraging results, project-based learning emerges as a highly interesting paradigm in the education systems worldwide. Moreover, robotics is an interdisciplinary field where students could learn and apply their skills in mechanics, electronics, computer science, mathematics and control engineering. This paper presents a robotics project-based learning methodology which focuses on collaborating with the industry to design, develop, evaluate, integrate and manage projects designated to be used in real-life applications. This learning method emphasizes and enables the students to apprehend the importance of fulfilling client requirements and the interactions with the client, the suppliers and with the other members of the team. The students, coached by a partner from industry, have the opportunity to apply and to improve their project management skills under a large-scale, highly complex project. This method is being applied since 2008 at ISEN Lille, France, with good results and significant impact.**

Keywords—project-based learning; robotics; project management; industrial partnership; collaboration; team work.

I. Introduction

In professional applications, service robots are already having a significant impact in areas such as agriculture, surgery, logistics and underwater applications. Their importance is also growing in economic and social areas. The IFR (International Federation of Robotics) defines a service robot as a robot that performs useful tasks for humans or equipment excluding industrial automation application. As highlighted by the latest figures published by the IFR Statistical Department in 2013 [1], the mobile platforms sold in 2012 featured a strong global growth, comparing with 2011 (see Fig. 1) and this growth will continue in the future years, going from 630 units in 2012 to 13000 in 2016 (as shown in Fig. 2), an increase of 20000%.

In this economic context, it is very important to train engineers in the technology in order to be able to meet the future challenges in service robotics.

The educational system in the university is still based primarily on lectures, lab practices and homework. Since several years, students in France also follow lectures on project management but, unfortunately, these are linked relatively weak to the scientific and engineering lectures. In the French academic educational system, students have to work in various companies, within internships ranging between 9 and 10 months. In the last year (Master 2 level), they usually spend the last 6 months prior to obtaining the diploma, working as trainees in a company. At ISEN, we propose to the students some small projects, for a group of 2 to 4 students, during the elective courses and a large project in Master 1 (about 250 to 300 hours) where they work in a group of 2 to maximum 8 students, depending on the subject. However, the occasions are extremely rare for the students to work in a large group in this kind of projects and to learn to apply all the project management skills.

Somewhat similar to the French system, undergraduate engineering studies in Romania are based on course lectures and lab workshops or projects, which substitute the lab workshops at some syllabuses. A total of around 270 hours are also allocated for practical internship in the industry. The internship hours, though, are evenly distributed over the first three years of study, thus resulting in a limited capability for developing very consistent projects and gaining deep, in situ, practical, skills on project management. Additionally, a total of 210 hours are allocated in the fourth year, for the development of the Diploma Project, which is the most consistent type of a project an engineering student in the Romanian system will face.

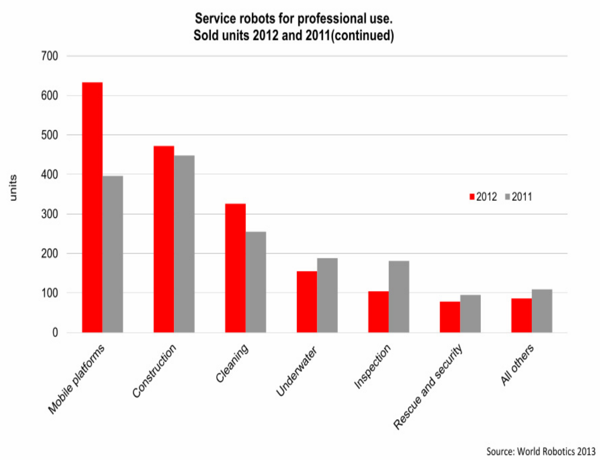

Fig. 1. Service robots for professional use: sold units in 2012 and 2011 (source [1]).

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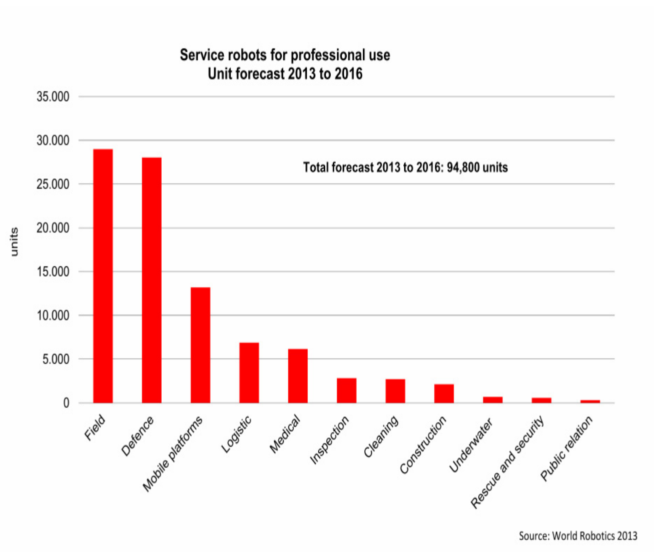

Fig. 2. Service robots for professional use: forecast 2013–2016 (source [1]).

In Belgium, the situation is very diverse, and large differences are observed between the regions, the universities and even (within) the engineering faculties. Moreover, the Flemish educational landscape is changing rapidly [2], and "flexibility" for students – not only choosing elective courses, but also deviating from the "model trajectory" by (re-)taking courses in different study years – heavily sollicitates both the educational system and the lecturers.

Engineering design exercises for small or larger groups of students, internal design contests, lab exchange sessions and so on, are both attractive to students and effective for staff and equipment allocation. Accent however is on "classic" lectures, labs and exercises. As an example, some aspects of project based engineering education on the Ghent campus of the KU Leuven (Faculty of Engineering Technology) are briefly described, mainly in the fields of automation and electronics.

Bachelor 3 electronic engineering students have an annual design challenge for small autonomous vehicles having to find their way through a maze. Students do predesign, stay for a full project week on location at the North Sea coast with an intensive program of design related lectures, planning and designing, learn and use (initial) project management skills, and have a final challenge on the open day of the campus (which serves as project dead line). Bachelor 3 automation engineering students have two initial project design exercises: an electronic and an electrical engineering design, the latter in cooperation with industry.

Master 1 automation engineering students apply knowledge acquired in both lectures and lab exercises into a group (typically 10-12 students for one topic) control design of a realistic industrial control system. They use different tuning methods and controllers, choose the best design – control and disturbance behavior, robustness and so forth – using a set of performance indicators, and implement the chosen final design. In a group presentation, design steps and final results are presented and discussed.

As the Faculty of Engineering Technology has campuses on different locations, each with research groups having specific expertise, equipment and test-rigs, Master 1 automation engineering students profit from lab exchanges with different campuses throughout Flanders [2], [3]. This one day short student mobility has in the context of the Interreg 2 Seas project i-MOCCA even been extended to nearby foreign partners.

Robotics is an interdisciplinary field where students can apply their skills in mechanics, electronics, computer science, mathematics and control engineering, thus stimulating the student interest of learning in these fields. A constantly increasing number of national and international robotics challenges motivate the students to work in a team, within strict time frames and deadlines, and encourage their creativity. Examples of such contests are RobotChallenge [4], founded in 2004, DARPA Grand Challenge [5] and Robotics Challenge [6], RoboCup [7], and the "Hard&Soft" International Computers Contest for Students, launched in 1994 [8].

Project-based learning methods, with special focus on robotics, have gained a lot of attention recently. Universities around the world are developing and implementing robotics project-based environments to emphasize active, cooperative and problem-based learning [9]–[11].

Modular robotic platforms based on LEGO components are used to develop remotely operated vehicle or autonomous underwater vehicle projects at Stevens Institute of Technology NJ, USA [12] and to study robotic design in creative ways, at the Chungnam National University Daejeon, Korea [13]. LEGO Mindstorms NXT programmable bricks are also used in many project-based robotics learning approaches, for example in conjunction with the Matlab or LabVIEW programming and analysis environments [14].

Custom made modular robotic platforms are another frequent approach, due to its favorable design flexibility over project implementation time ratio. Such platforms have been developed to support project-based learning methods in mobile robotic design at ITESM Monterrey, Mexico Campus [15], or in computer vision and robotic control fields at University of Lleida, Spain [16]. To further increase the flexibility of the robotic platforms, Arduino or FPGA-based modules are used in many cases as programmable control elements [17].

Although the experience gained from these relatively new approaches needs to be further developed, the results are encouraging. There still are open issues and problems to be solved, such as the lack of proper evaluation frameworks and consistent research evidence to validate these methods [11]. Another issue is the relatively low level of cooperation with the industry [18], which could provide the students with a very consistent, practical experience on real-life project development and management, which will be especially needed as future employees in companies.

From our point of view, *it is essential to integrate the project management dimension on the project and also, to give to the students the possibility to design, construct and evaluate a robot designated to be used in the industry or services*.

This point of view is also emphasized in [19], which considers that a successful implementation of a project-based learning requires interest, cooperation and integration of faculty from at least the engineering, mathematics, science and business/management divisions of an institution. This is one of the main challenges that an institution has to handle for a successful implementation of this learning methodology.

For over 5 years, we are proposing this kind of projects to the students who choose the robotics electives of Master 2 at the Institut Supérieur d'Electronique et du Numérique (ISEN), Lille, France. This work presents the method of robotics project based learning applied at the ISEN. The project is an independent activity proposed to the students who choose to specialize in robotics at the end of their curricula. It replaces the traditional learning methods and is the only technical training the students are pursuing during the last 6 months of their learning period. While at the Politehnica University of Timisoara the students have robotics courses containing some projects and the Faculty of Engineering Technology from Gent proposes to the students a full project week with a challenge at the end, at ISEN Lille the teachers did an organizational and cultural change to implement the philosophy of the project oriented based learning [20].

The paper is organized as follows. Section II introduces the objectives of the project based learning methodology and explains how the project is organized and evaluated. Section III describes as a case study, the project realized in 2012/2013. Some discussions and the impact of this method are proposed in section IV. Section V concludes with a summary and direction for future work.

II. Proposed Project Based Learning Methodology

A. Main Objectives

Since 2008, the students who follow the robotics option in Master 2 at ISEN have to design, construct and test a mobile autonomous robot. The goal and main specifications of the robot are defined by the client, who can be a company or a start-up, a research laboratory or a specific department of the university or any institution which needs a specific mobile robot. The students have 5 months to complete the project, at a working schedule of 2.5 days per week. The project team is composed of around 16 students.

A coach who works in the industry helps the students to manage the entire project and a team of academic staff members with different skills (mechanics, informatics, electronics and automatic control) serves as technical consultants.

The learning objectives of such a project are the following:

- discover all the technical skills necessary to construct a mobile robot;
- improve and increase technical knowledge in a specific field of robotics;
- learn to do proper documentation and state of the art design, and choose the best solution for a technical problem by taking into account both the technical and the economical aspects;
- express ideas and technical solutions;
- writing of the technical reports;
- manage a project using the V-Cycle methodology [21];
- learn to use collaborative platforms and software to share information;
- learn to meet the deadlines, to prepare purchase orders, to track the working progress and manage the delays;
- learn to work in a team, to manage the human resources and the conflicts.

B. Organizational Elements

Different stakeholders are involved in the project, as depicted in Fig. 3. The first one is the client, which specifies the general requirements of the project.

A group of academic staff, with different fields of expertise, assists the students throughout the project in deciding the best technologies to use and how to choose the appropriate suppliers, according to the project needs and taking into account the delivery deadlines. It also anticipates the critical tasks of the project, helping the students to manage these tasks and to keep the established deadlines.

The coach from the industry has as main goals helping the student team to define the SPARC of the system (Speed, Power, Area, Reliability and Cost) and organizing the project work by following the V-Cycle methodology. The coach also assists in the specification of the interface between the different components of the system, in the testing and validation procedures, as well as in the project documentation and reporting.

A project manager is elected from the student members of the project team. He or she is in charge of the following key tasks:

- overall organization and planning of the project work;
- management of the periodical (weekly) technical meetings of the team with the academic staff group;

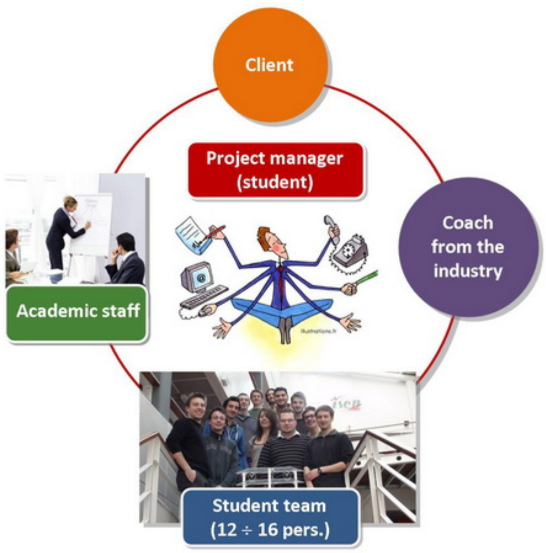

Fig. 3. Project stakeholders.

- identification of critical tasks and the appropriate planning of the required resources, in agreement with the coach from the industry and the academic staff group;
- supervision of the overall work progress;
- management of project budget and acquisitions;
- management of proper communication and information exchange between all the project stakeholders, and of the potential conflicts;
- project documentation: technical specifications, periodic reports, technical documentation, tests etc.

Depending on the project specificity, different development topics (workgroups) are defined. In the case of robotics projects, the following main workgroups will typically be identified:

- mechanics, mechatronics and physical body;
- batteries and power management;
- motor driving and mobility;
- robotic perception, sensors and actuators;
- robotic software and control;
- human-machine interfaces.

Each workgroup has a student leader, in direct relation with the project manager. The group leaders establish, under the supervision of the project manager, the deadlines and the tasks of each workgroup, and monitor the progress of the group.

In order to achieve the goals of the project, the student team members affiliate themselves to the workgroups, based on their competences and points of interest. On the other hand, depending on the project dynamics and planning, students can temporarily be allocated to other workgroups. For example, students from the robotic software group can work with the colleagues in the mechanics or motor driving groups during the initial stages of the project, when the robotic hardware must be implemented prior to writing the control software.

As a vital element of the project management framework, communication between the stakeholders must be supported through timely, comprehensive information exchange mechanisms. Our approach included the following efficient and accessible means of communication:

- Dropbox file hosting service, for storing and sharing the project documents, files and reports;
- SVN server, for managing the versions and revisions of the robotic software;
- Facebook group, for the general presentation of the project through social networks;
- Local directory service, to share the photos, contact information and personal schedules of the project team.

C. *Project Assessment Method*

Each year the project starts around middle of September and ends middle of February the next year. 15 ECTS points are allocated for it, thus involving between 375 and 450 hours of work for each student.

The project evaluation focuses on two main competences: the technical one and the communication one.

For the first competence, the evaluators are the coach from the industry and the academic staff. On one hand, the technical skills of the students in embedded systems are evaluated using a questionnaire. On the other hand, the technical work done by the students is assessed based on an evaluation grid which takes into account the following items: design (20%), implementation (20%), tests (40%) and autonomy of the student (20%). The final mark is the weighted average between the first mark (30%) and the second one (70%).

The second competence is evaluated by the academic staff, the client and the students themselves. The resulting mark is a weighted average between the marks given by the academic staff (20%), the student himself/herself (20%), the technical report (40%) and the final presentation of the work to the client (20%). Both professors and students use the same evaluation grid in order to have a homogenous evaluation. It takes the following items into account: the autonomy (25%), the involvement into the project (25%), the search of the best technical solutions (25%) and the implementation (25%).

III. Case Study: AliceN Project

AliceN is an autonomous holonomic robot (see Fig. 4) requested by the communication department of ISEN in order to show to the visitors a relevant application of the skills learnt by the students from ISEN and also to welcome and guide the visitors.

It has been built in the period September 2012 to February 2013, by a team of 16 students, which has been organized according to the principles described in the previous section (see Fig. 5). The robot detects the visitors via a Kinect motion sensing device and moves autonomously towards the nearest detected person. Then, it is going to interact with the visitor through tablet device and offers general information about the company, or about the employees. If the visitor doesn't need help from the robot, it leaves the visitor and starts looking for another one.

Fig. 4. AliceN, the visitor welcoming and guiding robot.

A modular hardware architecture has been designed for the AliceN robot, as depicted in Fig. 6. Its main control unit is an LS-373 embedded PC (Texas Instruments), running under the Ubuntu Linux platform.

Sensors producing a lot of data, such as the URG-04LX-UG01 Scanning Laser Rangefinder (Hokuyo) and the Xbox Kinect motion sensing device, are directly connected to the main control unit, through high bandwidth interfaces (USB). The other sensors such as the LV-MaxSonar-EZ0-3 ultrasonic (US) sensors (MaxBotix), the GP2Y0A02YKOF infra-red (IR) sensors (Sharp), accelerometer and electronic compass, are connected to a second control board, an Arduino Mega 2560 module.

Custom-made boards have been designed and implemented by the students, for the power management and motor driver subsystems of the robot. To implement the emergency stop module, a SN-SHK shock sensor (Cytron Technologies) and a manual emergency push button have been used.

To further increase the project reusability, a modular, class-based design has been employed for the main robotic control software, as seen in Fig. 7.

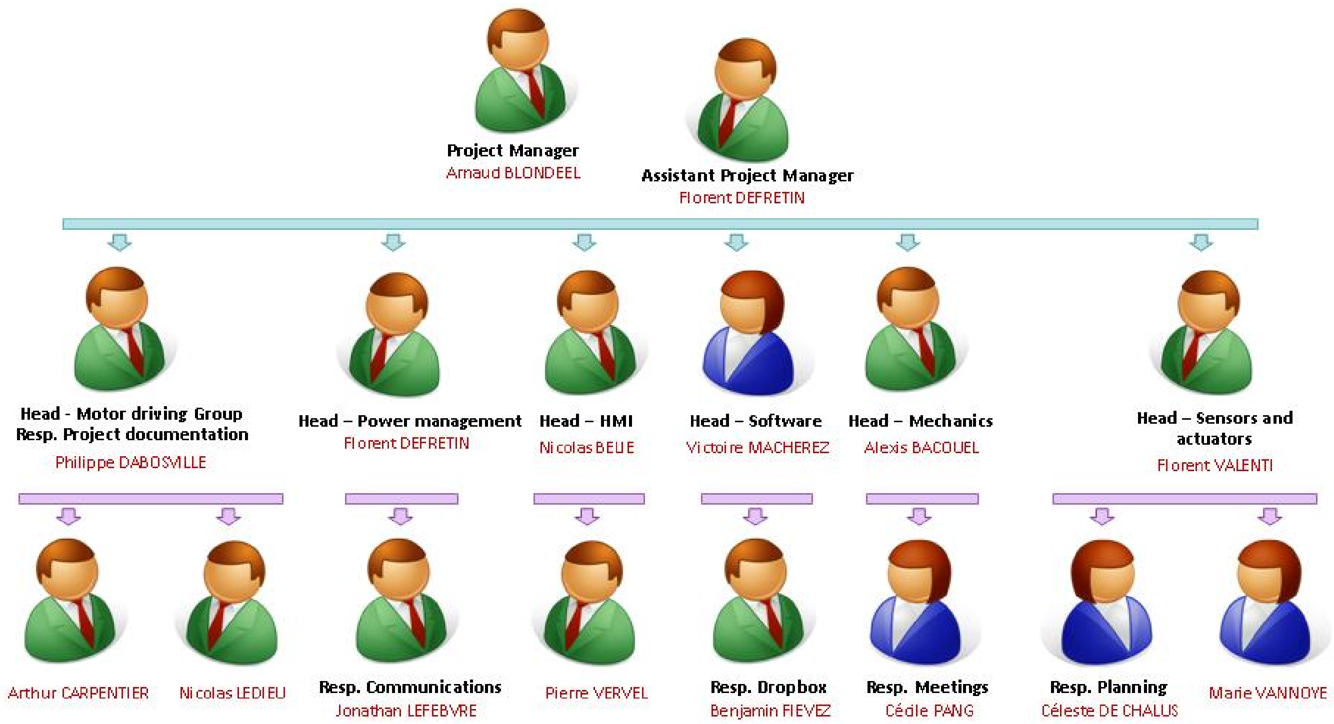

Fig. 5. Structure of the AliceN project team.

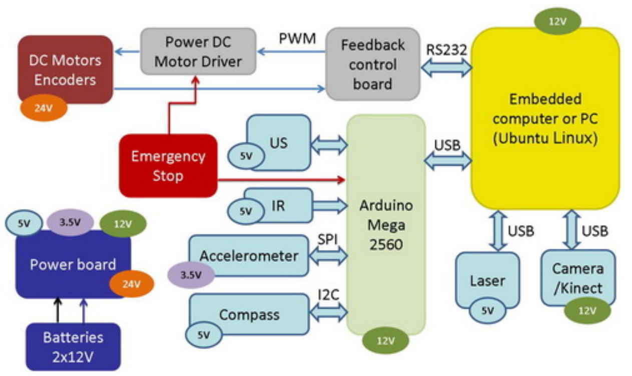

Fig. 6. Hardware architecture of the AliceN robot.

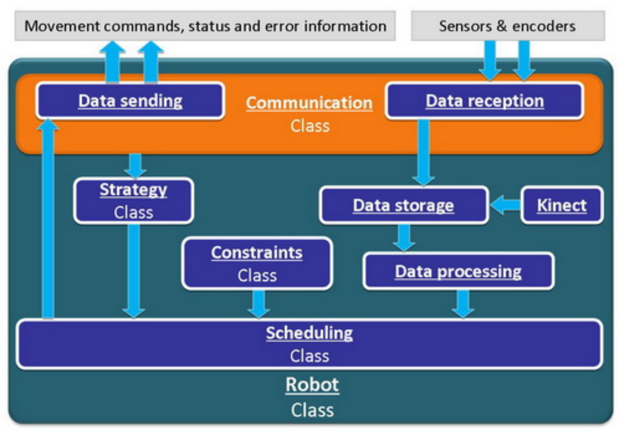

Fig. 7. General software architecture of the main robotic control unit.

IV. Discussion on the Results and the Impact of the Proposed Methodology

A set of evaluations and analyses have been performed to assess the impact of the proposed robotic project based learning system. Table 1 shows the averages marks for the group of students who followed the Robotics option of the Master's studies at the ISEN Lille, France, between the years of study 2003/2004 and 2012/2013. The French grading system includes the marks between 0 and 20, 20 being the best one. Before 2008, the students following the robotic option were evaluated using a classic notation system, a weighted average between exam (60%) and labs (40%).

The results of the new method of learning, which has been applied since 2008/2009, are highlighted in TABLE I. We can observe that the student averages have been steadily higher since our project based learning method has been used.

Detailed average marks just like underneath, for both technical and communication skills, are presented in TABLE II and TABLE III. It is interesting to notice that there is not a very large difference between the student and academic staff notations (see TABLE III). Moreover, in 2011/2012 the students evaluated themselves even more severely than the professors. The difference in the average marks given by the coach from the industry between the first two years and the others can be explained by the fact that at the beginning, the students had also some lectures, and the exam marks have been added to the marks given by the coach. We decided in 2010/2011 to stop the lectures because only the students who found a direct link between the topic of the lecture and their part of the project were really interested in these.

V. Conclusion

This paper presents a new way of learning, based on a project approach which is closely linked to a real need expressed by a client and is also managed as an industrial project. The robotic application requests various skills, allowing students to improve or acquire new competences on mechanics, electronics, informatics and/or automatic control. Moreover, the students will also significantly improve their project management skills, including the management of human resources and conflicts, management of equipment purchasing and of the budget.

This kind of learning method helps students understand the importance of preparing good technical specifications in order to be able to point out and define the interfaces between the project groups, and of keeping the deadlines. Moreover, this method emphasizes and enables the students to apprehend the importance of fulfilling client requirements, along with the interactions with the client, the suppliers and the other members of the team. The students, coached by a partner from industry, have the opportunity to apply and to improve their management skills under a large-scale, highly complex project.

The results obtained by the students who were involved in the project show that they are more motivated than by learning in a classical way. Moreover, the students spent a lot of time working on the project. Each year, since 2008/2009, they have been asking to work in the robotics laboratory during weekends and holidays. We had estimated that the last academic year (2012/2013), each student spent in total around 960 hours working on the project (including week-ends and holidays), which is the double compared with the number of hour defined by the ECTS.

In the future, as this experience proved to be very useful for the students, we would like to implement it also at the Politehnica University of Timisoara. Student exchanges through Erasmus programs have also been proposed for both Flemish and Romanians students, who are interested to follow this project, which provides the opportunity to work in a multicultural environment and, thereby, to gain new skills.

Acknowledgment

The authors would like to thank Maxime Agache, Head of Embedded system for the TGV, SNCF (France), the coach from industry, and the team of professors from ISEN, serving as technical consultants on the project: Jean-Marc Capron, Gérard Haw, Ferdinand Piette and Bruno Stefanelli.

TABLE I. Student averages at the Robotics option of Master's studies, since 2003

Year of Study	Number of Students in the Group	Average /20
2003/2004	21	11.9
2004/2005	32	12.3
2005/2006	16	12.6
2006/2007	11	13.8
2007/2008	6	13.45
2008/2009	**13**	**15.44**
2009/2010	**14**	**14.14**
2010/2011	**12**	**15.95**
2011/2012	**14**	**15.63**
2012/2013	**16**	**15.96**

TABLE II. Averages for the technical skills since academic year 2008/2009

Year of study	Coach from industry	Academic staff	Final average
	30%	70%	
2008/2009	12,61	15,84	**14,87**
2009/2010	12,67	14,31	**13,82**
2010/2011	16,23	16,75	**16,59**
2011/2012	18,41	15,2	**16,16**
2012/2013	18,71	15,13	**16,20**

TABLE III. Averages for the Communication skills since academic year 2008/2009

Year of study	Technical report	Final presentation	Academic staff	Student	Final Average
	40%	20%	20%	20%	
2008/2009	16,50	13,81	16,50	16,69	**16,00**
2009/2010	14,02	15,29	14,33	14,65	**14,46**
2010/2011	13,23	15,17	16,87	18,00	**15,30**
2011/2012	14,96	15,29	16,38	15,46	**15,41**
2012/2013	15,53	16,67	15,20	15,60	**15,71**

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