

Article

Multidisciplinary Engineering Educational Programme Based on the Development of Photovoltaic Electric Vehicles

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Abstract

This study compares two methodologies for organising the working groups of a multidisciplinary project-based learning programme aimed at strengthening students' transversal skills. The subject of the project was the design and manufacture of prototypes of light electric vehicles powered exclusively by photovoltaic energy. The difference between the two methodologies was the way in which the tasks were distributed among the working groups. In the first method, each group of students specialised in one of the tasks and many of these tasks were carried out simultaneously. In the second method, the tasks were organised sequentially and all groups were involved in some part of them. The results have shown that the first method allows a higher net return on the students' work and a greater reinforcement of the skills acquired in the project, while the second method requires a rather less complex organisation, enables a more balanced distribution of the students' work, allows rapid progress in the acquisition of a greater number of practical skills and presents a greater opportunity for implementing multidisciplinary teaching.

Keywords: electric vehicles; project-based learning; engineering skills; learning technologies; problem solving



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1. Introduction

Over time, technical degrees, and in particular, engineering studies, have shown a significant trend towards student dropout, especially during the first years of study. This phenomenon is well documented in the reports and statistics published by the Integrated University Information System (SIU), whose data clearly reflect the challenge faced by this academic field: 25.2% of students drop out of engineering studies before completing their engineering studies [1]. This percentage highlights a problem that goes beyond the national context, as a similar situation is observed in other countries, as highlighted in the reports of the Organisation for Economic Co-operation and Development (OECD) [2,3]. These reports provide an international comparative framework to analyse how the dropout rate in engineering studies continues to be a widespread trend in different regions of the world, highlighting the need to review and strengthen educational strategies to support students in these crucial early years of their academic education. In recent years, several studies have been carried out, such as those referred to in [4,5], analysing the characteristics of students, their achievements and difficulties, as well as the processes of change in specialisation from engineering to other fields. However, despite the efforts to investigate the low achievement and dropout rates, there is currently no clear and complete answer to the factors that influence students' academic decisions. Some authors, as reported in [6], highlight the importance of socio-economic factors and show that students who receive

a scholarship are more likely to continue their studies than those without such support. Similarly, other researchers [7,8] show the relationship between several variables that influence the academic process and analyse how each of them can influence the probability of dropping out of university.

In this context, although no single cause can be identified and attributed to the problem, several studies [9–13] suggest that a possible cause may lie in the structure and organisation of content in the early years.

In addition to all the above, industry and the current labour market increasingly require engineers not only to have a technical mastery but also a set of transversal competences and interpersonal skills. In this sense, several researchers [14–16] have discussed the need to strengthen the skills of engineering graduates by adapting education in order to respond to these new labour market demands. These studies highlight, for example, the importance of developing and strengthening skills such as leadership, team management, effective communication and collaborative work, which are considered fundamental in the professional world. These skills not only facilitate adaptation to complex and dynamic work environments, but also clearly enhance their ability to contribute the achievement of career goals.

The lack of multidisciplinary training in engineering programmes has negative consequences for students, as well as for organisations, companies and society in general. The lack of skills such as communication, leadership and time management that are so important in any working environment represents a deficit in the training of future professionals. Moreover, complex problems often require integrative and comprehensive solutions. Multidisciplinary training prepares them for an ever-changing industrial environment. It is therefore crucial that engineering programmes include multidisciplinary subjects in the formal curriculum to develop well-rounded and competent engineers.

Some studies, such as those cited in [17], show that students who learn collaboratively in teams tend to obtain better results than those who learn individually. In addition, other researchers [18] analyse the factors that influence student motivation through collaborative learning experiences, concluding that these practices increase both student interest and commitment.

A large number of Spanish and international universities have recognised the importance of transversal subjects and have incorporated them into their curricula, especially in technical and scientific degrees such as engineering. There is evidence and arguments that show the need for these subjects which go beyond the specific content of each discipline. In this sense, the European Higher Education Area (EHEA) has encouraged the introduction of transversal skills in European universities, promoting a comprehensive education that combines technical knowledge with transversal skills. However, the presence of multidisciplinary subjects in engineering education is not as common as it should be, and it is usually only in final projects that this multidisciplinary approach can be applied. In recent years, some Spanish universities have started to offer programmes or training courses that promote this multidisciplinary education, but in an unofficial way through educational innovation projects or specific programmes for the development of transversal competences.

Another way of introducing transversal competences into university education is through participation in student competitions, such as Moto Student [19] and Formula Student [20], which provide an opportunity to increase students' interest and motivation through a practical learning experience [21]. Researchers from the University of Malaga present in [22] the experience of the UMA Racing Team, dedicated to the development of racing motorbikes. In [23], the experience of a Formula Student team is described as an excellent opportunity to carry out a real, highly complex project, highlighting both

the benefits for students and the challenges involved. Another relevant experience is that proposed and developed by the Málaga Racing Team (MART), where a multidisciplinary team of students builds vehicles for the Formula Student competition [24].

Research such as that presented in [25] highlights the development of an electric motorbike, showing that this topic is not only highly attractive to students, but also involves a reasonable and well-balanced workload. In [26,27] they present a multidisciplinary project focusing on an electric vehicle (EV), integrating competences in areas such as electricity, electronics and software development, as well as addressing the optimisation of battery performance and energy consumption efficiency. In order to evaluate the impact of these multidisciplinary experiences, some authors use student performance and satisfaction surveys as a tool to obtain and analyse quantitative and qualitative data on this type of teaching methodology and to make continuous improvements in their application [28–30].

These types of educational programmes not only improve the technical competence of engineering students, but also encourage the development of soft skills, some of which have already been mentioned above, such as management, communication, ethics and sustainability, which are increasingly essential for the personal and professional development of future engineers.

To address all these challenges, some authors [12,13,31–33] suggest the implementation of the project-based learning (PBL) methodology. This methodology is gradually being introduced in engineering schools [17,34–47] and has shown positive results in developing both technical and non-technical skills in students, as well as increasing their motivation for their studies. PBL consists of presenting students with a project or problem that requires the application of a wider range of engineering disciplines. This approach encourages students to work in teams and apply what they have learned to real and complex situations, consolidating knowledge and skills that are essential for their future careers. A fairly comprehensive compilation of relevant studies in this field can be found in references [48,49].

These pedagogical strategies are well suited to integrating early career content, enabling students to connect concepts and understand how they relate to each other in the context of real-world situations [10,11]. The fundamental purpose of this pedagogical approach is to offer a global vision of engineering, providing students with a unified perspective that allows them to relate the different subjects and apply them to solve problems specific to the engineering field.

This type of project seeks not only to improve understanding of the content, but also to motivate students in the early years of training and reduce the drop-out rates by providing a learning experience in which students can see the practical usefulness of the knowledge acquired. Through these projects, students are able to see their subjects not as isolated subjects, but as parts of a whole, allowing them to visualise how each area contributes to their development as future engineers.

At the same time, the growing concern to reduce carbon dioxide emissions has boosted the development of new technologies in the field of electric vehicle engineering. In particular, light electric vehicles (LEVs) have gained ground as a viable alternative for sustainable mobility globally. The design and development of LEVs is considered an excellent topic for a PBL programme in engineering, as they provide a platform for integrating knowledge and skills from multiple engineering disciplines, where students have the opportunity to apply their knowledge, acquire new contents and experiment, contributing to the development of sustainable and innovative solutions in the mobility sector.

More specifically, the reasons why LEVs are suitable for such PBL programmes are as follows:

- It requires the implementation of a wide range of technologies in industrial engineering, such as electronics, automation, structures, fluids, mechanics, energy, design, graphical expression, manufacturing and projects. This enables their integration in the creation of a tangible and functional prototype.
- It is a constantly evolving, cutting-edge technology that represents a growing trend in urban and sustainable mobility and is having a significant impact on new forms of urban transport. There is a wide range of new designs available for students to develop, such as tricycles and quadricycles with all-wheel drive, highly manoeuvrable vehicles or the integration of renewable energy into power systems. These projects could address real problems in the field of sustainable mobility to improve vehicle autonomy, efficiency, safety and quality of life in cities.
- From an economic point of view, the development of LEVs does not involve high costs, thanks to the wide availability on the market of basic components such as engines, wheels, batteries, brakes, power regulators, processors and displays, which are currently used in electric bicycles and scooters.
- LEVs are excellent for organising competitions between the prototypes developed by different groups of students, where outstanding aspects such as energy efficiency, design or driving ergonomics are rewarded. Participating in such competitions provides an additional stimulus for students, increasing their motivation.
- LEVs have the potential to make a significant impact on society and the economy. Their development can boost sustainable urban mobility, reduce congestion and improve the quality of cities. For all these reasons, LEVs represent a great opportunity for the development of new innovative business models, start-ups and markets related to these issues.

The growing acceptance of this topic is evidenced by the existence of a large bibliography of papers that propose PBL programmes based on the development of sustainable vehicles [46,47,50–54].

A first decision to be made when implementing a course on LEVs would be to determine the educational level required of the students participating in the course. Traditionally, PBL experiences have been defined for first-year students (Cornerstone) or for senior (Capstone) students. This decision depends largely on the educational objectives being pursued. On the one hand, a Cornerstone course, implemented early in the curriculum, would foster the early integration of multidisciplinary knowledge and skills that would benefit learning in subsequent courses. It would also be effective in identifying their areas of interest and aptitude, thereby enhancing their academic and future career pathways. On the other hand, a Capstone course [26,27], given at the end of their studies, would help them to apply what they have learned during their degree in a job that could be of greater complexity. In both cases, they would be prepared for the professional environment having developed skills such as teamwork and project management. In addition, it can be an advantage when presenting their future applications to companies, thus better preparing them for their transition to the labour market [55].

Although initially it may seem that the best decision could be to implement a Capstone course due to the complexity and the need to integrate multiple disciplines involved in the development of an LEV, we think that the best option is to propose an intermediate solution such as a mid-programme [56,57], aimed at students in the second year of their degree. In the first year of engineering degrees in Spain, students study subjects related to basic mathematical and scientific concepts. It is not until the second year that they begin to study the basic engineering disciplines and acquire the basic tools to understand the operating principles of LEVs. For this reason, we think that a programme that reinforces

practical skills and helps to understand the interrelationship between these disciplines should help to reinforce the knowledge acquired in the formal subjects.

Our starting hypothesis for this work is that the inclusion of a subject that implements a PBL programme, transversal to the Bachelor of Engineering degrees and with an eminently practical orientation, is a differential factor for the development of complete and competent future professionals in the working environment of engineering, which will also reinforce the motivation of students for their studies and help to reduce dropout rates. Firstly, the development of soft skills, e.g., communication, leadership, time management and teamwork, are essential because future engineers will often work in multidisciplinary teams where they must be able to communicate complex problems or ideas clear and concisely. Secondly, since engineering involves diverse areas, a multidisciplinary approach will offer a broader perspective that will help to understand and apply knowledge from different fields more effectively. Thirdly, they will be prepared to be able to adapt to constant changes due to the evolution of technology, and they will develop resilience to face new challenges. Finally, students will understand the importance of social responsibility and sustainability in engineering when designing projects and integrating them into systems with the least environmental impact. In short, it will enrich the training of future engineers and prepare them to face multifaceted challenges in the world of work by applying technical knowledge together with the personal, social and ethical skills that are fundamental for their personal and professional development.

Based on this approach, the fundamental question addressed in this work is to determine the most appropriate methodology to obtain maximum performance from practical training and to reinforce transversal competences, fundamentally teamwork, in a subject with the aforementioned characteristics and taught in all engineering degrees.

To find an answer to this question, a PBL programme has been developed with a specific focus on the design, manufacturing and evaluation of a photovoltaic electric vehicle prototype (PV-EV).

This article presents and evaluates the results obtained in two editions of this programme. In both editions, a group of volunteer students from different specialties of the School of Industrial Engineering of the University of Malaga (UMA) was selected to include a wide representation of the various degrees offered by the institution. This group of students was given the challenge of manufacturing and evaluating an experimental PV-EV prototype.

In each edition, a different methodology for organising the working groups has been tested, with the aim of obtaining results that support which one is the most appropriate for this type of experience. In the first edition a "Specialized Teams" (STs) methodology was implemented and in the second edition a "Everyone makes everything" (EME) methodology was tested. The results show that the EME methodology is more appropriate for use in PBL cornerstone or mid-programs.

The data and results collected during the two editions of this experience, both qualitative and quantitative, will serve as a basis for the design of a future subject that will be common to all engineering degrees at the University. This course will use a PBL methodology designed to be compatible with the official curricula. It is expected that the implementation of this academic programme in the future will allow a greater integration of multidisciplinary competences in engineering education, contributing to a more complete education aligned with the needs of the market and industry.

2. Materials and Methods

The PBL programme is focused on the production of an EV prototype powered exclusively by a photovoltaic generator. The vehicle does not have any type of traction

battery. This design was chosen for two reasons: Firstly, the team of professors in charge of the project has considerable experience in the design of this type of vehicle [34,58–60]. Secondly, we think that it is the ideal type of vehicle to organise student competitions on energy efficiency in mobility, as it does not require any expenditure on expensive measurement systems or a team of judges to determine the winner of the competition. We are currently preparing to organise a competition involving engineering students from the University of Malaga using the vehicles developed in these projects.

The vehicle specifications were defined prior to the start of the project. This included the general design of the vehicle, the materials and dimensions of the chassis, the design and materials of the photovoltaic generator, the type of electric engine and controllers used for propulsion and the electronic system for acquiring and displaying operating data. The students' work consisted of following the instructions provided by the teachers to carry out the assembly and installation of all these components. The students had more freedom to decide on the design of some mechanical elements, such as the steering and braking systems, and some electrical systems, such as the lighting system. For this reason, the main differences between the prototypes produced in each edition of the project were in these systems.

Figure 1 shows the photovoltaic EV prototypes.

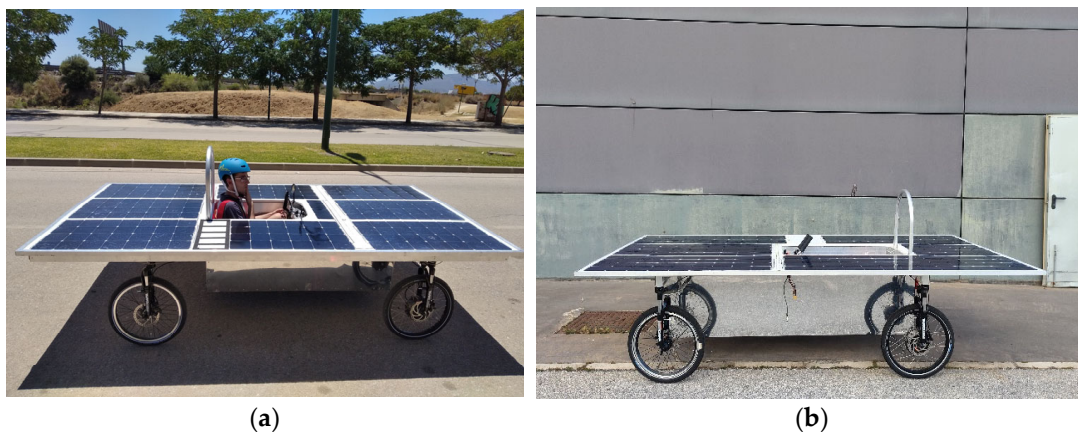


Figure 1. Photovoltaic EV Prototype. (a) Helios21 and (b) Helios23.

The manufacturing process was organised into 4 basic tasks, each dedicated to the construction of the following elements:

- Chassis.
- Photovoltaic generator.
- Mechanical systems.
- Electrical systems.

1. Chassis

The chassis was made of aluminium tubes assembled with rivets and reinforced with composite panels made of aluminium and extruded polystyrene. Welding was not used because its execution requires a high degree of experience that the students do not have. To carry out this task, the students used electric tools (saws, drills, deburring machines), pneumatic tools (riveting machines) and hand tools (files, adhesive guns, etc.) (Figure 2).

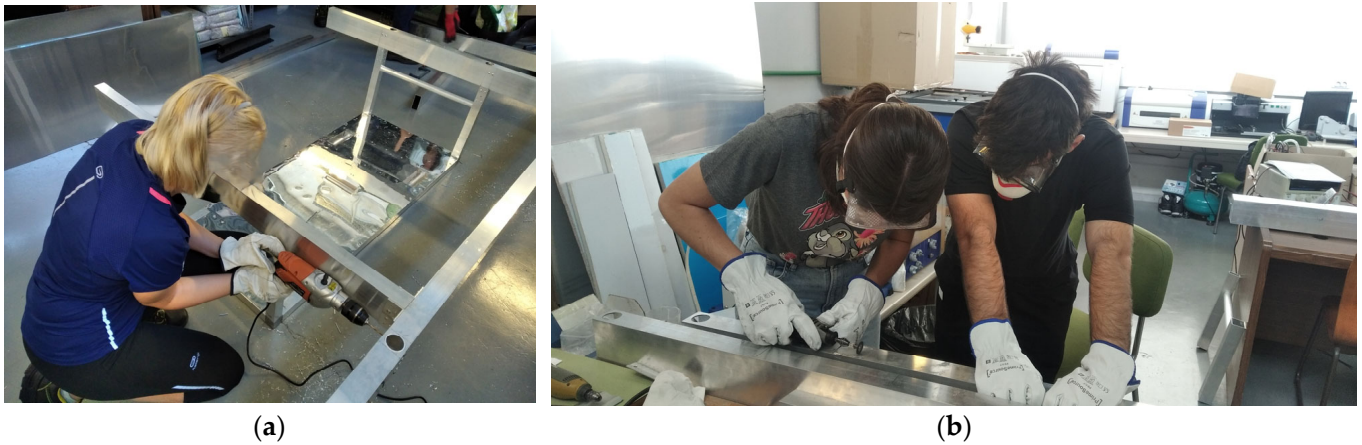


Figure 2. Chassis construction. (a) Drilling; (b) sawing.

2. Photovoltaic generator

A total of 224 photovoltaic cells (SunPower™ C60, Shenzhen Xiangxinrui Solar Energy Co., Ltd., Shenzhen, China) were used and installed on an aluminium and polystyrene composite panel. The first prototype was encapsulated using EVA, while the second prototype was encapsulated using photovoltaic resin. To carry out this task it was necessary to use soldering irons and heat guns, as well as the necessary tools for the preparation of polyester resins. Electronic instrumentation (multimeter and electronic load) was also used to evaluate the performance of the generator (Figure 3).

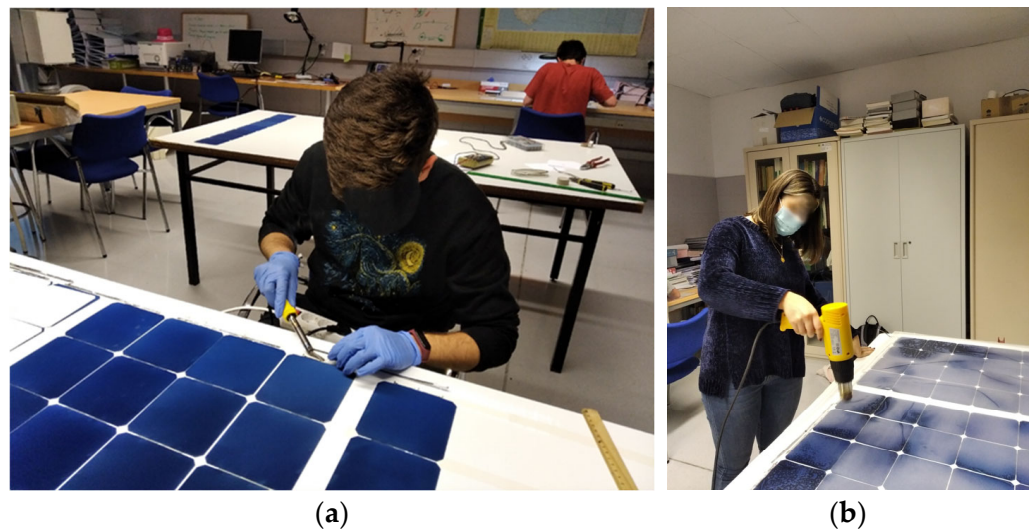


Figure 3. PV generator manufacturing. (a) Cells soldering; (b) EVA encapsulated.

3. Mechanical systems

They include the steering and braking systems. Standard bicycle components, aluminium tubes and various screws and bolts were used for their manufacture. For this task, the students mainly used hand tools such as pliers, spanners, screwdrivers and files (Figure 4).

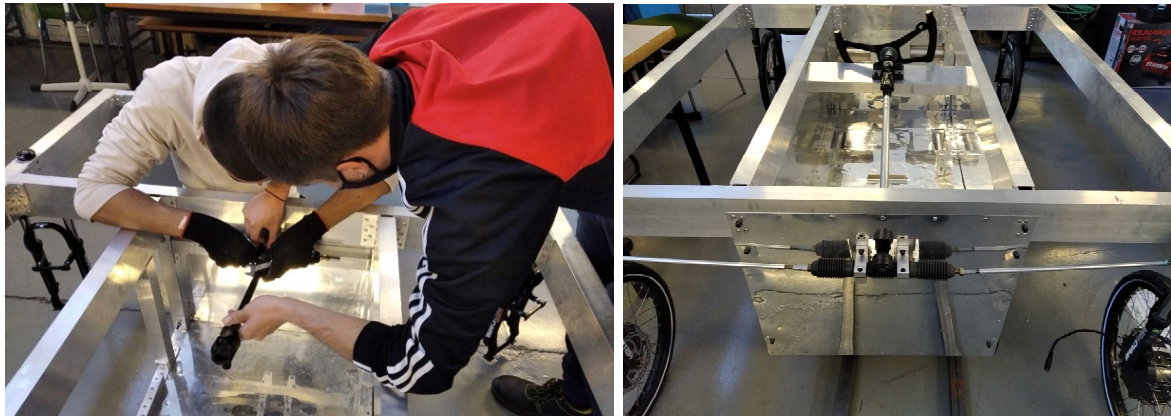


Figure 4. Manufacture of the steering mechanism.

4. Electrical systems

Two Crystalyte G40 electric engine and standard electric bicycle controllers were used. In the first prototype they were installed on the front axle and in the second prototype on the rear axle. An electronic data acquisition and display system designed specifically for this project was used. The students used connector and cable crimping tools and precision electronic soldering tools to perform this task (Figure 5).



Figure 5. Electrical system manufacture. (a) Soldering; (b) Crimping.

Due to the high degree of standardisation of the vehicle components, the economic cost of each prototype was less than €4000. Both prototypes were funded by the “Key-Project” programme of the Vice-Rectorate for Social Innovation and Entrepreneurship of the University of Malaga.

The first edition of the programme took place in the years 2021/2022 and consisted of 20 volunteer students from different courses of the School of Industrial Engineering of the University of Malaga. For the selection of students, priority was given to students who were in their second year of study.

The training programme was organised in two distinct phases: the first focused on fundamental theoretical and practical training on electric vehicles and the second one on the application of the manufacturing processes of this type of vehicle. The main objective of the first phase was to ensure that all students, coming from different engineering branches, acquired a solid and homogeneous base on the fundamental concepts of EVs, so that they could work effectively as a team. During this training phase, sessions were delivered that combined theory and practice, covering basic topics such as electric propulsion technology,

energy storage and conversion systems, the design of photovoltaic systems for vehicles, chassis structure, braking systems, and the mechanical and electronic components that make up this type of vehicle. By ensuring that all students had the same basic knowledge, the group was levelled, which facilitated smoother communication between the students. This preparation was essential to create a collaborative working environment. These sessions took place in the electronics laboratory, complemented by outdoor testing using already existing EV prototypes (Figure 6).



Figure 6. Electric vehicle training session (2023/2024 edition).

The second phase of the project consisted of the manufacture of the vehicle. This phase began with the organisation of the working groups. In this first edition of the project, the ST methodology was implemented, which is the one normally used by teams participating in university competitions [19,20,22,61] and which is a simplified version of the organisational structure of professional motorbike and car racing teams. In this methodology, each working group is responsible for performing one of the tasks in which the manufacturing process is organised. Each student decided which group they joined, depending on the tasks they found most attractive. The teachers took on the role of team project manager, coordinating the students in the different working groups and preparing the manufacturing procedures for each group.

Once the manufacturing phase was completed, various tests were carried out to evaluate the performance of the prototype. Firstly, aspects of the dynamic behaviour, such as stability, braking ability and acceleration, were analysed. The energy efficiency of the vehicle was then evaluated by analysing energy consumption data under different conditions of slope, speed and acceleration. The results of these tests can be found in [62].

The second edition of the project was then launched, in the years 2023/2024, for which a total of 25 students were selected according to the same selection criteria as in the first edition.

The training programme was organised in the same way as in the first edition: a first phase of theoretical-practical training and a second phase of manufacturing. The first phase was similar to that of the previous edition, except that the content on the photovoltaic systems was expanded.

The most significant changes were made in the second phase. In this second edition, the way of organising the work groups was changed by implementing an EME methodology. The groups were formed according to the time availability of each student, grouping those with a similar timetable and the tasks were organised sequentially so that all the groups participated in some part of them. Each student was integrated into a single working group and each working group had two or three hours per week to devote to the activity that corresponded to it within the general schedule of tasks. In this way, all the students were active during all the weeks of the project. At the beginning of the project, 6 working groups

were formed, which were reduced to 4 at the end, as 10 students left the project before its completion.

The tasks were scheduled sequentially, starting with the manufacture of the chassis and ending with the manufacture of the photovoltaic generator. Each working group continued the manufacturing process at the point where the previous group had left off, regardless of the task being carried out.

The teachers modified the manufacturing procedures to adapt them to this new strategy. This modification included a short report to be made by each group at the end of the day indicating the tasks they had completed and where the next group was to start work.

Based on their initial approach, the following differences between the two methodologies can be highlighted:

- In the ST methodology, students are only involved in one manufacturing task, so they only experiment with the manufacturing processes related to that task. Students who regularly attend the working sessions are involved in all phases of the task, from the beginning to the end.
- In the EME methodology, students participate in all the manufacturing tasks, so they can experiment with all the manufacturing processes necessary to make the complete vehicle. However, they do not carry out any complete task, only some phases of it, as the activities of each task are distributed among all the working groups.
- The ST methodology requires a much more complex planning of activities, allowing an appropriate synchronisation of tasks and a workload that is as balanced as possible over time. The difficulty lies in the fact that on the one hand, the workload associated with each task is different and, on the other hand, there are tasks that cannot be started until others have been completed or are sufficiently advanced.
- In the EME methodology, in contrast, planning is much simpler, as the workload of each group is established in a balanced way by establishing a schedule in which all groups spend the same amount of hours per week on the task that corresponds to them at each moment.

Another aspect worth highlighting in both editions was that although the vehicle design was fairly well-defined, the students encountered problems and failures throughout the development of the prototype that they had to deal with through tests, adjustments or even improvised modifications, depending on the resources available and the limitations of the project itself. Far from being a problem, we think that this allowed them to develop essential decision-making and leadership skills. In addition, this real-world context taught them to take into account other important factors such as time, cost and efficiency, thus fostering the ability to think strategically and prioritise the most important tasks.

In both editions, an activity report was drawn up for each task carried out throughout the process, which included the following data:

- Documentation and materials used.
- Number of sessions and time required for their execution.
- Students participating in each session.
- Description of problems encountered, actions taken to solve them and suggestions for possible future improvements.

At the end of each edition, the learning and achievements in engineering education were analysed by means of a survey in which the students' opinion about the experience were collected [63].

3. Results

3.1. Project Results

A series of quantitative data have been extracted from the reports of each edition of the programme to allow an objective comparison of the results of the experience. Firstly, we have analysed the time data, both general data on the experience and student participation.

Regarding the general temporal data, it is necessary to clarify that these experiences were developed simultaneously with the academic programming of the official degrees. In order not to interfere with the students' studies, the programming of activities was suspended during examination periods and holidays, which is why they were spread over two years. However, none of them took up more than 40 weeks in total.

Figure 7 presents a Gantt chart showing the time distribution (in weeks) of the different tasks and activities in each edition of the project. The diagram consists of three main elements: a list of tasks on the left, a schedule on the right based on the weeks devoted to the project and planning bars indicating the duration of each task. This diagram allows you to visualise the duration of each task or activity, the dependencies between them and the milestones achieved over time.

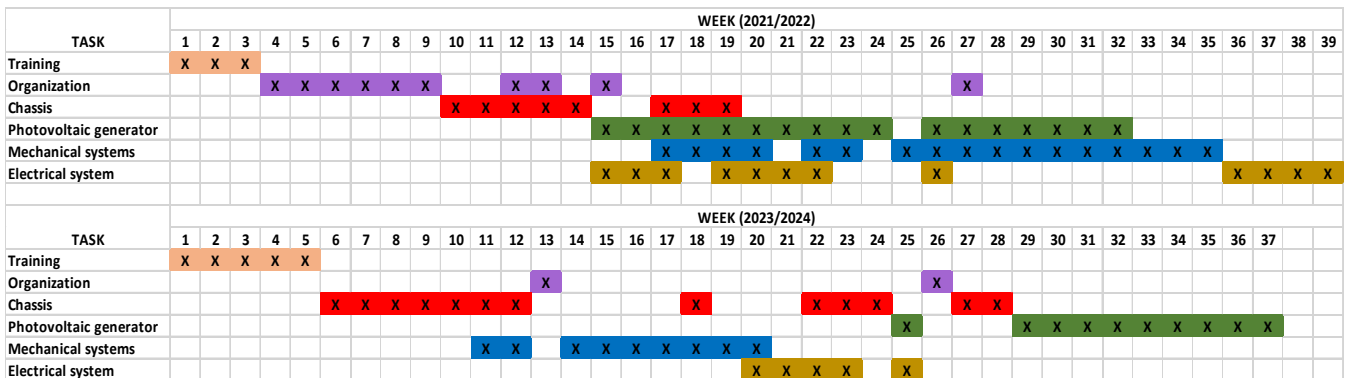


Figure 7. Gantt chart for each edition of the project.

In terms of total duration there are no major differences between the two editions. While the second edition lasted 37 weeks, the first edition was extended to 39 weeks, but there was an excess of 4 weeks because, after the prototype was completed, it was decided to completely remake the electrical system due to various problems encountered in the first test runs. If this problem had not arisen, the first edition would have lasted 35 weeks, slightly less than the second one.

The most remarkable feature of this figure is that there is a significant difference between the two editions regarding the overlapping of tasks. In the central weeks of the first edition, three and even four tasks overlapped, so there was a high concentration of working hours and, consequently, a greater complexity in managing the resources and in the coordination of the working groups. In contrast, in the second edition, the sequencing of the tasks is perfectly observed. There were only several weeks where at most two tasks overlapped, normally because the end of one and the beginning of the next coincided in the same week. An exception was the chassis construction, which had to be taken up in several phases to make some necessary modifications to properly install the rest of the systems. This organisation greatly simplified the coordination work and meant that the workload was distributed more evenly over time.

Another remarkable difference between the two editions is that the manufacturing phase started 4 weeks later in the first edition than in the second one, despite the fact that the first basic training phase was shorter. This was because it was necessary to hold several meetings, both general and with each of the groups, to organise a complex coordination

system implemented on an online communication and collaboration platform. Each group had to record its progress on this platform so that all participants had an overview of the progress of the project. In the second edition, these meetings were not necessary because this system was replaced by the elaboration of a small report at the end of each working session. In this edition, meetings were only held at the beginning of each academic semester, with the aim of adapting the timetable for the project to the students' new class schedules.

Figure 7 provides an overview of the sequencing of the tasks, but it is not possible to obtain precise information on the time required for the completion of the tasks. Table 1 shows a more detailed analysis of the time spent on the manufacturing tasks.

Table 1. General temporal data for both editions of the project.

Edition	2021/2022			2023/2024		
	Hours/ Session	Hours/ Student	Student/ Session	Hours/ Session	Hours/ Student	Student/ Session
Chassis	47	124.5	2.65	55	258	4.69
Photovoltaic generator	51.5	127.5	2.48	49.5	119.5	2.41
Mechanical systems	67.5	217	3.21	42	167.5	3.99
Electrical system	35.5	87.5	2.46	16	46	2.88
Total	201.5	556.5	2.68	162.5	591	3.64

The "hours/session" columns show the total number of hours that have been invested in each manufacturing task and their data have been obtained by adding up the hours of each of the sessions of each task. For example, in the first edition, 8 sessions of the chassis task were carried out, totalling 47 h, while in the second edition, 13 sessions of the chassis task were carried out, totalling 55 h. The number of students who participated in each session was also different. The number of total working hours spent on a task has been obtained by multiplying the number of hours of each session by the number of students who participated in it. This result is shown in the columns "hours/student".

The columns "student/session" show the result of dividing the value of "hours/student" by "hours/session", i.e., they indicate the average number of students who participated in each working session. This last piece of data is interesting because it gives an estimate of the performance of the students' work. The lower this value, the fewer the number of students needed to perform the same task, that is, the greater the performance of their work.

The total data in the first column shows that the time required to manufacture the prototype in the first edition (201.5 h) was significantly higher than in the second edition (162.5 h). The table also shows that there was little difference in the number of session hours needed to manufacture the chassis and the PV generator in each of the editions. The big difference was in the Mechanical Systems and Electrical System tasks, where the number of session hours was much higher in the first edition than in the second.

The second column of the table shows information that is apparently contradictory to the previous one, namely, that the total number of working hours of the students in the first edition was, however, somewhat lower than in the second edition. Combining this with the data in the third column, which shows that the average number of students per work session was higher in the second edition, it can be concluded that the students' work performance in the first edition was higher than in the second edition.

Looking at the data in more detail, it can be concluded that this "anomaly" was mainly caused by the chassis task, which required more than twice as many hours of student work in the second edition (258) as in the first edition (124.5), although the difference between

the hours spent on each task was not significant (55 in the second edition versus 47 in the first edition).

Combining the data of the sequence of tasks shown in Figure 7 with the data of the students' work performance in the second edition shown in Table 1, it can be seen that the average number of students needed to perform each task decreased as the project progressed: Chassis (4.69)—Mechanical systems (3.99)—Electrical system (2.88)—Photovoltaic generator (2.41). This last task was the only one where the average number of students was lower in the second edition of the project than in the first. In contrast, the performance of the students' work in the first edition was more evenly distributed across all tasks.

To further analyse the students' participation in the project, the total number of hours spent by each student has been computed. The result is shown in Figure 8.

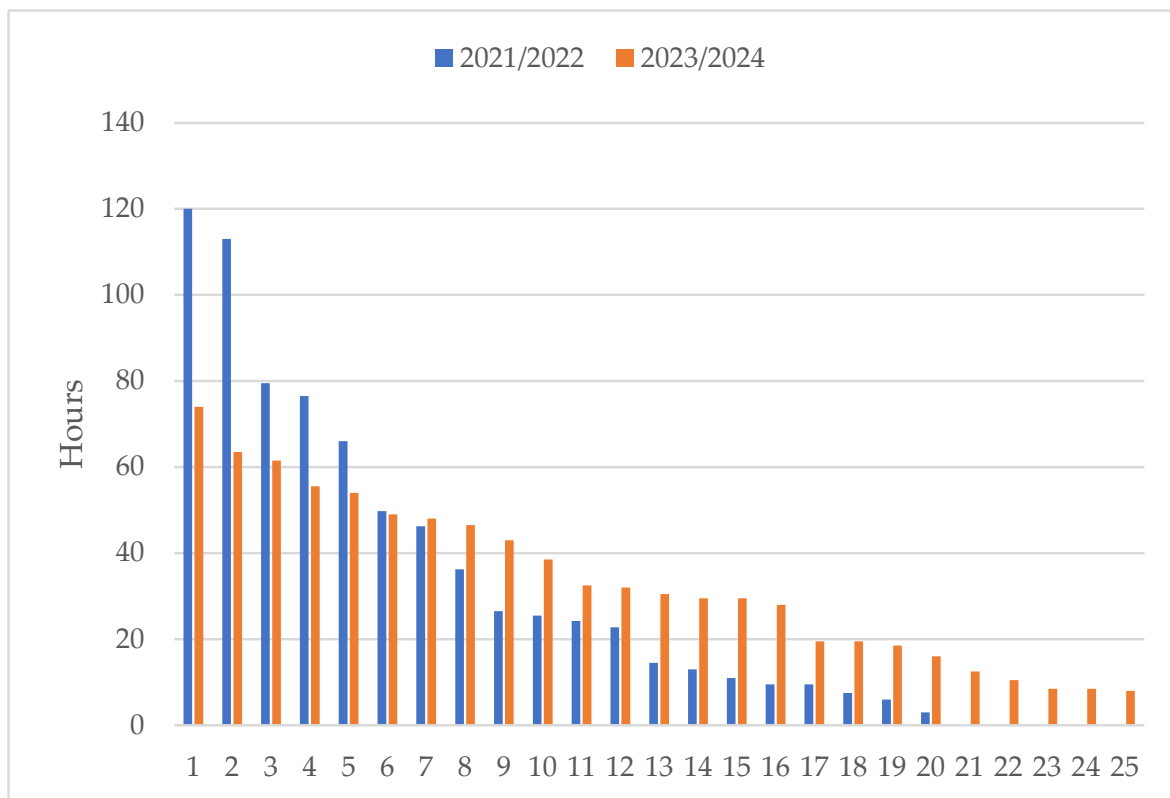


Figure 8. Diagram of the hours of dedication of each student.

This graph shows the number of hours that each student has devoted to the project in each edition, ordered from highest to lowest. The vertical axis shows the hours worked and each point on the horizontal axis corresponds to one student. Only 20 students participated in the first edition, so there is no data from 21 to 25 in this edition.

In the first edition, there was a large variation between the hours spent on the project by each student. Some students worked considerably longer than average, while another group of students remained well below average. In contrast, in the second edition, the variability in hours of attendance was considerably lower, indicating a more balanced and consistent participation among all students.

This graph also shows that many students in each edition spent very little time on the project. This is due to the fact that there were many absences throughout the project and many of them dropped out before the end of the project. To quantify this data, we have established that students who did not participate in any session from the middle of the course until the end dropped out of the project. The drop-out rate has been defined as the percentage of students who have dropped out with respect to the total number of

students who started the project. According to these definitions, in the first edition a total of 9 students dropped out, with a drop-out rate of 45%, while in the second edition 10 students dropped out, with a drop-out rate of 40%.

The students who dropped out of the project devoted very few hours to its development, which is why their impact on the final results can be considered statistically irrelevant or negligible. Including these cases in the quantitative analysis would not provide meaningful information; on the contrary, it would introduce greater dispersion in the data and distort the overall interpretation of the results. Consequently, it was decided not to include them in the final sample in order to preserve the validity and accuracy of the estimate of the actual commitment of the group of students who completed the experience.

Table 2 compiles the attendance and participation statistics for the students shown in Figure 8 but excluding the data for students who dropped out of each project. The mean value and standard deviation of two variables are shown: the number of weeks each student participated in the project and the total number of hours each student spent on it. The mean value of the number working hours per student per week is also shown, dividing the total number of hours by the number of weeks.

Table 2. General attendance data for both editions of the project.

Edition	2021/2022			2023/2024		
	Nº Weeks	Total Nº of Hours	Hours/Week	Nº Weeks	Total Nº of Hours	Hours/Week
\bar{x}	17.25	57.19	3.32	26.27	45.83	1.74
$\sigma(x)$	7.25	32.71	-	5.03	13.48	-

It can be observed that there are no major differences in the average hours of attendance per student in both editions, although it is slightly higher in the first edition (57.19 h) compared to the second (45.83 h). However, there is a considerable difference in the dispersion of attendance hours. In the first edition, the standard deviation was 32.71 h, while in the second edition it was reduced to less than half (13.48 h). These data confirm that the distribution of working hours is much more balanced in the second edition than in the first edition, as shown in Figure 8.

Another important fact in Table 2 is the average number of weeks of attendance, which was significantly higher in the second edition (26.27 weeks, 71% of the total) compared to the first edition (17.25 weeks, 44% of the total). The last data in the table shows that in the first edition there was a higher concentration of student work (3.32 h per week) than in the second edition (1.74 h per week). These data confirm that the distribution of work in the second edition was more uniform over time and that students spread their participation over a longer period of time.

To conclude this study, student participation data for each manufacturing task was analysed.

Figure 9 shows the number of different students (as a percentage of the total number of participants) who have participated in each of the manufacturing tasks.

The figure clearly shows that in all tasks except the Electrical System task, a much higher percentage of students participated in the second edition of the project than in the first edition. The exception in the electrical system task may be caused by two factors:

On the one hand, it can be seen that in the second edition, this was the task with the lowest participation. This was due to the fact that in order to install the electrical system, the chassis had to be modified, as shown by the simultaneousness of both tasks in Figure 7. Because of this, some students had to devote themselves to modifying the chassis and did not participate in the electrical system task. On the other hand, the electrical system was

completely rebuilt in the last weeks of the first edition and students who were not originally included in this group participated in this rebuilding. This was a general trend in this first edition of the project. As the project progressed and the number of drop-outs increased, the composition of the groups had to be modified and some students who had started in one group ended up joining a different one to cover the drop-outs.

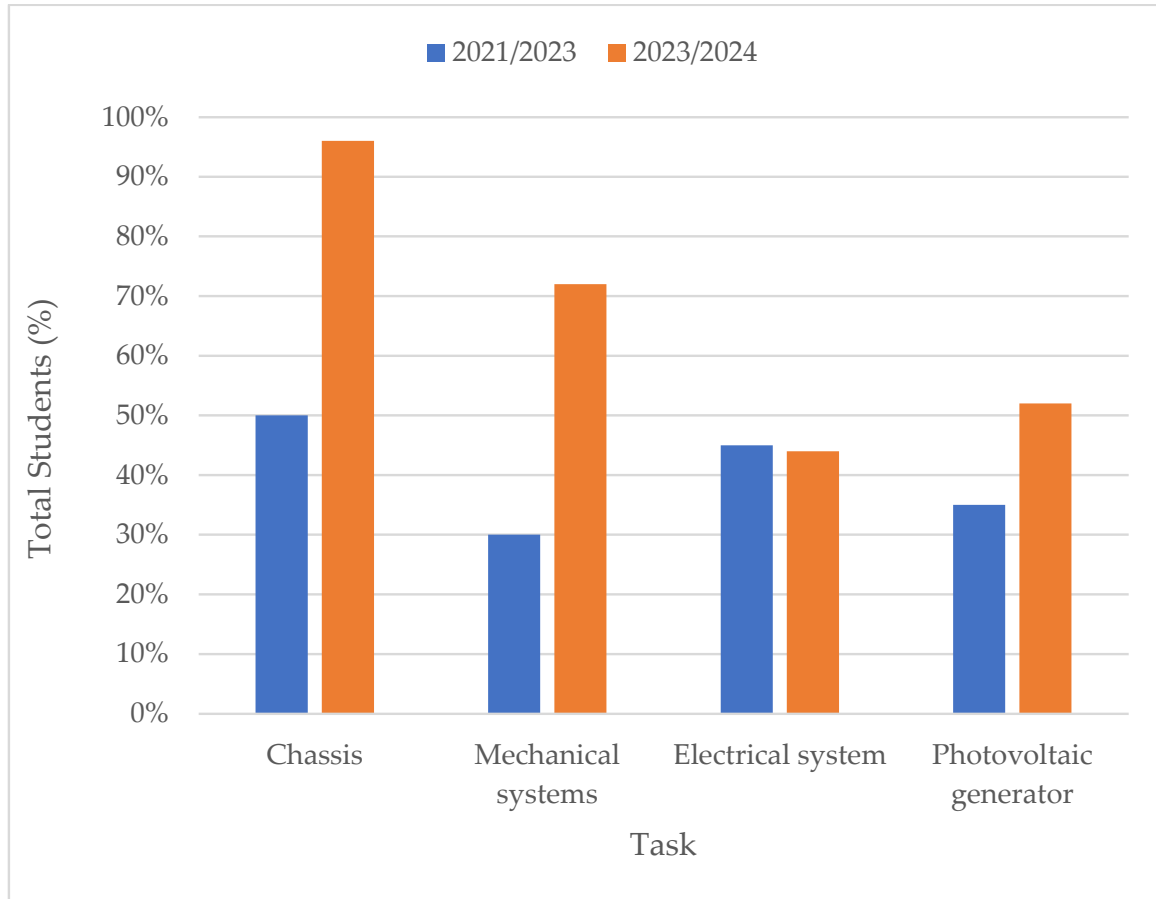


Figure 9. Percentage of students in each task.

The impact of the dropouts in the second edition can also be seen in this graph. With the exception of the electrical system task mentioned above, it can be seen that the tasks that were executed at the beginning of the project had a higher participation than those at the end of the project, and this was due to the fact that, by the time these final tasks were carried out, the actual number of students participating in the project had been reduced due to drop-outs.

Figure 10 shows another way of visualising student participation in the manufacturing tasks. It shows the percentage of students (also in relation to the total) who participated in one, two, three and all four manufacturing tasks. The graph clearly shows that in all cases this number was higher in the second edition than in the first edition.

A first detail to highlight is that except for one, the rest of the students in the second edition participated in at least one manufacturing task. In contrast, in the first edition only 75% of the total number of students did so. This means that 25% of the students in the first edition only participated in the first basic training phase and dropped out before starting the manufacturing tasks. The reason for this was that some students who joined groups whose task started many weeks after the end of the basic training, such as Mechanical Systems, dropped out of the project before being able to participate in the second phase.

It may also seem strange that in the second edition, less than half of the students (44%) participated in all tasks of the vehicle manufacturing process and only 52% participated in three of them. In the EME methodology, all students should have participated in all tasks. The cause of this is to be found in the high drop-out rate (40%), which caused many students to abandon the project before the start of the last tasks. To filter this data and to show in more detail the students' participation in the manufacturing tasks, Figure 11 shows the hours spent on these tasks by students who did not drop out of the project.

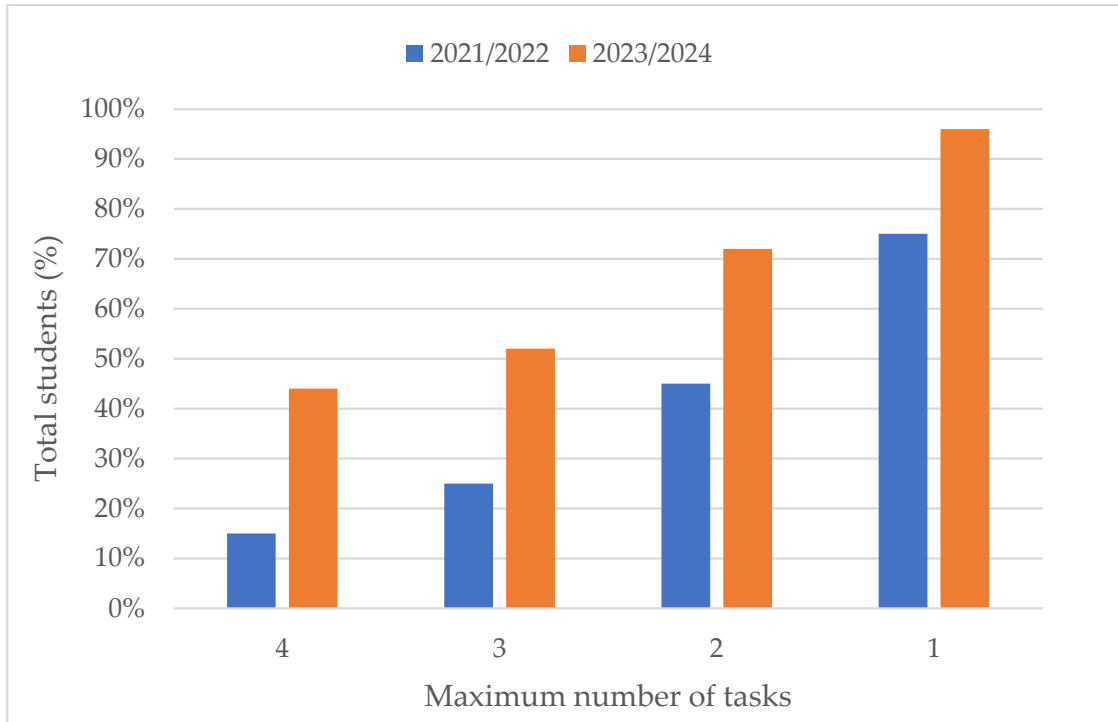


Figure 10. Percentage of students by number of tasks.

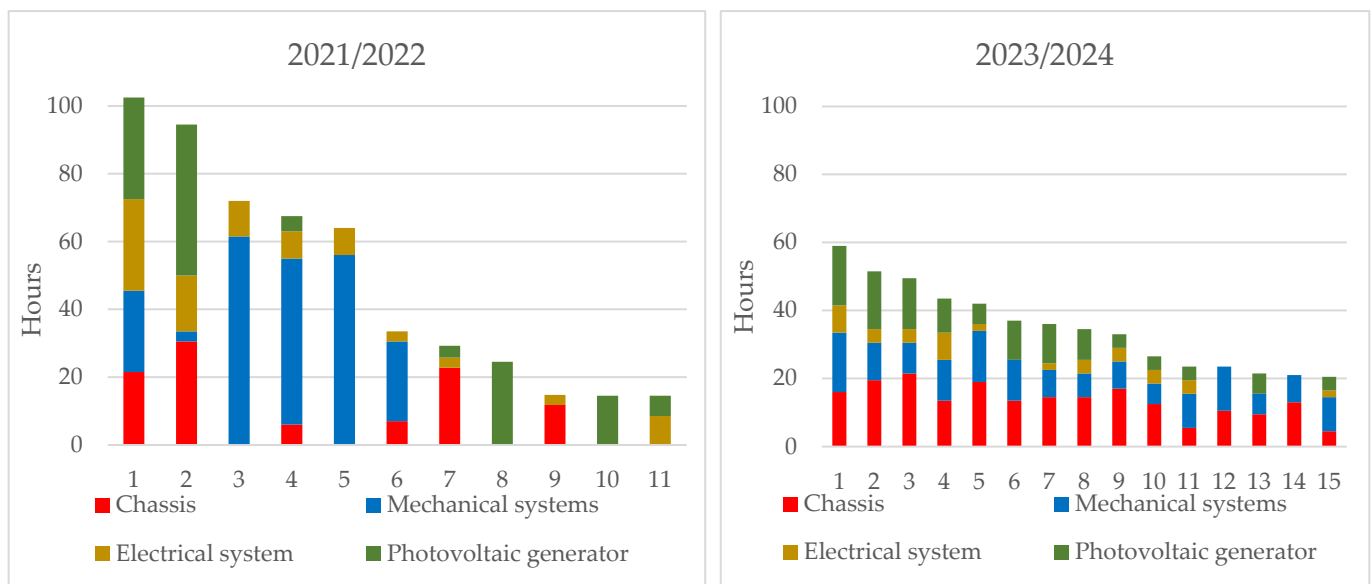


Figure 11. Hours spent on each task by students (excluding drop-outs).

The figure shows big differences in the two editions of the project. In the second edition, almost all students participated in at least three tasks and the dedication to each

task was quite balanced in most of them. The task with the least participation was the electrical system task, due to the problem discussed above. On the other hand, in the first edition, most of the students devoted themselves mainly to a single task, with the dedication to other tasks being quite residual. The number of hours dedicated to this main task was also considerably higher than the number of hours dedicated to the same task by students in the second edition.

3.2. Vehicle Technical Characteristics and Performance

To conclude, this section will present the technical specifications of each prototype, as well as the results of the tests conducted to evaluate their performance.

Table 3 shows the technical characteristics of both vehicles.

Table 3. Technical characteristics of the vehicles.

Edition	2021/2022	2023/2024
Overall dimensions (length/width/height) (m)	3.00/1.65/0.75	2.92/1.62/0.75
Track/wheelbase (m)	1.35/1.80	1.25/1.75
Total weight (kg)	101.9	115.7
Steering system	Rack and pinion steering; Ackermann geometry	Single tie rod and drag link system; Ackermann geometry
Braking system	Hydraulic, with four independent circuits and 160 mm disc in each wheel	
Propulsion system	Front-wheel drive with a motor in each wheel, Crystalyte G40, in electric differential configuration	Rear-wheel drive with a motor in each wheel, Crystalyte G40, in electric differential configuration
Photovoltaic generator	224 Sunpower C60 cells distributed in two parallel arrays. Power in standard conditions: 715 Wp	

Table 4 shows a comparative analysis of the performance of both vehicles. The tests were carried out on the same circuit but under varying environmental and operational conditions, including different days, irradiance levels, wind speeds, and student drivers. These variations, although inherent to real-world scenarios, introduce a degree of variability that must be considered when interpreting the results, as they reflect the robustness and adaptability of the prototypes under non-controlled conditions.

Table 4. Comparison of the performance of both vehicles.

Edition	2021/2022	2023/2024
Average Speed (km/h)	17.57	20.51
Total Time (s)	207	163
Average Power (W)	178.07	292.87
Total Energy (W·h)	10.29	13.34
Efficiency (km/kWh)	95.02	69.92

Furthermore, Figure 12 illustrates the evolution of speed and power along the circuit for both vehicles during the tests. This representation provides a view of their dynamic performance and allows for a direct comparison under similar trajectories.

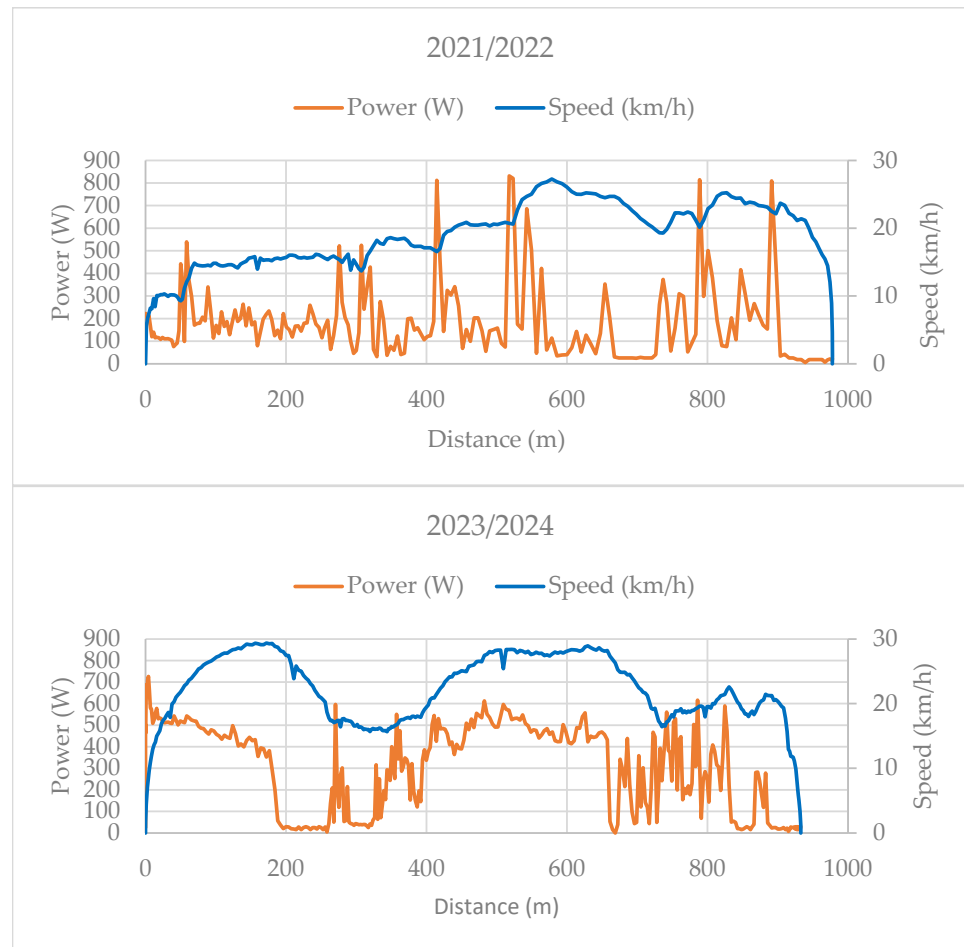


Figure 12. Speed and power consumption of both vehicles.

4. Discussion

The previous section shows some noticeable differences between the results obtained in the first and the second edition of the project. First of all, it is necessary to determine which of these differences are due to the methodology applied and which can be attributed to other causes.

We will start by analysing the results where the different methodologies used in the two editions of the project seems to have had a minor influence.

4.1. The Drop-Out Rate

In the first edition the rate was 45% and in the second edition it was 40%. Both are rather high values, although the fact that they are similar seems to indicate that this figure is not directly related to the methodology used. For this reason, it is necessary to analyse other causes that may have had a greater influence on these values:

- The students' participation was voluntary and free of charge, they had no commitment to remain in the project, so they could leave it whenever they considered it appropriate.
- Both projects spanned two years. From one year to the next, the number of official subjects and the students' schedules changed significantly, making it impossible for many of them to combine the project with their official studies during the second year.

Some of the students who dropped out of the project in both editions were interviewed and all of them stated that the reason for dropping out was that they could not continue with the project in the second year because it did not fit in anymore with their schedules of their official studies.

4.2. The Time Needed to Manufacture the Prototype

The time required to produce the prototype for the second edition was 20% less than for the first edition (162.5 h versus 201.5 h). As shown in Table 1, this difference was mainly due to the mechanical and electrical system tasks.

The most likely explanation for this is that it was in these assignments that students were given more freedom to design some elements of these systems. The students in the first edition had no previous reference and made quite a few mistakes that they had to correct for the system to work properly. The students in the second edition had the first prototype as a reference and, although they made modifications and improvements in both systems, they did not make as many mistakes and took less time to complete the tasks.

For this reason, we consider that it was not the methodology used that had a major impact on the time taken to manufacture the prototype, but rather the order in which both methodologies were used that made the difference. It is likely that if this order had been reversed, that is, the EME methodology had been applied in the first edition and the ST methodology in the second edition, it would also have taken longer to manufacture the prototype in the first edition than in the second edition.

Figure 7 shows that the number of weeks the project took was quite similar in both editions, but this was due to the extension of the Mechanical and Electrical System tasks in the first edition, due to the causes already mentioned. Had these problems not arisen, it is quite likely that the first edition would have taken several weeks less than the second edition.

In conclusion, although the methodology used does not seem to have a decisive influence on the total time needed to manufacture the prototype, the possibility of carrying out tasks simultaneously, which the ST methodology allows, does have the capacity to reduce the time interval needed required for this.

There are other results that also seem to have been influenced by the methodology applied, and these are as follows.

4.3. The Complexity of the Organisation

Figure 7 shows that the first edition of the project required a more complex organisation than the second edition for the following reasons:

- After the basic training phase, six weeks were devoted to coordination meetings and the development of the online platform, which was not necessary for the second edition.
- The workload was more unevenly distributed, being concentrated during the central weeks of the project: from week 15 to week 26. Most of the work on the 4 tasks was concentrated in this period of time, which required a much greater effort of coordination of schedules and workspace than in the second edition. The reason for this high concentration of work was the need for all students to be active as soon as possible, since it was found that the fact that students were inactive for a long time after the basic training phase caused a great deal of demotivation. This did not happen in the second edition either, as the organisation of the work itself meant that all the students were active during all the weeks of the project.

In conclusion, in the ST methodology, the need for most of the students to have as much time as possible occupied throughout the project in order to avoid demotivation means that as many tasks as possible have to be scheduled simultaneously, which greatly complicates the overall organisation of the project.

In contrast, the need to use a communication platform efficiently enables students to acquire expression and communication skills, which are very important in today's working environments.

4.4. The Performance of Students' Work

Table 1 clearly shows that in total fewer students were needed to complete the same work in the first edition of the project than in the second edition. However, it has also been found that, while in the first edition the performance of the students' work was fairly uniform across all tasks, in the second edition the performance improved as the project progressed so that the last task completed (photovoltaic generator) required many fewer students per session than the first task (chassis). We can find two possible causes for this result:

- Due to drop-outs, the number of students at the beginning of the second edition of the project was greater than at the end, so the working groups were also larger at the beginning. The organisation of a group's work becomes more complicated as the number of group members increases, so that some group members are more likely to be idle for some time during the work session because they have to wait for others to finish a task before they can start their own. These intervals of inactivity are shorter the smaller the number of group members.
- At the beginning, the students often had little or no experience working in the workshop, using tools, etc., so they needed more time to complete the tasks. As the project progressed, they gained more experience and therefore the time spent on tasks decreased, which led to a significant increase in performance.

Based on this, it can be concluded that the ST methodology provides a higher net output of students' work, but, in contrast, the EME methodology allows for rapid progress in the acquisition of skills by students.

4.5. The Distribution of Students' Work

Table 2 shows that there is not much difference in the total average hours worked by each student (57.19 h in the first edition versus 45.83 h in the second edition), however Figure 8 shows a big difference in the distribution of the hours spent on the project by each student in each of the editions.

In the ST methodology, each student should have been included in a single working group. According to this, ideally the maximum difference between the number of hours worked by each student in the first edition (assuming no absences) should be similar to the difference between the most demanding task, Mechanical Systems (67.5 h) and the least demanding task, Electrical Systems (35.5 h). This difference is inherent to this methodology, as not all tasks require the same amount of working time.

However, the differences shown in Figure 8 and the dispersion in 2 are much larger than these values. The reason for this larger difference can be deduced from the data shown in Figure 10. If the method had been applied strictly, all students would have participated in only one task. However, this figure shows that 15% participated in all four tasks, 25% in three tasks and 45% in two tasks. The students who participated in all four tasks spent significantly more hours of work than those who only participated in one task only.

The reason for this was the need for several students to complete tasks assigned to other groups of which they were not initially a part, mainly due to the high dropout rate.

Although it has already been mentioned that the cause of a high drop-out rate is not fundamentally due to the methodology used, these data seem to confirm that its consequences are very different depending on the methodology used.

In the case of ST methodology, a high drop-out rate has a major effect in the organisation of the project, forcing some students to take over the tasks of those who have dropped out of the project what leads to a great inequality in the working hours spent by each student.

The data in Figure 8 and Table 2 for the second edition show much less dispersion in the working hours of each student and this difference must be attributed to absences since in the EME methodology all students were assigned the same number of working hours. In this methodology, a high drop-out rate only affects the need to increase the working hours of all students, but in a balanced way.

Finally, Table 2 also shows that students in the second edition spread their participation over a longer period of time. This has the advantage of giving them more time to assimilate the knowledge and skills developed in the work and confirms the conclusion of the Section 3 that the methodology applied in this edition allows for greater progress in the acquisition of skills by the students.

4.6. The Diversity and Depth of the Tasks Undertaken by the Students

Figures 10 and 11 clearly show that in general, the students of the second edition participated in many more tasks than those of the first edition, which clearly indicates that the EME methodology allows a larger number of students to participate in all the vehicle manufacturing tasks and, therefore, that it is easier to implement a multidisciplinary teaching approach in this methodology than in the ST methodology.

On the other hand, another reading of these data indicates that most of the students in the first edition concentrated all their work on one or two tasks, from which it can be deduced that the ST methodology allows students to spend more hours on their assigned task and, consequently, to have the opportunity to obtain greater reinforcement of the skills related to that task.

Finally, we can establish that the EME methodology allows for the acquisition of a wide range of skills, but with little depth, while the ST methodology limits the number of skills but allows for greater depth in their development.

To summarize, Table 5 below shows an analysis of strengths and weaknesses that allows for a comparison of the different approaches of each methodology.

Table 5. General analysis of strengths and weaknesses.

Methodology	Strengths	Weaknesses
EME (Everybody Makes Everything)	<ul style="list-style-type: none"> - Promotes the acquisition of a wide range of skills. - Encourages versatility and adaptability among members. - Facilitates a comprehensive understanding of the process or project. - Improves collaboration by sharing responsibilities. - Planning activities is much simpler 	<ul style="list-style-type: none"> - Limited depth in the development of each skill. - Risk of superficial results. - May lead to duplication of effort. - Difficulty in achieving a high level of specialisation.
STs (Specialized Teams)	<ul style="list-style-type: none"> - It allows for a solid deepening of specific skills. - It promotes efficiency by assigning tasks according to competencies. - It increases technical quality in critical areas. - It enhances individual specialisation. 	<ul style="list-style-type: none"> - Less diversification of skills acquired by each member. - Risk of knowledge silos. - Strong dependence on specific specialists. - May hinder overall understanding of the project. - Complex planning of activities

A comparative analysis of the EME and ST methodologies shows that both offer distinct advantages: while the former promotes versatility and a global vision, the latter enhances specialisation and technical quality.

Table 6 presents recommendations that allow us to identify in which situations it is most appropriate to apply each working methodology.

Table 6. Recommendations for use.

Methodology	
EME (Everybody Makes Everything)	<ul style="list-style-type: none"> - In the early stages of learning or training, when it is important for participants to understand the entire process. - In small-scale projects where flexibility is required and everyone can contribute to different areas. - In small teams where it is not possible to specialise roles due to a lack of resources. - In environments where collaboration and versatility are valued more than technical efficiency.
STs (Specialized Teams)	<ul style="list-style-type: none"> - In complex or technical projects, where a high level of quality is required in specific areas. - When time is limited and efficiency is a priority. - In large organisations or teams, where the division of tasks allows for greater productivity. - When seeking to further innovation in a specific area thanks to specialists.

5. Conclusions

This paper presents the results of the application of two different working group organization methodologies to a teaching programme based on the PV-EV manufacturing project. The first edition of the programme used the ST methodology and the second edition, the EME methodology.

Both editions had a high drop-out rate (45% in the first edition and 40% in the second). It was found that the cause of this problem is not to be attributed to the type of methodology, but to the fact that both experiences have been extended over two years. However, the consequences of a high drop-out rate were found to be more detrimental to the ST methodology. It is concluded that the best way to reduce the drop-out rate in such projects is to restrict their duration to a maximum of one year.

The data obtained also showed that it is not possible to establish which methodology minimises the total number of hours required to manufacture the prototype. The time was quite similar in both editions, and it was found to be more influenced by the order in which the methodologies were used. However, it is expected that the ST methodology can reduce the time needed to manufacture the prototype, as the different tasks can be carried out simultaneously.

Other advantages of the ST methodology are that it allows a higher net performance on the students' work and a greater reinforcement of the skills acquired in the project, not only of a practical nature but also of the ability to express and communicate.

In contrast, the EME methodology has the advantages of requiring a considerably less complex organisation, of distributing the students' work in a more balanced way, of allowing rapid progress in the acquisition of a greater number of practical skills and, therefore, of presenting a greater facility for implementing multidisciplinary teaching than the ST methodology.

Our final conclusion is that the EME methodology is more suitable for implementing project-based educational programmes at the cornerstone or mid-program level, while the ST methodology may be more appropriate for more experienced students in capstone programmes.

In terms of the project's scalability, digital tools could be developed to facilitate collaborative management and enable the experience to be replicated. In addition, the possibility of extending the model to larger groups could be explored, maintaining the balance between breadth of knowledge (EME) and technical depth (ST).

Based on these experiences, replicable models could be developed and transferred to other educational institutions, facilitating the integration of active methodologies (PBL, EME and ST) into programmes focused on sustainability, technological innovation and multidisciplinary training. Design and implement the project as an experimental subject within a curriculum, in order to systematically evaluate its pedagogical impact. This would allow for the measurement of results in technical, cross-curricular, and socio-emotional competencies, as well as the collection of comparative data between different cohorts and educational levels. In this way, it would be possible to evaluate longitudinally how the combination of both methodologies influences learning retention and student motivation.

Finally, regarding adaptation to other contexts, we consider that it will be possible to transfer the methodological approach to projects related to renewable energy, sustainable mobility, or the creation of other technological prototypes, where collaboration and diversity of tasks are valued. While it is true that the results cannot be directly extrapolated to any problem-based learning (PBL) experience, the development of an FVE has substantial similarities with other projects aimed at manufacturing prototypes that integrate mechanical, electrical, and electronic systems. For this reason, we think that the results obtained can be generalised to this type of project. It could also be implemented in environments with limited resources, where each member must take on multiple roles.

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Conflicts of Interest: The authors declare no conflicts of interest.

Abbreviations

The following abbreviations are used in this manuscript:

EME	Everyone makes everything
EV	Electric vehicle
LEV	Light electric vehicle
PBL	Project based learning
PV	Photovoltaic
PV-EV	Photovoltaic electric vehicle
STs	Specialized Teams

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