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A Pedagogical Intensive Collaborative Electric Go-Kart Project

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Abstract—This paper provides an initial feedback from an intensive, multi-disciplinary, and collaborative project implemented in France in higher engineering education through a case study on electric go-kart conception. This kind of project was proposed during 2 successive academic years in collaboration with an industrial partner who is currently a relevant expert in the field. The project consisted in designing, developing, and validating the operation of several electric go-karts within 56 hours of teaching only. Several groups of approximately 10 4th-year university students were involved in this new project-based learning (PBL) approach. This article points out knowledge and skills that the learners had to acquire at the end of the project, and the methods of assessment. In particular, an innovative oral communication based on a theatrical oral session was tested. The various steps in the project development, management, and the interactions with the students, the teachers and the industrial partner are highlighted. Qualitative and quantitative data were extracted from the transcript of grades and the satisfaction surveys. All results demonstrate that the students were encouraged to become active throughout the project. They developed particularly co-operative and collaborative competencies, and critical thinking skills. Although this experience is overwhelmingly positive for the teaching staff, the worse part of the project consisted in developing efficient methods and tools both to organize the project, and evaluate the students' knowledge and skills. As a consequence, a preparatory phase was absolutely necessary to warrant the success of the project.

Keywords—Innovative pedagogical approach, intensive PBL, collaborative framework, electric go-kart

1 Introduction

Over the past years, a lot of interest has been expressed in new educational practices, also referred to as innovative pedagogical approaches, used, for instance, in higher education [1], [2]. However, these concepts have been emerging for several years, and especially in the primary and middle school curricula [3]. For instance, Maria Montessori, an emblematic pioneer of the 20th century, was able to initiate such practices

[4]. In particular, she demonstrated that the "Learning differently" method is included as a "daily living support", because a school should promote the development of human potential [5], [6]. Célestin Freinet, involved in the learning printing technique in October 1924, is also famous for the development of the learner-centered approach. This method supports students' choices of preferred learning styles and learning environments [7]. The high degree of interest in this technique also encouraged the implementation of a work schedule that helped the students to plan their work over a period of time [8]. The work schedule is then discussed and evaluated together with the teacher.

Project-based learning (PBL) is an example of an innovative pedagogical approach that is widely used today. This method of knowledge and skills acquisition promotes, among other things, problem solving, creativity, and critical thinking [9]. It also encourages students to become self-directed learners and work cooperatively in small groups to seek solutions to problems [10]. Above all, PBL assists students in understanding and contextualizing lessons that are sometimes too theoretical through the use of case studies [11-14].

The graduate school of engineering (Polytech Tours) of the University of Tours (France), represented by its Electrical and Electronic Engineering Specialty, has recently proposed and implemented a new approach of teaching in the science of engineering: the intensive collaborative project. This new PBL method consists in getting some 30 engineering students to work together around a common issue: how to design, develop, and validate the operation of an industrial system within 3 weeks on a full-time basis (56 hours of teaching)?

The success of such a project shall be determined by the choice of a relevant pedagogical and industrial support that reflects today's industry realities. Polytech Tours has chosen the electric car. This choice is further supported by environmental issues and current technical developments and socio-economic challenges, because the electric vehicle (EV) has significantly participated in the effort against climate change over the last decade [15]. For example, in 2015, the French government announced its commitment to strengthen its policy to significantly decrease greenhouse gas emissions. So, attention was focused on the decrease of air pollutants in the transport sector (e.g., automotive transport). The objective was to reduce dependence on traditional fossil fuels such as oil. Thus, a call for projects was launched to promote the design, development, and marketing of an electric car "for the people" (i.e., something cost-effective, light, small, and fast-charging that "may not look like traditional electric cars"). This a major issue, especially for car manufacturers. Despite all the financial measures taken by the French government, some unfortunate experiences can be identified. For example, in spite of significant investments (20 million euros), the French car manufacturer Mia Electric had no choice but to dismantle its company in 2016. This may be due, in part, to the EV market which is still in its infancy because of the limited range, maintenance, and reliability of electric cars [16].

This background clearly shows that it is crucial to give the next generation of engineers all the necessary means to face up to such technical and economic, social, and environmental challenges [17].

To reflect today's transportation industry realities, Polytech Tours has chosen to develop an electric go-kart. For several years now, this scale model of electric car has taken multidisciplinary, educational, and interactive considerations [18], [19]. In particular, it fosters the development of a broad range of skills and knowledge, including among others mechanical design, electronic on-board systems, and electrical energy conversion and management.

The intensive collaborative project described in this article involved several teams. Each team was composed of about 10 4th-year university students (second year of the engineering degree) of the electrical and electronic engineering specialty. Each group of students had one go-kart chassis. This project is the result of a strong cooperation between 2 academic partners – Polytech Tours (Electrical and Electronic Engineering Specialty) and the University Technology Institute in Tours (Electrical Engineering and Industrial Computing Department) –, the e-Kart association, and an industrial partner named Kart Masters. Once the project was completed, each group of students had to:

- Carry out the go-kart electrification in compliance with a set of specifications.
- Design, size, and test the functioning of a vehicle on-board unit, such as display of battery status.

This paper serves several purposes. First of all, the methodology and students' outcomes are described. Then, 2 years of feedback concerning the assessment of knowledge and skills for each student is discussed. The aim is to demonstrate the relevance of this new PBL approach. The communication actions around the intensive collaborative project are also highlighted.

2 Methodology

2.1 Project's Preparatory Phase

A preparatory phase, which is carried out in the first half year, is essential to meet the project's expectations, especially as the study is planned in the second half of an academic year. It is important to note that within this period, the students are working 100% of their time on the intensive collaborative project. No other pedagogical activities is planned in their schedules. Thus, it is necessary to have all material (hardware and software) and human resources to perform the go-karts' electrification, and particularly over the first year of the project. That is the reason why, the key actions necessary to ensure the success of the study are detailed below.

3 teachers were in charge of the project's preparatory phase. Of course, they also had to stimulate and evaluate the acquisition of knowledge and new competencies throughout the duration of the project.

For the 2015-2016 university year, regarding the material resources, Polytech Tours invested in 3 second-hand go-karts. Each one of around 500 Euros is composed of disk brakes in both front and rear. Next comes the costs of all components to carry out the electrification of the 3 go-karts. The budget is between 2,000 Euros and

5,000 Euros for each vehicle. The electric motor and its controller represent equally two-thirds of this budget. The ME1304 PMSM Brushless motor was chosen. It is a 3-phase, Y-connected synchronous motor with an axial air gap. It is composed of one stator that includes 3 coil windings, and a permanent magnet rotor. The energy efficiency of the motor is about 92% at dc voltages between 24 V and 72 V. Its rated power is equal to 8.5 kW at 72 V dc voltage. Regarding the controller, the SEVCON GEN4 G4845 system was chosen. It is totally configurable using the design verification test (DVT) software tool. The SEVCON GEN4 G4845 controller is composed of a low voltage (nominal battery voltage between 36 and 48 V dc) and high current (peak current up to 450 A) 3-phase inverter. The control circuit of this inverter implements 3 control loops to drive the electric motor speed, the current (so, the torque), and the voltage. The reference engine torque value is given by the driver through the throttle pedal. Voltages and current values shall be transmitted to the controller through the DVT software tool. The last third of the budget corresponds to the electrochemical batteries and their power chargers. 4 OPTIMA YELLOW 12 V, 38 Ah batteries, which are in series, provide the dc voltage (i.e., 48 V) for one electric go-kart. Despite its low specific energy (between 20 Wh/kg and 40 Wh/kg), the conventional technology of the lead-acid batteries was selected, mainly for cost reasons. The OPTIMA YELLOW battery uses the SpiraCell® technology, which is composed of a series of individual spiral-wound cells composed of two pure (99.99%) lead plates coated in a precise coating of lead oxide. This technology provides enhanced security features, because the electrolyte is absorbed in absorbent glass mat (AGM) separators. Thus, it prevents the battery from acid leaking. Regarding the power chargers, 4 CTEK MXS 7.0 7A/12V maintenance chargers (one per battery to ensure load balancing) were selected, because the electric go-karts are used less than a few times a year. At other times, the EVs are in standby mode. However, the battery maintenance is mandatory to avoid cyclic important discharges, and deep discharges. This kind of battery charger is highly satisfactory, since a battery can be fully charged in a few hours (typically, 3 hours).

It is important to note that all of these investments were necessary over the first year of the project. Such equipment were reused in the next academic year. However, small consumable items (less than 500 Euros), such as electronic components and printed circuit boards, were bought so that students could design and manufacture a vehicle on-board unit, as foreseen in the project terms described above.

2.2 Project Team Composition and Roles of Each Partner

Regarding the new PBL approach described in this paper, the students were typically divided into several groups of 10 people. A group of about 10 students is particularly interesting because the learners must develop a proactive role in a comfortable learning atmosphere. Such an atmosphere is helpful to promote open discussions about the ins and outs of the project, and to define the roles and responsibilities of each student. A group environment enables also learners to make mistakes without fear of criticism. For example, during the 2015-2016 academic year, 33 4th-year university students were involved in the research project. A random draw was conducted

to arrange the students into 3 groups with 11 students per group. This method was chosen to force them to work together, and promote dialog, critical mind, and intellectual and social openness. For all engineering students, the electric go-kart represented a multidisciplinary and friendly product reflecting current industrial preoccupations in the transport sector. The choice of this case study greatly contributed to maintain their motivation throughout the project.

Each group of students was supervised by a teacher during 56 hours. For the 3 teachers, they had 4 main roles to play. The first consisted in becoming a professional coach to provide advice and expertise, and to make the right decisions, while managing risk and uncertainty around the project. The second was related to the project coordination, especially by being attentive to all students' activities, and supervising their work. The third role was to be a motivator and a facilitator rather than a lecturer. In particular, the aim was to promote and support the students' motivation throughout the project. The last role was to evaluate the knowledge and skills acquired. This also included a comprehensive performance feedback to each learner at the end of the project.

The electric go-kart as an end-product was proposed and supported by a French start-up company named Kart Masters. This company is specialized in the manufacturing and maintenance of electric go-karts. Since September 2013, the opening of a website for online sales has greatly contributed to expand the company in the education sector. Regarding the intensive and collaborative project described in this article, Kart Masters contributed its technical expertise both for the students and the teaching staff. It did not have the responsibility to manage the research project, but its involvement was required for envisioning and strategizing.

2.3 Learning outcomes and Methods of Assessment

Upon completion of the project, the students had to master the methods and tools for engineers necessary to identify, model, and solve specific problems, whether or not they are familiar, and not completely defined. As can be seen in Table 1, 4 competencies were particularly assessed:

- The ability to apply and develop the concepts of electrical energy conversion and management (competency named "C1").
- The ability to develop and practice the particular issues and challenges related to electrical energy management in a sustainable environment (competency named "C2").
- The ability to take part in a dynamic team, manage the relations with the various partners, and steer developments: leadership, commitment, project management, explain and communicate to non-specialists and specialists (competency named "C3").
- The ability to fit into professional and social life: team spirit, commitment, exercise in responsibility, and even innovative startup company management (competency named "C4").

Table 1. Competencies assessed, learning outcomes, methods of assessment

Competency assessed (C)	Learning outcome (LO)	Expected level	Method(s) of assessment
C1. Ability to apply and develop the concepts of electrical energy conversion and management.	LO 1.1. To develop methods and tools to size, design, manufacture, test, and validate a product.	Level of application*	- Laboratory experiments. - Theatrical oral session.
	LO 1.2. To develop a critical analysis, and provide experience feedback.		
C2. Ability to develop and practice the particular issues and challenges related to electrical energy management in a sustainable environment.	LO 2.1. To gain an overview of a product, allowing a clear identification of all inputs/outputs that involve environmental impact.	Level of application*	- Group discussions and sharing of resources and ideas. - Theatrical oral session.
	LO 2.2. To make choices from appropriate scenarios of design and manufacturing of modern electronic products, and quantify their impact on the environment.		
C3. Ability to take part in a dynamic team, manage the relations with the various partners, and steer developments: leadership, commitment, project management, explain and communicate to non-specialists and specialists.	LO 3.1. To be a team-player and foster a dynamic collaboration.	Level of mastery**	- Logbook. - Laboratory experiments. - Theatrical oral session.
	LO 3.2. To demonstrate team leadership.		
	LO 3.3. To summarize the results and report them to wider audiences including those without a technical background.		- Logbook. - Frequently asked questions. - Theatrical oral session.
C4. Ability to fit into professional and social life: team spirit, commitment, exercise in responsibility, and even innovative startup company management.	LO 4.1. To have an exemplary behavior (regular attendance, punctuality…).	Level of mastery**	- Logbook. - Laboratory experiments. - Theatrical oral session.
	LO 4.2. To apply the team's strategies, values and codes.		
	LO 4.3. To identify and anticipate trends, potential innovations in the field.		- Group discussions and sharing of resources and ideas.

* Level of application: accomplishment of the activity with assistance.
** Level of mastery: accomplishment of the activity independently.

Each group of students had to keep a logbook throughout the project. A Web platform of exchanges was specifically devoted to this purpose. The aim was to get all significant information on a day-to-day basis. The logbook is particularly suitable for ensuring that the milestones and deliverables were accomplished, and everything all ran to schedule.

Regarding the acquisition of practical skills and knowledge, 2 levels were defined:

- Level of application: it corresponds to the accomplishment of an activity with assistance. This level was required for the competencies named "C1" and "C2".
- Level of mastery: it corresponds to an accomplishment of the activity independently. This level was requested for the competencies named "C3" and "C4".

Regarding the first competency named "C1", the students had to be particularly proficient in establishing an energy analysis of the electric go-kart. In particular, they should be able to quantify the electricity needs inside the EV, justify all elements of the electric powertrain, and size an onboard electronic system to inform the driver of the EV range. Several laboratory experiments (case studies) were proposed to focus on specific items of the electric go-kart quoted previously. The main benefit of this method of assessment is that the students had immediate feedback about their performance. Therefore, they could more readily identify areas for improvement. These issues were presented during an oral session planned at the end of the project. The students had also met the level of application in testing and validating the functioning of the electric go-kart. All stages of these learning outcomes had been tested during laboratory activities. Finally, they had to be presented during the oral session.

The second competency named "C2" was focused on the application of the main concepts related to electrical energy management in a sustainable environment. The startup company was a key player in the acquisition process of such competencies. Several workshops were proposed to introduce the engineering students to the foundations of sustainable construction in electrical and electronic engineering. As a result, the teachers provided special oral sessions in the form of frequently asked questions (FAQs) to ensure that all students acquire information and clarifications to help them properly understand the challenges that were crucial to achieve the project outcomes on that particular aspect. The results of this work were also presented during the final oral session.

The third competency named "C3" was focused on leadership, commitment, project management, and communication actions. The members' responsibilities to the group were tested through various laboratory activities (oral situation simulation exercises). Those exercises encouraged students both to think about how teams should work together, and rate the quality of collaboration. The teachers' role was crucial in that case, because they had to support a scoreboard to evaluate the ability of each student to manage the project team. This task management chart was, amongst others, composed of the following items:

- The title and objectives of each task.
- The name of the student who was responsible for task.
- The date on which task was due.
- The date on which task was completed.
- The difficulties and problems that were encountered.

All this work was helpful to set up group discussions to identify and anticipate trends and potential innovations around electric go-kart conception. These group discussions also encouraged the students to be proactive.

The last competency named "C4" evaluated the ability to fit into professional and social life. The aim was to raise awareness and responsibility of the students towards today's society's rules and values. The following items were evaluated by the teachers through a dynamic dashboard: regular attendance and punctuality, thoroughness, hard work, and implication. Another aim was to encourage entrepreneurship. All these elements had also to be highlighted during the final oral session.

At the end of the project and in a way never before seen in the graduate school of engineering, each group of students had to summarize the results of their investigations during a theatrical oral session, in front of a jury of professionals (whether or not they are from the domain) and teachers. Each group of students had to develop a scenario. Each scenario was presented to an audience of all engineering students involved in the project, assistant / associate professors and full professors of the graduate school of engineering, and, of course, the jury. As an example of scripting, one group of students defined a set of scenes about the finish of an electric go-kart race. This scenario was based on their leading positions throughout the race. One student of the group who took on the "Reporter Role" interviewed all the others to explain positive results achieved. For all members of the jury, such proposal was of particular interest because the interview aspect gave the opportunity to assess competencies related to communication actions. Communication was also dedicated to initiated and non-initiated audience. Moreover, choosing a scenario based on a flashback (i.e., explaining the reason why the students won the race) enabled the jury to assess the technical and scientific skills necessary for the electric go-kart to meet the targeted functions.

3 Summary of the Students' Work

In this section of the article, a summary of the main students' work carried out during the 2015-2016 academic year is described. Particular attention is drawn to the mechanical sizing of the electric go-kart which is of major importance to design the electric motor and its controller, and the setting up of the electric powertrain and dashboard.

3.1 Electric Motor Sizing

The electric motor sizing was a capital step because it helped the students justify technological and technical choices made by the teachers in charge of the project, particularly the ME1304 PMSM Brushless motor. From a literature review, the engineering students defined an appropriate protocol allowing any user to manufacture his own EV. This protocol takes into consideration all technical information (mechanical, electrical, configuration…) and practice orientated data (legislation, manufacturing costs…) [20], [21].

Five main steps are particularly necessary (see Figure 1). The two first ones consist in calculating the engine power. To achieve this, the dimensioning of the electric motor is performed at a steady speed. The calculations are based on required technical data: the mass of the vehicle (including the driver), the basic dimensions of the chassis (width, height), the height and width of the driver (to extract the air penetration surface), and the efficiency of the electric motor. The third step consists in calculating the acceleration and deceleration forces from a speed profile. Finally, it is necessary to calculate the motor and resistive torques, extract the quadrants of operation, and choose the electric motor type.

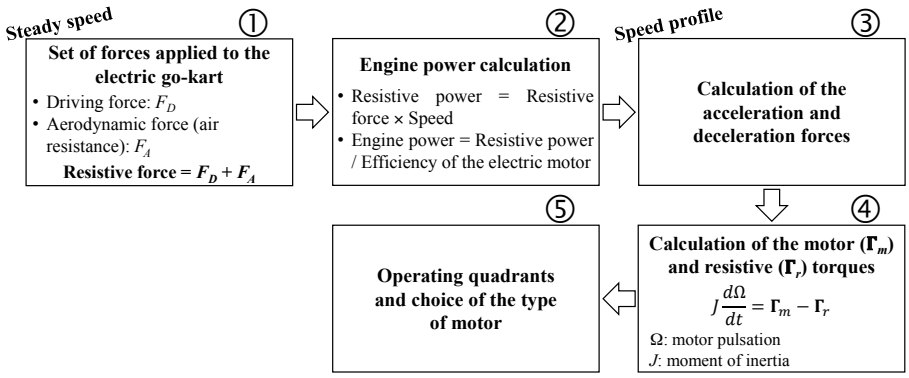


Fig. 1. Five main steps necessary to size the electric motor

3.2 Lightering, Widening and Reinforcement of the Chassis

At the initial stage of the project, one chassis of a go-kart was given to each group of students. The empty weight of the vehicle is about 100 kg. This one is composed of several tubular borders. Some docks are attached to the side of the vehicle. It enables to protect the whole system against mechanical shocks.

First of all, as can be seen in Figure 2, the engineering students removed the steel frame and docks. The objectives were both to widen the vehicle and reinforce the chassis. Then, the students fixed several blocks of high-density polyethylene (HDPE) of one centimeter-thick. These blocks are used to fix the batteries.

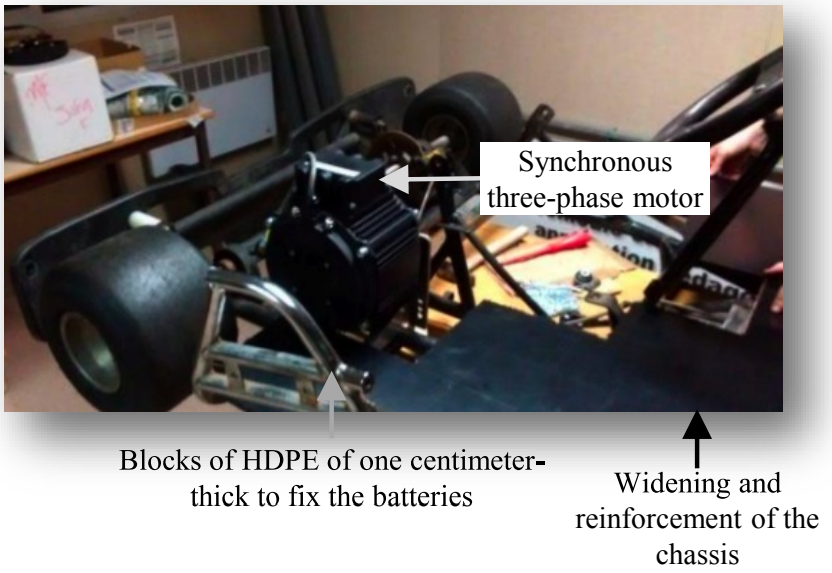


Fig. 2. Lightering, widening and reinforcement of the chassis

3.3 Electric Powertrain and Dashboard Setup

As can be seen in Figure 3, after reinforcing the chassis of the electric go-kart, the engineering students of each group fixed the main elements of the electric powertrain:

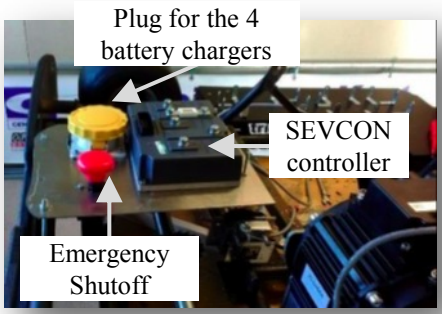
- The 4 OPTIMA YELLOW 12 V, 38 Ah batteries.
- The connecting system of the 4 battery chargers.
- The ME1304 PMSM Brushless motor.
- The SEVCON GEN4 G4845 controller.

All electrical equipment of a vehicle must be disconnected in case of any malfunctioning or emergency. That is the reason why, the engineering students installed the main circuit breaker (one emergency stop push button). Each EV must also be composed of a short circuit protection. All students had the opportunity to practice wiring of all electrical circuits in an electric go-kart.

Regarding the dashboard, it is typically composed of an on/off switch, a warning light indicating the EV power up, and a three-position switch (drive, neutral and reverse functions).



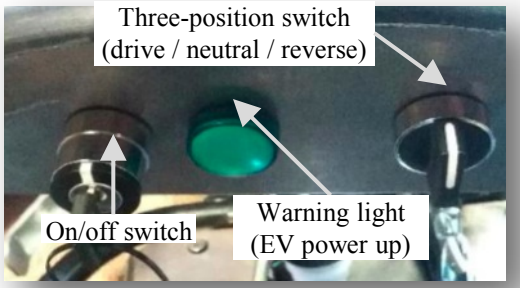
(a) Battery set mounting including practical mounts and accessories



(b) SEVCON GEN4 G4845 controller attachment, emergency shutoff setup, and mounting of a plug for the 4 battery chargers



(c) Accelerator by foot setup



(d) Dashboard setup

Fig. 3. Electric powertrain and dashboard setup

4 Relevance of the Teaching Method

4.1 Transcript of Grades

At the end of the project, all students' skills were evaluated by the teachers from the competencies listed in Table 1. For each competency, all learning outcomes were rated using a numerical value based on a 0-20 scale with higher scores representing better performances and greater achievements. An equivalent ECTS grade was assigned to each mark of the local grade (i.e., 0-20 scale), with "A" (local grade from 16 to 20) being the highest and "Fail" denoting failure (local grade strictly less than 10).

A competency was validated by the teachers when the average grade of the related sub-competencies was at least equal to "C" (local grade from 12 to 14).

Table 2 shows the score distributions of the learners of the class of 2016 (33 students were surveyed) and the class of 2017 (23 students were surveyed). In comparing both academic years, the conclusions are approximately the same. Firstly, none of these students had a score less than "C". It means that all students validated the competencies listed in Table 1, whatever the academic year. These positive results may be explained by the following main facts:

- The pedagogical material supports interdisciplinary research. It is also extremely innovative.
- The students had the opportunity to work on an EV that represents today's key industrial preoccupations. That generated enthusiasm and great commitment.
- The students were encouraged to become active throughout the project. In particular, they developed co-operative and collaborative competencies, and critical thinking skills.
- The teachers promoted group discussions and sharing of resources, and ideas for the whole project duration. Their role was that of facilitator rather than teacher, especially by guiding the discussions and raising many questions.
- The technical guidance of the industrial partner throughout the project motivated the students and the teachers.

From Table 2, the competency entitled "Ability to develop and practice the particular issues and challenges related to electrical energy management in a sustainable environment" (competency named "C2") returned worse than expected results. This mitigated result can be explained partly, because the environmental dimension of sustainable development was not so far well covered in the engineering curriculum. From the first half of the 2017-2018 academic year, a new course entitled "Renewable energy systems" will be proposed to 4th-year university students to better tackle these issues. The aim of this course is to provide an introduction to the most recent developments to interface and control sustainable energy systems and equipment. The main expected learning outcome is to get a better understanding of challenges in electrical engineering associated with environmental concerns. The training focuses particularly on design and control methods both to optimize the performances and the energy efficiency of electrical systems.

4.2 Comparison with a Non-Intensive Collaborative Approach

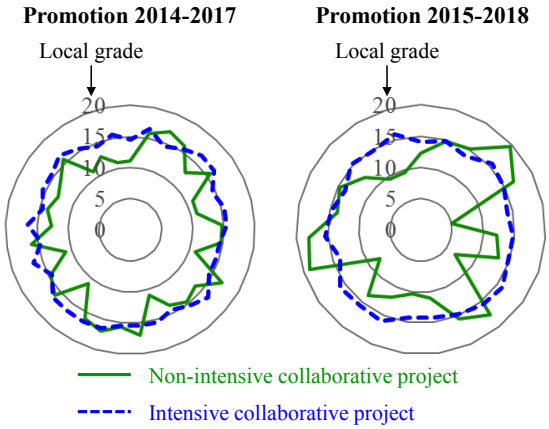
In this section, the aim is to emphasize the relevance of the intensive collaborative project, and particularly in comparison with a traditional PBL approach as described, for instance, in [14]. In this latter case, it is important to remind that the project is also conducted in a group of students, but in a non-intensive way. Thus, it is planned throughout one semester in association with other pedagogical activities.

Table 2. Transcript of grades: score distributions. The students' results of the Class of 2016 (33 students were surveyed) and the Class of 2017 (23 students were surveyed) appear in **blue** and **green**, respectively.

Competency assessed (C) and learning outcome (LO)	Grade A	Grade B	Grade C	Grade D	Grade E	Grade Fail
C1. Ability to apply and develop the concepts of electrical energy conversion and management						
LO 1.1.	72.7% 60.9%	12.1% 17.4%	15.2% 21.7%	0.0% 0.0%	0.0% 0.0%	0.0% 0.0%
LO 1.2.	57.6% 60.9%	24.2% 21.7%	18.2% 17.4%	0.0% 0.0%	0.0% 0.0%	0.0% 0.0%
C2. Ability to develop and practice the particular issues and challenges related to electrical energy management in a sustainable environment						
LO 2.1.	60.6% 56.6%	21.2% 21.7%	18.2% 21.7%	0.0% 0.0%	0.0% 0.0%	0.0% 0.0%
LO 2.2.	54.6% 52.2%	21.2% 30.4%	24.2% 17.4%	0.0% 0.0%	0.0% 0.0%	0.0% 0.0%
C3. Ability to take part in a dynamic team, manage the relations with the various partners, and steer developments: leadership, commitment, project management, explain and communicate to non-specialists and specialists						
LO 3.1.	69.6% 69.6%	15.2% 17.4%	15.2% 13.0%	0.0% 0.0%	0.0% 0.0%	0.0% 0.0%
LO 3.2.	57.5% 69.6%	27.3% 21.7%	15.2% 8.7%	0.0% 0.0%	0.0% 0.0%	0.0% 0.0%
LO 3.3.	63.6% 65.3%	21.2% 21.7%	15.2% 13.0%	0.0% 0.0%	0.0% 0.0%	0.0% 0.0%
C4. Ability to fit into professional and social life: team spirit, commitment, exercise in responsibility, and even innovative startup company management						
LO 4.1.	69.7% 73.9%	30.3% 26.1%	0.0% 0.0%	0.0% 0.0%	0.0% 0.0%	0.0% 0.0%
LO 4.2.	75.8% 73.9%	12.1% 17.4%	12.1% 8.7%	0.0% 0.0%	0.0% 0.0%	0.0% 0.0%
LO 4.3.	30.3% 34.8%	51.5% 56.5%	18.2% 8.7%	0.0% 0.0%	0.0% 0.0%	0.0% 0.0%

Figure 4 compares the overall students' performance at the end of a non-intensive collaborative project (the results appear in green), and an intensive collaborative project (the results appear in blue). This assessment is proposed for the same engineering students, and for 2 graduating classes (Promotion 2014-2017 and Promotion 2015-2018). For example, regarding the Promotion 2014-2017, the engineering students (33 students) performed one project during the second half of the first year of the engineering degree. The following year (second year of the engineering degree), in the spring semester, the same students carried out one intensive collaborative project.

As can be seen in Figure 4, the overall performance of one graduating class can be monitored using radar charts. Each circle of a radar chart corresponds to one local grade (from 0 to 20). So, the aim is to plot the results' distribution of the students on this kind of graph. 2 main conclusions can be drawn, whatever the 2 graduating classes:



ECTS	Local grade
A	[16 ; 20]
B	[14 ; 15]
C	[12 ; 13]
D	11
E	10
Fail	< 10

Fig. 4. Comparison with a Traditional PBL Approach (non-intensive collaborative project)

- On average, the students' performances are very positive, whatever the PBL approach. For example, regarding the Promotion 2014-2017, using the traditional PBL method, the mean local grade was equal to 13.9 (it corresponds to an ECTS grade equal to "C"). The intensive collaborative PBL method scored about 15.5 (it corresponds to an ECTS grade equal to "B"). So, these results seemed a little better.
- The fluctuations around the mean were much lower using the intensive collaborative PBL approach. To clearly illustrate this, regarding the Promotion 2014-2017, this method exhibited a standard deviation about 0.8, while the non-intensive PBL approach reflected results more than twice as low (standard deviation about 2.2).

4.3 Satisfaction Survey Summary from Likert Scaling

The Likert scaling can be adopted to measure students' feedback at the end of the project. This method, which can easily be constructed and modified, has proven good reliability ratings. Moreover, a large quantity of data can be collected and analyzed with a reasonable effort, and over a short period of time.

All engineering students involved in the intensive collaborative project completed a satisfaction survey. A detailed questionnaire, which was composed of 8 items, was proposed to gather their perceptions about this new teaching approach. Each item was quantified by a Likert-scale of 1 to 5:

- "1" means that the students strongly disagreed [SD] with the statement.
- "2" means that the students disagreed [D] with the statement.
- Regarding the scale named "3", students' opinion was regarded as being neutral [N].
- "3" means that the students agreed [A] with the statement.
- "4" means that the students strongly agreed [SA] with the statement.

Table 3 summarizes the results. A total satisfaction score higher than 85% was obtained, whatever the academic year (88.1% in 2015-2016, and 86.5% in 2016-2017). This is a great achievement. Despite these optimistic results, additional communication efforts will have to be increased for any future research project using this teaching approach. In particular, the roles and the responsibilities of the partners will still need to be clearly defined. The engagement of the industrial partner will probably have to be increased in all steps of the project, from the definition of specifications to the evaluation of students' skills.

Table 3. Satisfaction survey summary from Likert Scaling. The students' results of the Class of 2016 (33 students were surveyed) and the Class of 2017 (23 students were surveyed) appear in **blue** and **green**, respectively.

Question	SD = 1	D = 2	N = 3	A = 4	SA = 5	Mean score	Satisfaction score
1. Scope, ends and results, interactions with partners (engineer students, teachers, and industrial partner) are clear and explicit.	0.0% 0.0%	0.0% 0.0%	6.1% 8.7%	42.4% 43.5%	51.5% 47.8%	4.45 4.39	89.0% 87.8%
2. Terms and conditions for project assessment are clear, explicit and well-known by the engineering students and tutors.	0.0% 0.0%	0.0% 0.0%	0.0% 0.0%	51.5% 47.8%	48.5% 52.2%	4.49 4.52	89.8% 90.4%
3. The electric go-kart is an appropriate platform usable for multidisciplinary and intensive PBL within a collaborative framework.	0.0% 0.0%	0.0% 0.0%	0.0% 0.0%	9.1% 17.4%	90.9% 82.6%	4.91 4.83	98.2% 96.6%
4. The intensive collaborative research project reflects the knowledge and skills acquired by students during engineering curriculum.	0.0% 0.0%	3.0% 0.0%	21.2% 26.1%	54.5% 60.9%	21.3% 13.0%	3.94 3.87	78.8% 77.4%
5. Multidisciplinary and intensive PBL within a collaborative framework encourages engineering students to be active throughout the research project period.	0.0% 0.0%	0.0% 0.0%	0.0% 0.0%	42.4% 56.5%	57.6% 43.5%	4.58 4.44	91.6% 88.8%
6. Multidisciplinary and intensive PBL within a collaborative framework facilitates communication between students and teachers.	0.0% 0.0%	0.0% 0.0%	24.2% 13.0%	51.5% 65.2%	24.3% 21.8%	4.00 4.09	80.0% 81.8%
7. Multidisciplinary and intensive PBL within a collaborative framework encourages thinking and collaboration.	0.0% 0.0%	0.0% 0.0%	0.0% 0.0%	60.6% 52.2%	39.4% 47.8%	4.39 4.48	87.8% 89.6%
8. Theatrical oral session brings new opportunities of emphasizing research activities, and oral communication.	0.0% 0.0%	0.0% 0.0%	12.1% 17.4%	27.3% 69.6%	60.6% 13.0%	4.49 3.96	89.8% 79.2%

5 Conclusions

This article provides first positive results of an intensive, collaborative and multi-disciplinary PBL implemented in a French graduate school of engineering (Polytech Tours, Electrical and Electronic Engineering Specialty) during 2 successive academic years. A case study on electric go-kart conception was proposed. The project's originality lies in the fact that several groups of approximately 10 4th-year university students had to design, develop, and validate the operation of this kind of system within 3 weeks on a full-time basis (56 hours of teaching only). In that case, no other pedagogical activities was planned in their schedules.

The electric go-kart, which is currently supported by a French start up named Kart Masters, represents a multidisciplinary and friendly product reflecting current industrial preoccupations in the transport sector. This kind of industrial product greatly contributes to maintain students' motivation and commitment throughout the project.

During the project, each group of students had to size an electric go-kart and particularly, all elements of the electric powertrain (batteries, chargers, electric motor and its controller). For one chassis, the students fixed all elements of the powertrain (mechanical and electric assembly). Finally, they validated the correct functioning of the EV through appropriate experimental measurements. At the end of the 56 hours of teaching, each electric go-kart was fully operational. The aim was not to put the EVs in direct competition in terms of energy efficiency. However, this could be considered in the next editions of the intensive collaborative project.

All results described in this paper demonstrate that this new PBL approach both is relevant, and overwhelmingly positive, because the students were particularly encouraged to become active throughout the project. Moreover, they developed co-operative and collaborative competencies, and critical thinking skills. For the teachers, their role was that of a facilitator rather than a teacher, especially by guiding the discussions and raising many questions. Nevertheless, the worse part of the project consisted in developing efficient methods and tools both to organize the project, and evaluate the students' knowledge and skills. Finally, the theatrical oral session was considered as an original way to explain the main outcomes at the end of the project.

An extensive communication program was implemented to enhance the work done by the students. For instance, a Facebook page was created (https://www.facebook.com/Projet-Kart-Electrique-Polytech-Tours-DEE-912424955459788). The students practiced spotlight to promote their engineering curriculum (https://www.youtube.com/watch?v=12n4PNHRpHM). This new pedagogical approach was widely recognized by the local and regional press. All these communication actions are essential for the graduate school of engineering, because they generate better readability of the engineering curricula. They also enable to share information with a large audience, especially in connection with training institutions (middle and high schools, University Institutes of Technology, and graduate schools of engineering) or EV enthusiasts.

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