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An electric vehicle energy efficiency race as a basis for a project-based learning programme in engineering

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Executive Summary

This paper shows a project-based learning programme for engineering degrees that is being developed at the Escuela de Ingenierías of the Universidad de Malaga and that consists of two stages. The first stage is aimed at first-years students and consists of the design and manufacture of the basic structure of photovoltaic electric vehicles specifically designed to be used in a race whose characteristics are also presented in this paper. The second stage is aimed at final-year students and consists of the design and manufacture of the electronic control and power regulation systems of the vehicles to maximise the performance. In this stage, the teams that will compete in the race will also be organised.

Keywords: Light electric Vehicles & Micro Mobility; Education, Skills and labor market; Energy Management; Sustainable energy; Electric Vehicles

1 Introduction

The rapid progress currently taking place in all areas of engineering requires a continuous rethinking of university curricula to introduce new technologies and teaching methodologies that allow students to obtain new knowledge and skills that will be essential for their professional future.

Project-based learning (PBL) has established itself strongly as an educational methodology capable of facing these new challenges with very promising results [1]-[3]. This methodology is based on the approach of a real engineering problem whose solution requires the use of knowledge from different industrial technologies, as well as a variety of transversal skills that are not usually sufficiently developed in traditional educational methodology.

There are a large number of works [4]-[8] that show that a very suitable topic for carrying out PBL experiences is the development of racing electric vehicles (EV) for student competitions. Among the advantages of this type of experiences, we can highlight:

- To achieve the goal of developing a fully functional vehicle prototype, it is necessary to apply knowledge from most areas of industrial engineering: electronics, automation, structures, fluids, mechanics, energy, design, graphic expression, manufacturing, projects, etc.
- To obtain the best results in a competition, it is necessary to acquire different types of transversal skills such as the ability to have a global vision of the problems to be solved, to manage and participate efficiently in work groups or to establish fluid oral and written communication. In

addition to this, it has been found that participation in this type of competition offers an additional stimulus for students to increase their motivation for the grade studies.

Races that encourage energy efficiency in mobility attract greater interest for EV teams and programs, because it demonstrates the great advantage they have over vehicles with combustion engines. Although there are currently a large number of energy efficiency races of vehicles on all continents, two basic race formats can be distinguished, so that most races approach one of these models.

On the one hand, we have the World Solar Challenge (WSC) model [9]. This race is intended for vehicles powered by photovoltaic (PV) energy and is characterized by taking place on an open track in Australia, starting in Darwin and ending in Adelaide. In the "challenger" category, vehicles have a PV generator and an energy storage system consisting of batteries and, in some cases, supercapacitors. The vehicle starts with a fully charged battery and can only obtain energy from the PV generator throughout the entire race. The winning team is the one that crosses the finish line first.

Alternatively, the other paradigm is represented by the Shell Eco-Marathon Challenger Competition (SE-M) model [10]. The event takes place on a closed track, usually in an urban environment, over several days and organiced as a qualifying round rather than a unique race in which all vehicles compete simultaneously. Cars drive a fixed number of laps around the track. After each valid run, event organisers calculate their energy efficiency and rank the results. The laps can be completed at any time within the race days. Thus, it is very unlikely that all the vehicles will be found on the track at the same time. The vehicle with the lowest energy consumption value is declared the winner.

Although these competitions have significant prestige, their characteristics present a series of drawbacks for their use in univertsity PBL programs, among which we highlight:

- They are expensive: In the WSC, the vehicles must meet the requirements to be able to travel for more than 3,000 km on conventional roads, which greatly increases their cost. In addition to this, as it takes place on an open track, the technical support required by each vehicle (trucks and other additional vehicles) is much more expensive than that required for a closed track race. In the SE-M, the vehicles are much less complex and, therefore, their development requires much lower economic resources. However, the organization of the race is very expensive, since very precise energy and time measurement equipment is needed for each vehicle, as well as a highly qualified team of judges to ensure that the results are correct.
- In general, they are not very attractive to the public because they do not show the typical excitement of a conventional car race. An example of an attractive race format is the Formula-E competition: a closed circuit within a time interval limited to two hours. All vehicles participate simultaneously, and the winner is the first one to reach the finish line. Both the WSC and SE-M last more than one day, which makes them less exciting as it is not possible for fans to follow them continuously.

A suitable race format to be used in university's PBL programmes should be very economical and, at the same time, attractive not only to the students involved in the programme, but also to the rest of the university community. Accordingly, the main characteristics of the vehicles and the race format could be the following:

- Vehicle prototypes must be very simple and light and must be manufactured with highly standardized components that are easily accessible on the market. All this results in low costs.
- The race must be held on a closed track, lasting no more than one hour, where all vehicles participate simultaneously, and the winner is the first to reach the finish line.
- All vehicles must have exactly the same amount of energy available. This ensures that the winning vehicle is the one that has made the most efficient use of the available energy. Therefore, there is no need for any precision measuring device to establish the race ranking or for highly specialized judges.

Based on this approach, the Escuela de Ingenierías of the University of Malaga started a PBL program in 2021 that should end in the summer of 2025, the main objectives of which are the following:

- To establish a work methodology in which students from different engineering degrees can be integrated organized into two levels. The first level is aimed at first-year students of any degree and

requires very basic knowledge of science and engineering. Students should gain practical experience in the assembly of metal structures, installation of automotive mechanical systems (steering, brakes, suspension, etc.), manufacturing of PV modules and basic electrical installations (wiring, connectors, switches, etc.) and organization into work groups. The second level is aimed at final-year students from degrees in electrical, electronic, automatic engineering or industrial design. These students carry out the tasks of designing and programming electronic control systems, data acquisition, monitoring, transmission and energy storage, or designing, manufacturing and installing aerodynamic elements that optimize vehicle performance. These students are the leaders of the teams that will participate in the race that concludes the program.

- Develop a prototype vehicle and a race format that meets the requirements set out above: low-cost and an attractive format for the public.

2 Work Methodology

The experience has been developed in two periods. The first stage has been carried out in the period from 2021 to 2023 and has involved the development of the first level of the training programme. Two different work organisation strategies have been tested and, as a result, vehicle specifications have been established and two prototypes of PV EVs have been manufactured and evaluated.

The second stage has started in 2024 and is due to end in the summer of 2025. The second level of the training programme is being developed at this stage. Four working groups have been formed, each of which is responsible for designing and programming the power regulation and control systems of the PV vehicle prototype. In parallel, two working groups have been formed of the first level which are manufacturing two new prototypes. The aim is to have four prototypes completed by the summer of 2025. Each prototype will have installed each of the systems developed by the four groups of students at the second level.

2.1 First stage: Definition of the vehicle

This stage began with the definition of the specifications of a vehicle suitable for the programme. The strategic decision was to build a purely PV vehicle, in which the energy generator directly supplies the propulsion system without batteries. This choice was made to ensure that all vehicles have exactly the same amount of energy, which is provided by solar radiation. To meet this requirement, it is mandatory that the surface area of the PV generator is the same in all vehicles participating in the race.

In the 2021-22 period, a first group of 20 students from different degrees was formed with the aim of designing and manufacturing a first prototype. The methodology of grouping the students into specialized work groups by engineering area was used. Groups dedicated to the tasks of manufacturing the chassis, the mechanical systems, the PV generator and the installation of the propulsion system were formed. The tasks of developing the aerodynamic elements and the electronic control system were also proposed, although these groups were ultimately not formed because to the complexity of these tasks was excessive for the level of training of the students who participated in the project. In [11] the manufacturing process and the tests of this first prototype are shown in detail.

In this first experience, it was found that the workload of the students was very uneven, since the time needed to develop the tasks of each group was very different and also that some students were involved in more than one task. Thus, the mechanical systems task occupied 39% of the total time, the PV generator task 23%, the chassis task 22% and the propulsion system task 16%.

In the 2022-23 period, a new group of 25 students was formed to manufacture a second prototype of vehicle. In this edition, the methodology was modified, establishing new criterions: the creation of non-specialized groups under the motto “Everyone makes everything.” Each group carried out the task that corresponded to the general plannning of activities, so that throughout the entire design and manufacturing process all students were able to participate in all tasks. This change had two positive consequences. The students’ workload was more uniform and all of them acquired knowledge of all the tasks necessary for the manufacture of the prototype, not just one of them, which is a basic objective in this first stage of the PBL program. Figure 1 clearly shows these differences. The total number of hours dedicated by each student to

the project in both editions, in order from the highest to the lowest, has been represented. Vertical axis shows the hours worked and each point on the horizontal axis corresponds to one student.

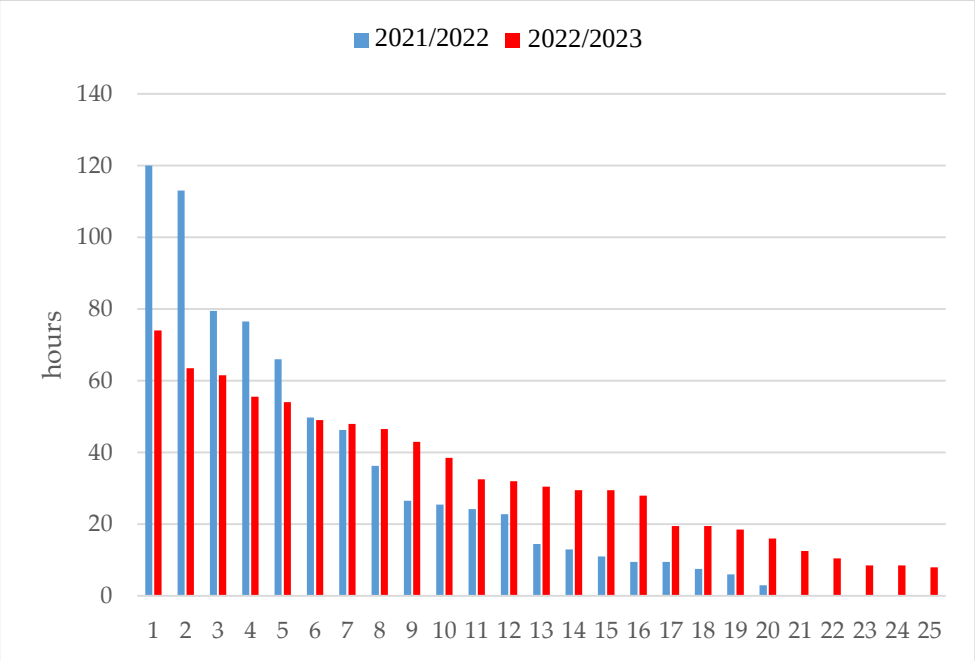

Figure 1: Chassis of the first and second prototypes

The second prototype had dimensions and characteristics similar to the first design, although some modifications were introduced, such as an improvement in the steering system, a reduction in the weight of the chassis and the placement of the electric motors in the rear wheels, unlike in the first prototype, in which they were placed on the front wheels (Fig 2).

Figure 2: Chassis of the first and second prototypes

2.2 Second stage: Energy management optimization

This stage began in early 2024 with the formation of four groups of two students each. All of them are in the final year of their degree. The task of each group is to develop the electronic control and power regulation system of the vehicles. The objectives to be achieved are:

- Maximizing the energy provided by the PV generator at any given time. This is a complex function, since this energy is not stored in a battery, but is fed directly to the power regulation systems of the electric motors, so it is necessary to adapt the EV to sudden changes in the power demand. Another aspect that increases the complexity is that the PV generator is not static, but since it is installed on a vehicle that is constantly in motion, the value of the irradiance on it will also be continuously changing (Fig. 3). For this task, the teams were provided with references in this field [12].

- Optimizing the power applied to the electric motors. Vehicles have two motors that can be installed on the two rear wheels or on the two front wheels (the arrangement is chosen by each group). This configuration is known as electric differential. The objective to be achieved is that the available energy is distributed between the two motors in an optimal way, regardless of the conditions of the circuit (curves, slopes, etc.). The teams also have information to address this task, published in [13].

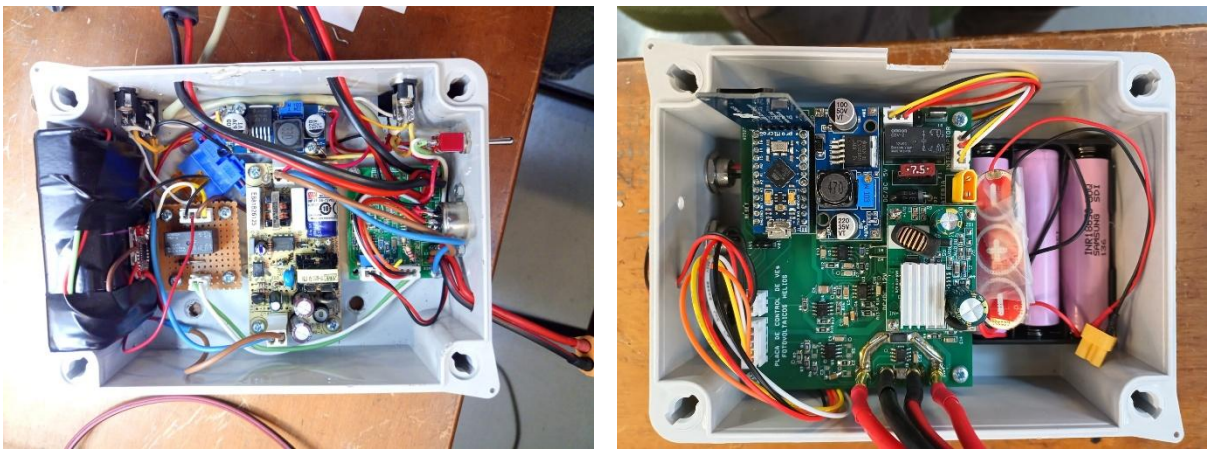

Figure 3: Control system of the first and second prototypes

The teams are currently testing the operation of these systems on the two prototypes that are currently available. The objective is to have four complete prototypes, each equipped with the system developed by each of the working groups. If all goes well, the first race is expected to take place in July 2025.

3 Conclusions

The bulk of an ambitious PBL programme has been developed, revolving around a low-cost and highly attractive EV race format. In the first stage, students from the first years of their degree have participated and two fully functional prototypes of PV EVs have been designed and manufactured. In the second stage, the electronic systems that optimise the performance of the vehicles are being developed and tested. The manufacture of two new prototypes is currently being finalised and preparations are being made to organise a first race for July 2025.

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Biographies

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