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EXPLORIA, STEAM Education at University Level as a New Way to Teach Engineering Mechanics in an Integrated Learning Process

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Abstract: The objective of our research is the implementation of STEAM (Science Technology Engineering Art Mathematics) learning in the bachelor of Engineering in industrial design and product development at CEU Cardenal Herrera University through the EXPLORIA project. This article implements and develops the proposal for the first year of this bachelor, which includes 24 students aged 18–20. This article focuses on how to integrate STEAM learning within the EXPLORIA project for the improvement in the learning of the physics subject, and in particular, regarding the part of the syllabus related to mechanical engineering through different projects, challenges and milestones that allow the student to see the use in the design and development of products. The EXPLORIA project connects the competencies of the different STEAM subjects included in the bachelor, designing a learning process as a logical, sequential and incremental itinerary. Through concepts on which the fundamentals of design are based: shape, volume, color, space and structure. In particular, this article shows the adaptation made in the physical part to be able to teach the integrated mechanics part in this learning process. The complete learning was carried out through several challenges and two milestones the students had to overcome through the application of the physical knowledge learned in class. To validate the effectiveness of the proposed methodology, at the end of the paper, an ad hoc questionnaire is carried out showing the students' assessment regarding the new teaching methodology.

Keywords: STEAM; active methodologies; project based learning; challenge-based learning

1. Introduction

STEM learning (Science, Technology, Engineering and Mathematics) was developed at the beginning of the 90s, focused on non-university studies, mainly for middle and high school. STEM is a curriculum based on the idea of educating students in four specific disciplines: science, technology, engineering and mathematics, by using an interdisciplinary and applied approach. Rather than teaching the four disciplines as separate and discrete subjects, STEM integrates them into a cohesive learning paradigm based on real-world applications [1].

The United States has historically been a leader in these fields in trying to motivate high school students to choose STEM careers. This decline in student interest regarding this type of bachelor is not unique to the United States, it is a global problem, as recognized in [2]. In this context, the STEM approach becomes important since this term refers, in a generic way, to the development of initiatives and projects that promote and develop scientific-technological skills and competencies and involve the participation of STEM disciplines [3]. From an educational perspective, we seek the intentional integration of the four disciplines used to solve real-world problems [3]. In this comprehensive and interdisciplinary approach, sciences provide the scientific method. Technology and engineering provide the techniques and tools to build objects and solve technological problems, and mathematics provides a way of expression and representation that allows interpreting the environment and applying strategies to solve problems as well as promoting logical and critical thinking [4].

The implementation of STEM learning generated a deep debate on how the four disciplines should be integrated, whether independently or according to an integrated approach [5]. Of the two approaches, the integrative approach is currently the most widely accepted, in which the four disciplines constitute a single teaching–learning practice [3]. Still, there are researchers who believe that a fair interaction is the right thing to do [6], while others place one discipline above the other [7]. In [3], they observed that, although the disciplines were treated jointly, there was no true connection among them, and [8] considered that educational institutions did not agree on how the four disciplines should be established or connected. To solve this problem, in [5] a proposal has been made to include Art as a new discipline in the STEM context, which was renamed STEAM. In STEAM learning, Art, in addition to promoting interdisciplinarity, facilitates communication and understanding of reality and provides creative strategies and solutions [9]. The concept of Art proposed by [5] is a very broad concept that encompasses, in addition to the so-called fine arts, other fields such as language and social sciences. The combination of scientific and artistic disciplines, apparently opposed, provides "the variety and diversity necessary for innovative product design", and they complement each other because "science provides a methodological tool in art and art provides a creative model in the development of science" [10]. The European Parliament [11] considers the inclusion of art essential, as it leads to the acquisition of key competencies. They consider that art in STEAM is primarily concerned with creativity, and creativity includes divergent thinking [12], which leads to multiple solutions for a single problem.

1.1. Active Methodologies

In general, STEAM projects promote the use of so-called active methodologies, encouraging the student's active participation, who becomes the protagonist of the teaching–learning process and develops his/her own knowledge [13]. In [14], the importance of the activities carried out in STEM projects is demonstrated as a fundamental part to enhance attitudes, scientific creativity and motivation, generating positive emotions in learning. Active methodologies place students at the center of this process and make them protagonists of the discovery, rather than passive recipients of information [15]. There are different teaching strategies for creating an active learning environment and engaging students in it. The most common ones are project-based learning, problem-based learning, collaborative learning, etc. [15]. These methodologies allow the development of practical knowledge and critical thinking through formal analysis and creative thinking through empirical analysis and complete active learning.

1.1.1. Project-Based Learning

Project-based learning starts from an initial question or challenge and raises the objective of generating a final product, generating learning through the tasks that are carried out to develop it [13]. If any of these tasks, in addition to being part of the project, pose a new challenge or problem to solve, we will need to overcome these by using techniques taken from another methodology: problem-based learning. Both methodologies, project-based learning and problem-based learning, use the large methodological umbrella of cooperative learning, and therefore for their implementation we need a new organizational structure of the classroom, a different way of managing times and evaluation systems as well as changing the role of teachers and their training. Project-based learning is being used in many educational programs at university level, also including physics subjects, see [16,17].

1.1.2. Challenge-Based Learning

One of these active methodologies is challenge-based learning, which, based on an initial and global question or challenge, sets out the objective of guiding the students' learning to focus them on an achievable and upcoming challenge, which allows them to get personally involved in the search for effective and plausible solutions [13]. Learning is based on a complete process of research, ideation, documentation and communication, also enhancing personal skills such as teamwork, consensus, negotiation and leadership, as key elements of emotional intelligence. Challenge-based learning allows the process to be approached in a creative and innovative way, so that the process allows the detection of other challenges or problems to be solved. It therefore implies a broader vision than project-based learning. Challenge-based learning is being widely researched for its application in a multitude of Bachelors, and also as an integrating argument between mathematics and physics, see for example [18].

2. The EXPLORIA Project, a New Learning Approach for University Students

The implementation of this type of learning techniques, STEAM projects, in which active methodologies such as project-based learning and challenge-based learning are promoted, is a subject of debate among researchers in education, since for it to be successful there must be cooperation between and integration of, at least, professors of engineering, mathematics and sciences and the Institutions' management [19]. It also implies a change in the teachers' attitude since they not only have to make an effort to interconnect subjects, but also become facilitators of knowledge [20].

2.1. Integrating STEAM Projects in Bachelor Degrees

The integration of STEAM projects in bachelor degrees is not easy since there are a wide variety of Bachelor degrees in which this integration is complex or almost difficult. In Bachelors such as law, literature, history, etc., it is very hard to develop these projects. The Bachelors most likely to adapt to this methodology are the engineering ones since scientific principles are used to design and build machines, structures and other entities. We can take advantage of the accumulation of technological knowledge for innovation, invention, development and improvement of techniques and tools to satisfy the needs and solve technical problems of both people and society [21].

The engineer relies on the basic sciences (fundamentally mathematics and physics) to later apply them to his/her field of study (electronics, mechanics, product design, etc.) in which all STEAM areas and active methodologies can be used. However, currently, STEAM areas are treated separately, generating serious consequences in student performance.

2.2. University Students' Attitudes towards Maths

In [22], an in-depth study is carried out on the rejection of mathematics and negative attitudes towards it from primary education to the first year of university studies. The results show a high taste for mathematics in the initial levels, 87%, however, the taste for mathematics decreases as students go up in level, showing a 57% when they reach the first year of university. The results obtained in [22] were later corroborated in [2], which showed that 67% of the students disliked mathematics and they did not fully understand it. On the contrary, only 38% of them showed an interest and liking for this discipline.

Recently, in [23] a study has been carried out on attitudes towards mathematics in university students. We tested 1293 students in the study (830 women and 453 men) from different bachelors, Agri-food Engineering, Biology, Food Science and Technology, Pre-school and Primary Education, IT and Tourism. As a result, the average percentage in attitude obtained was 54% which shows that, in general, men have a more positive attitude towards mathematics, agreeing with other existing studies in this regard, such as in [24,25]. Additionally, in [23], it was found that students in engineering Bachelors showed a better attitude towards mathematics than the rest, agreeing with other studies such as in [26]. These bachelors tend to have a greater number of men than women.

2.3. University Students' Attitudes towards Maths and Their Effect in Physics

The rejection towards mathematics has direct consequences in the rest of the subjects and especially in the other basic subject, physics, since, as indicated in [27], the role of mathematics is to be the language of physics. Thus, the success or failure of students in physics subjects can be predicted taking into account their math skills [28–33]. The research results show that having insufficient skills in mathematics, such as analytical skills, algebraic processing skills, geometry, calculation skills, tables and graph interpretation skills, etc., required to solve physics problems, is the cause of low student performance in physics subjects.

2.4. Basic Subjects vs. Engineering Subjects

In the same way, Math and Physics results predetermine the results of the engineering subjects. Poor performance in mathematics may be the cause of a downward trend in student performance in engineering subjects [34]. In [35], a study is carried out on how it affects the performance of basic subjects (mathematics and physics) related to engineering subjects (Machines, Electrical Engineering, Topography and Building). In this study we did not find a direct relationship between the grades obtained in the basic and specific subjects, but we found a relationship between the years it takes students to pass the basic subjects and the number of years it takes to complete the bachelor. Another important conclusion drawn from the study presented in [35] shows that students do not usually perceive a solid relationship between the basic and applied subjects analyzed in the study.

In this context, STEAM projects applied to the university environment, together with active methodologies such as challenge and project-based learning and collaborative learning can be the way to generate positive emotions in the students who will be able to change their perception and improve their academic performance.

2.5. The EXPLORIA Project

The EXPLORIA project was born from the need to update university learning methodologies to the new trends and requirements of the labor and professional market.

In this sense, the CEU Universities (CEU San Pablo, CEU Cardenal Herrera and CEU Abat Oliva), are developing different pilot projects for bachelor degrees such as Advertising, Political Science, Business Administration, Journalism and Engineering in Industrial Design and Product Development to rethink the learning processes of university students for a context as the current one. Among the pilot projects for bachelors, we have the bachelor of Engineering in Industrial Design and Product Development which integrates subjects that coincide with the STEAM classification.

The EXPLORIA project aims to develop an integrated competency map of the learning process in which the subjects are no longer considered as isolated contents, by elaborating an integrated learning process in which the competencies and learning outcomes of the subjects are considered as a whole, that is, as global and comprehensive learning.

The pilot project makes use of integrated learning and temporal sequences focused on different learning objectives linked to Bloom's taxonomy, see [36]: understanding, applying, experimenting and developing. In this way, through active methodologies, the students address all levels of learning and they "learn by doing". They develop critical and creative thinking, through formal and empirical analysis, and they also develop creativity and innovation, and the capacity for global and multidisciplinary analysis, essential in the current context.

The teacher assumes the role of a learning guide who accompanies students in their personal and professional development process. The teacher leaves the instructor role, encouraging students to discover, motivating them to learn and making them aware of the need to learn from each challenge, stage or new situation that may arise. In this way, the student is prepared to deal with difficult problems in changing, unstable and equally complex contexts.

In the previous work [37], we explain the effect that this methodology may have on the perception and predisposition of students towards mathematics from previous cycles. In this case, mathematics is linked with the rest of the subjects through active methodologies that generate positive stimuli and emotions in the students.

3. Research Objectives

Our research objective is the implementation of STEAM learning in the bachelor of Engineering in industrial design and product development through the EXPLORIA project. In our previous work [37], we showed the efficiency of STEAM learning within the EXPLORIA project to improve learning in mathematics and change students' perceptions. This paper focuses on how STEAM learning can be integrated within the EXPLORIA project to improve the learning of physics, in particular, the part of the syllabus related to mechanical engineering. The proposal is to do it through different projects, challenges and milestones that will allow the student to see the use in the design and development of products.

4. Materials and Methods

4.1. Participants

The participants in the study were the students of the bachelor of Engineering in Industrial Design and Product Development from the academic year 2020/2021 at the University CEU Cardenal Herrera. The number of students included was 24, which was the total number of students registered in the first year of the bachelor, so we did not need to select any participants for the study. Most of the students were from Spain, except for three who came from South America (El Salvador, Colombia and Honduras). The participants' age ranged between 18 and 20 (similarly distributed), except for one of them aged 24.

4.2. Scope of Application

STEAM learning has been planned and applied to the first year in which the following subjects are included, see Table 1.

This article focuses on the second semester when engineering mechanics is taught. The syllabus of the physics extension course is, see Table 2.

Table 1. First-year subjects of bachelor of engineering in design and their classification into STEAM categories (Science, Technology, Engineering, Art, Math).

Semester 1	STEAM Classification	Semester 2	STEAM Classification
Physics	S, T, M	Physics Extension	S, T, M
Maths	M	Maths Extension	M
Art History	A	Anthropology	S
Basic design	A, S, T	Design Extension	A, S, T
Shape representation	A	Descriptive geometry	A, S, T

Table 2. Syllabus of the physics extension subject.

Item	Contents
1	Newton's laws
2	Moment of forces.
3	Kinematics
4	Friction
5	Centroid and center of gravity
6	Free body diagram
7	Equilibrium of a particle
8	Equilibrium of a rigid body

4.3. Tools

An experimental design was carried out through a qualitative analysis following experts in this field [38] in which multiple-question Likert scale questionnaires are reliable [39]. In our experiments, data collection was obtained through an ad hoc questionnaire, following other validated methods found in the scientific literature, such as [38]. There are 21 items in the questionnaire. The first 20 questions follow a Likert-type scale within a range of five points (from 1 = Strongly disagree to 5 = Strongly agree). The last question, item 21, is an open-ended question. The questions are shown below in Table 3.

Table 3. Questions asked in the students' questionnaire.

ID	Question
1	I know what the center of gravity is and how to apply it in product design
2	I know Newton's laws and how to apply them in product design
3	I know what the moment of a force is and how it affects product design
4	I know what friction is and how it affects product design.
5	I know what the free-body diagram is and its usefulness in product design
6	I know what equilibrium equations are and their usefulness in product design
7	I know the usefulness of integral calculus in product design
8	I know the types of traditional wood joints applied in the design of products and their physical restrictions.
9	I understand that the decision to cut a product determines it, both from the physical/functional point of view, as from the aesthetic one.
10	I recognize the aesthetic impact and the added value, in detail, that can determine the choice of any traditional wood joint applied in the product design.
11	The Pringles ring exercise helped me understand how the gravity center of friction works
12	The "Equilibrium challenge" exercise helped me understand how the center of gravity works and is calculated
13	The letter design exercise helped me understand how joints work
14	The letter design exercise helped me understand the usefulness of equilibrium equations
15	The letter design exercise helped me understand the importance of integral calculusl of several variables applied to design.
16	The letter design exercise helped me model mathematically and visualize the triple volume concept
17	The letter design exercise helped me relate the concepts of transversal section and volume
18	The letter design exercise helped me understand the importance of the center of gravity.
19	The letter design exercise helped me understand the importance of the value of detail incorporated into the design.
20	The letter design exercise helped me understand which graphic system/s to use to render them according to the required objective.
21	What do you think about the physics, Pringles ring, Equilibrium challenge and letter design exercises?

5. Design and Implementation of the EXPLORIA Pilot Project

The EXPLORIA project was born from the need to improve university methodologies to solve the deficiencies found in the use of the traditional system. In this sense, CEU University has started different pilot projects in different bachelors, including the bachelor of engineering in industrial design and product development. This bachelor in particular includes subjects easily classifiable according to the STEAM model, see Table 1.

The EXPLORIA project connects the competencies of the different STEAM subjects, in which the standard subjects disappear, designing a learning process as a logical, sequential and incremental itinerary. In this learning process, teachers do not have a fixed weekly schedule, and therefore it is designed based on the learning sequence planned at each moment.

The EXPLORIA project is designed from the concretion and synthesis of the specific and general competencies of each subject included in the curriculum for the bachelor of Engineering in Industrial Design and Product Development. It was considered appropriate to group these skills following a learning process based on Bloom's Taxonomy according to the verbs understand, apply, experiment and develop.

The EXPLORIA project for the 1st year of the bachelor of Engineering in industrial design and product development was designed by the teachers of the subjects included in the first year of the bachelor, and by part of the Faculty's management team, including multidisciplinary profiles of mathematics, engineering, fine arts and designers. The design was based on five concepts derived from the fundamentals of basic design used for the itinerary of this course and these are: shape, volume, color, space and structure. In order to adjust to the academic year of two semesters, we divided the learning itinerary of design fundamentals into two modules. These in turn are divided into three acts as shown:

MODULE I

- Act I: Shape
- Act II: Volume
- Act III: Color

MODULE II

- Act IV: Space
- Act V: Structure
- Act VI: Project

In addition, we decided to introduce a milestone at the end of each Act to strengthen the objective of each of the fundamentals worked on and obtain a global vision of the related competencies. This milestone is a challenge-based methodology in which students, actively and autonomously, and based on a general topic raised by teachers, respond to their own concerns through a challenge. This is formalized and sustained through the application in a project of the skills and learning acquired by the student during the weeks for each act. In this activity, the teacher role is to accompany and guide the student according to the needs required by each phase of the project, being flexible when intervening and adapting to the team requirements depending on their specialization.

Since one of the pillars that sustain the EXPLORIA program is the creation and consolidation of the learning community, it is therefore appropriate to develop the milestone within a team. That is how transversal competencies such as decision-making, communication, critical thinking, etc., are integrated. In addition, the group is changed for each Act, which allows the students to vary their role depending on the idiosyncrasy of the team and obtain different experiences. The project developed based on the challenge is presented by each team to the community (other teams and teachers) and evaluated on the one hand by the teaching staff, who will determine the cohesion of the acquired competencies and the learning results established for the Act through a rubric designed for this activity. The other teams, by using the Post Motorola tool (Questionnaire with 4 questions: What has gone well? What has gone bad? What have I learned? What could improve?), will qualitatively evaluate what items worked, what can be improved and what has been learned, determining a quantitative score based on the responses. Finally, the team itself, based on an attitudinal and aptitude rubric, carries out a self-evaluation and co-evaluation. The weighting of all these results will be the final grade of each student.

6. Physics (Mechanical Engineering) in EXPLORIA

Physics, as a basic subject for the first year of engineering, is part of the EXPLORIA project, which required analyzing the subject role and its connection with the students' learning. Physics is a core element that not only provides the necessary knowledge for the learning of other subjects, but also guarantees the functionality of the students' designs. This article focuses on mechanical engineering, which is particularly important in product design.

The physics sessions can be of two types, sessions of theoretical concepts (master class) and work sessions in the classroom. In any of these, there is a challenge the student must overcome. Four challenges are proposed, two for act IV and two for act V where, through the resolution of the challenge, the student must understand, apply, experiment and develop the concepts of physics, linking them to the contents from other subjects such as mathematics, geometry and design. The milestone makes it possible to evaluate the acquired physics competencies, applied to real problems and designs proposed by the students, who must also establish a link with the other competencies developed in the other subjects.

6.1. Description of Sessions and Timing

The sessions carried out and the subjects included in Act IV and V are shown below (EXPLORIA project module II).

6.1.1. The Transportation Challenge

The challenge involves transporting an object in a LEGO EV3 robot, from an initial to a final position without falling, by using a Bézier curve for the robot's path, see previous work [40]. Students select an object and calculate, through the force moment, the acceleration limit so that the object does not fall. Subsequently, the students design a Bézier curve using an application developed in Geogebra where, by moving the control points, they design the trajectory so that it does not exceed the calculated acceleration limit. Finally, the students test the trajectory generated in the LEGO EV3 robot through an application programmed in Matlab, see [40]. Figure 1 shows the Geogebra application used for the design of the Bézier curve, see Figure 1 (left) as well as photos of the test with the LEGO EV3 robot, Figure 1 (right).

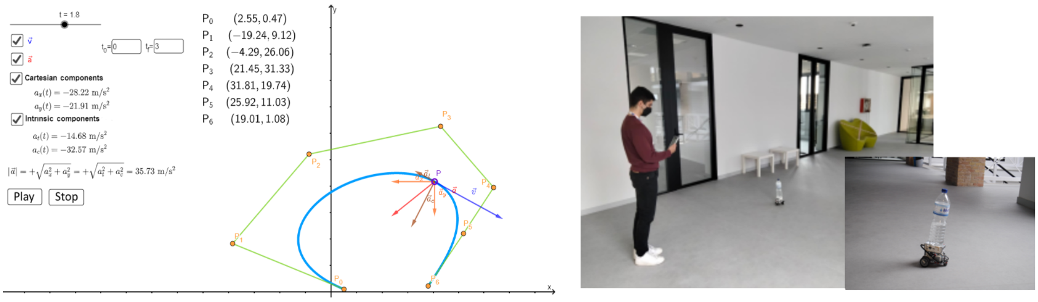


Figure 1. The transport challenge.

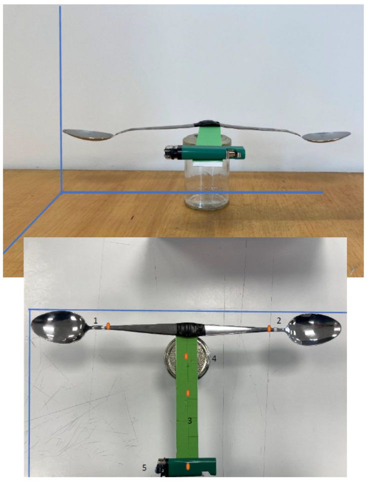
The development of each of the 7 challenge sessions is specified below:

- Session 1. The project begins with a motivational session explaining the problem to be solved from the point of view of mobile robotics, AGVs (Automated Guided Vehicle), AMR (Autonomous Mobile Robot), autonomous robots used to transport materials in industry and society.
- Session 2. A theory session is held in which Newton's 3 laws are explained. Inertial frames of reference are defined and the limitations of Newton's laws are explained.
- Session 3. A math session is held in which students work on the vector and scalar product.
- Session 4. A Physics session is carried out in which the force moment (M = D × F) is explained and a practical exercise is carried out on how to calculate it on a bottle of water.
- A mathematics session is held in which parametric curves, Bézier's curves, Frenet's Diedro, etc., are explained.
- Session 5. A physics session is carried out in which kinematics is explained, the accelerations suffered by a moving object when it follows a curved path and centripetal/centrifugal acceleration. After, all this is linked to the reference frames in which the centrifugal force is a fictitious force found in the non-inertial frames. Here, we explain how to calculate the limit centrifugal acceleration when an object is transported. The ability of parametric curves to approximate any curve, circle or clothoid is also explained, the latter being explained in depth given its mathematical properties and therefore its application in road design and in the generation of mobile robot trajectories [41]. Students select an object and calculate the centripetal acceleration limit. The condition of moment equilibrium and the centroid are indirectly introduced for their calculation.
- Session 6. A mathematics session is carried out in which the developed Geogebra applet is explained and the students design the path the robot will follow, with the centripetal acceleration limit calculated in the previous session, moving the control points of the Bézier curve and simulating it to verify that the restriction of centripetal acceleration limit is met.

- Session 7. A test session of the trajectories designed by the students is carried out in which they verify whether the designed trajectory manages to transport the object to the destination. Otherwise, the students will redesign the trajectory until the selected object is transported to the destination.

6.1.2. The Equilibrium Challenge

The objective of this challenge, inspired by similar tests carried out in architecture [42], is to make a sculpture by using everyday objects we can find at home, such as forks, spoons, knives, shoes, etc., and also diverse rigid objects. By completing this challenge, students will begin to learn about static balance in space and its importance in the design process. Through the exploration of the tangible materiality and the physicality of the objects, the students were implicitly advancing until reaching a series of hierarchical rules for the assignment of the objects in the space in order to achieve the global static balance of the compositions under the effect of the gravity. To finish the test, students must calculate the gravity center of each object, either by coincidence with the centroid or by alignment with the balance point. Once each object has been calculated and weighed, the student must calculate the sculpture's gravity center. Figure 2 shows one of the tests in which Figure 2 (left) shows the composition and position of the gravity centers of each object and Figure 2 (right) shows a table with the measurements of distances and masses, as well as the calculation of the gravity center of the proposed composition.



OBJET	m (g)	X (cm)	Y (cm)	Z (cm)	mX (g/cm)	mY (g/cm)	mZ (g/cm)
1	52	9.7	2.3	9	504.4	119.6	468
2	52	33.5	2.3	9	1742	119.6	468
3	3	21.3	10	9	63.09	30	27
4	178	21.3	4	9	3791.4	712	1602
5	9	21.3	20	9	191.7	180	81
Σ	294				6269.59	1134.2	2646

X → ΣmX / Σm = 21.32 cm

Y → ΣmY / Σm = 3.86 cm

Z → ΣmZ / Σm = 9 cm

Figure 2. The equilibrium challenge.

The development of each of the 2 challenge sessions is specified below:

- Session 1. A physics session is held in which the centroid and gravity center are explained. We explain how to calculate the centroid and gravity center both analytically and experimentally in irregular objects, by finding the equilibrium point. Finally, we explain how to calculate the gravity center of composite objects and tests are carried out.
- Session 2. The students bring objects from home to make the sculpture and firstly they calculate the gravity center of each object and their weight. Later, they make their sculpture in equilibrium, measure it and calculate the composite center of gravity of the composition.

6.1.3. The Pringles Ring Challenge

The objective of this challenge, inspired by the viral challenge with the same name found on the internet, is to let students experiment with the gravity center, friction, and warped surfaces, in particular the hyperbolic paraboloid and its geometric and physical properties. Figure 3 shows the development of one of the exercises by a student. Figure 3 (left) shows the construction at its intermediate point where you can see the importance of the base and how the Pringles chips on the side of the ring are supported thanks to the friction and normal force they exert between them. Figure 3 (right) shows the finished ring.

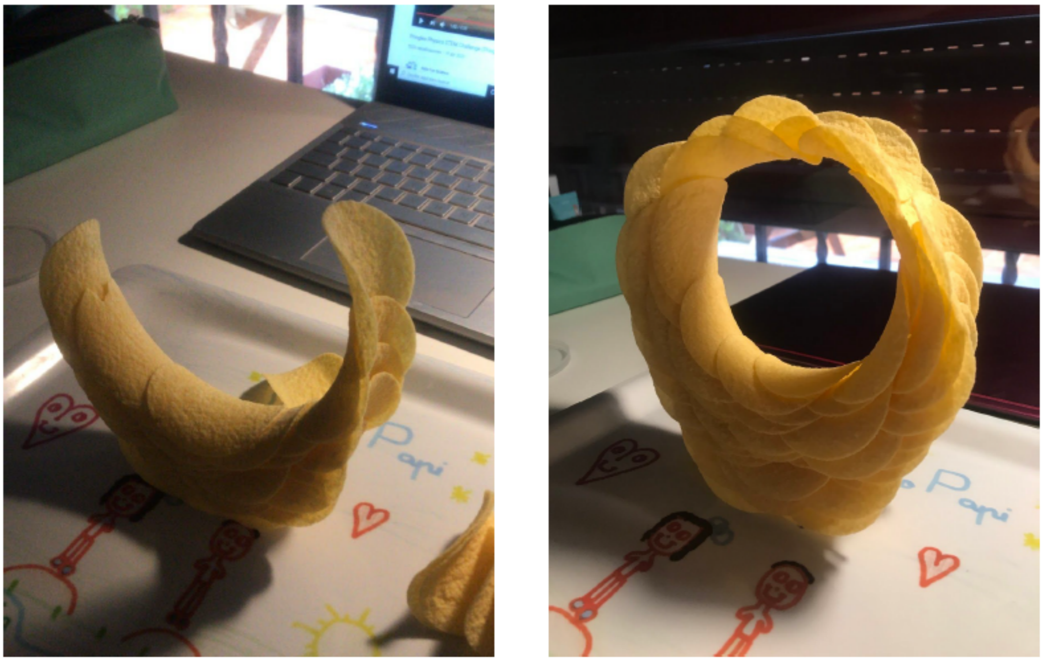


Figure 3. The Pringles challenge.

The development of each of the 3 challenge sessions is specified below:

- Session 1. A descriptive geometry session is carried out explaining the warped surfaces, including the hyperbolic paraboloid, its mathematical formulation and its properties.
- Session 2. The concept of friction is introduced and exercises are carried out in class with different objects using a ramp and throwing different objects over it to demonstrate that the challenge is met.
- Session 3. The students bring at least 2 Pringles cans and the basic concepts are explained to them to be able to carry them out. These include:
    1. Object stacking: we explain to them what happens when objects are stacked, how much space can protrude from an object to another and how it affects the gravity center of composites.
    2. Friction: The side walls of the ring are supported by friction between the Pringles and the normal force they exert on each other.
    3. Gravity center of composites: One of the keys to overcoming the challenge is to generate a good base of the ring and force the gravity center of composites to remain in that area.

6.1.4. The Letters Challenge

The objective of this challenge is to encourage students to design and manufacture the initial letter of their name with 3.2 × 3.2 cm strips by using joints. The present challenge involves reformulating the concept of joints for rigid body mechanics that is usually explained in traditional physics lessons, see for example [43] (Table 5.1, pp. 210–211), and regarding the specific needs of designers who are using wood joints, see for example [44]. Thus, the classic roller, pin or rocker type joints are replaced by "butt", "miter" joints, and a great diversity of wood joints as we can see in [44]. The challenge consists of designing the letter with certain restrictions, which are:

1. The letter must include at least 3 different joints (from an initial list provided by the teachers), in this challenge the use of one of the joints will be mandatory and assigned through a first draw.
2. The letter must be self-supporting, that is, it must be able to stand upright and must be able to be transported, by grabbing it from a higher point and moving it from one point to another without dismounting.
3. The use of glue or any other element to anchor or fix the joints is not allowed.

- Session 1. A basic design extension session is held in which the concept of structure is explained from the design point of view and real objects and sculptures are analyzed.
- Session 2. A physics session is carried out in which the equations of equilibrium and the calculation of the free-body diagram are introduced. The same real objects and sculptures from session 1 are used for analysis from the physical point of view.
- Session 3. Students are proposed to do research and analysis. They must check the websites of famous designers, select a product and obtain:
    1. The free-body diagram of the selected product.
    2. Dimensions and information from their designer.
    3. Proposal for design improvements, both from a physical and design point of view.
- Session 4. Combined session with the Design and Physics teachers in which an elevator pitch is held: a 2-min short presentation in which each student explains his/her results from session 3 to the rest of their peers. This session is used to share the results but also used as an evaluation for the teacher.
- Session 5. Basic design extension session in which the different types of joints used in design are explained, the challenge is defined and the draw for the mandatory joint to be used is carried out for each student.
- Session 6. Physics session in which the equations of equilibrium are explained and their calculation from the free body diagram.
- Sessions 7 and 8. Work session in the combined classroom with design and physics teachers in which students design their letters, calculate their free body diagram and equilibrium equations to guarantee the viability of the challenge.
- Session 9 and 10. Workshop session. The students go to the workshop and mechanize their letters. Figure 4 shows the students working in the workshop.

Figure 4. The letters challenge. Pictures of the building process.

- Session 11. Combined session with the Design and Physics teachers in which an elevator pitch is held: a 2 min short presentation in which each student presents his/her letter design, calculations, manufacturing problems and they perform the self-support test on-site, moving the letter from a table to the center of the classroom. Figure 5 shows the resulting letters placed in a vertical position on a table. In the elevator pitch session, each student takes his/her letter with one hand from a point chosen by him/her and moves it to the central table where the student will explain his/her design and manufacturing process. Figure 6 shows details of some designs in which we can see how the student, in the case of the letter “P”, has used the calculation of the center of gravity to calculate the angle at which the base should be cut in order to keep the P in balance.

Figure 5. The letters challenge. Letters made by students.

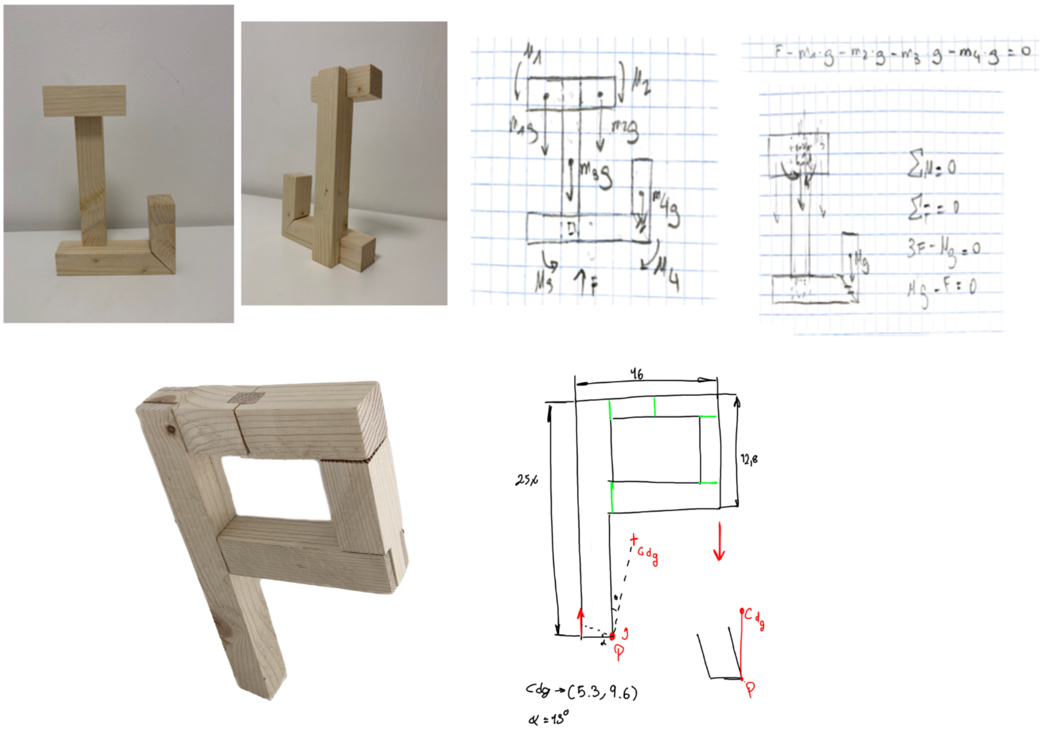


Figure 6. The letters challenge. Examples of results and calculations.

6.1.5. Milestones

At the end of act IV and act V, a Milestone week was carried out. In the Milestone, a topic is proposed on which the students have to provide solutions. In the Milestone of Act IV, the topic Community “Alfara del Patriarca” was proposed, this is the name of the town where the ESET (Technical School of Engineering) of CEU Cardenal Herrera University is located. In this Milestone, the students had to propose design solutions for the inhabitants of the town and the space where they coexist, with the aim of improving common spaces, coexistence, the well-being of the elderly, etc.; and always under the project implementation from the learning and skills obtained in Act IV: Space.

In the Milestone of Act V, Structure, the topic was The Trip, in which the students generated design proposals related to this theme, and in the same way as they did in the previous Milestone, they applied competencies obtained in the previous weeks which were linked, in this case, with the learning outcomes from Act V, Structure. Figure 7 shows one of the resulting works where the students proposed to make a suitcase with drawers. In this case, the students used what they had learned in physics, taking into account the weight limit of the suitcase, the maximum opening of the drawers and the distribution of masses so that in the event that the user had all the drawers open, the suitcase would not overturn, see Figure 7.

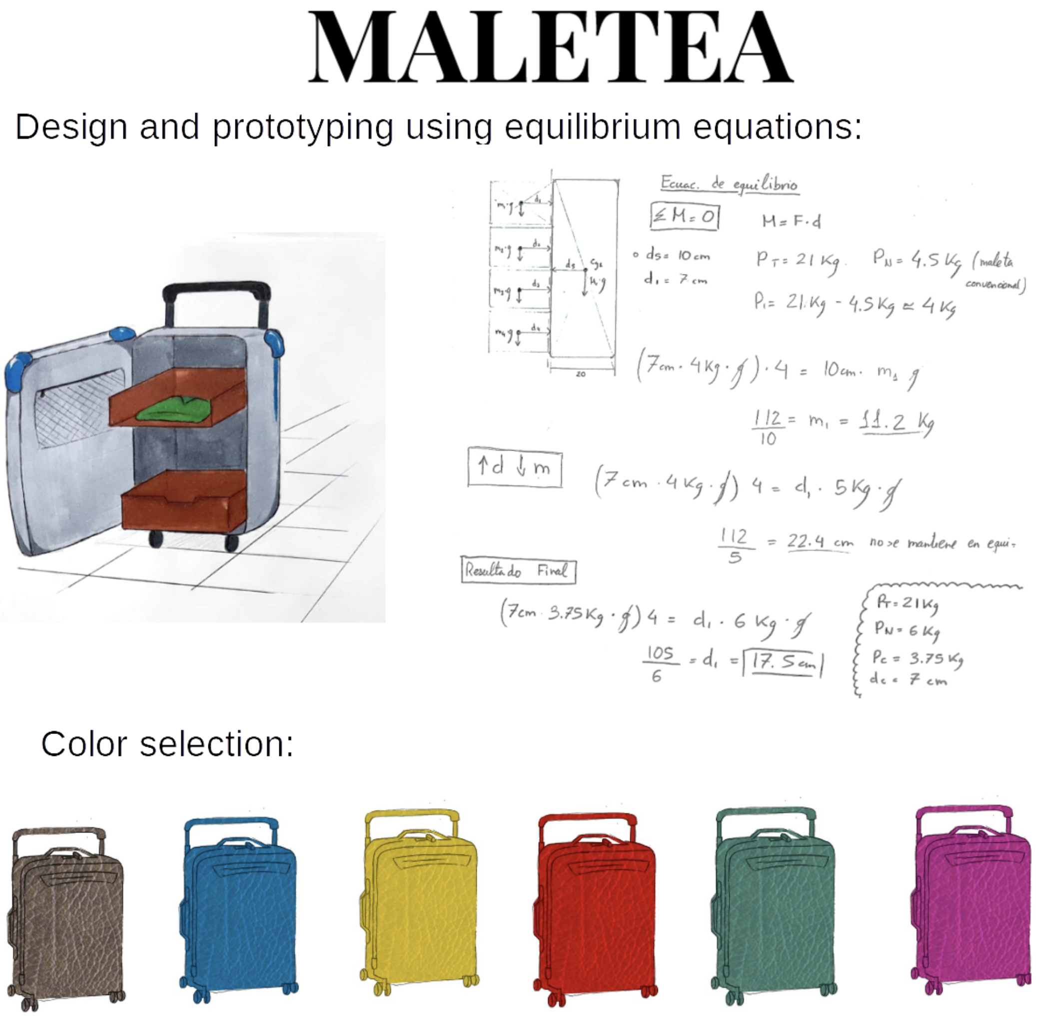


Figure 7. Example of one of the results of Milestone V. The trip.

7. Results

Table 4 shows the answers to the Likert-type questions.

The questionnaire was answered by 95.8% of the enrolled students.

If we focus on the first six questions related to knowledge of physics, in question 1 related to the center of gravity, 100% of the students agree or strongly agree. In question 2, Newton's laws, 91% agree or strongly agree, in question 3, moment of a force, also 91% agree or strongly agree. In question 4, friction, 95% agree or strongly agree. In question 6 related to the free-body diagram, 82.6% agree or strongly agree, and in question 7 related to the equations of equilibrium, 69% agree or strongly agree.

Regarding the usefulness of the challenges for learning physical knowledge, in question 11 related to the challenge of the Pringles ring and in question 12 related to the equilibrium challenge, 82.6% of the students agree or strongly agree, in question 13, understanding how the joints work in the letter, 100% agree or strongly agree and in question 14, the letter exercise and the equilibrium equations, 82.6% agree. Finally, question 18 asks if the exercise of the letter helped them understand the importance of the gravity center, in which 100% of the students agree or strongly agree.

Table 4. Student's questionnaire responses, Likert-type questions.

Question	SD	D	N	A	SA
1	0	0	0	8	15
2	0	0	2	12	9
3	0	0	2	13	8
4	0	0	1	11	11
5	0	0	4	9	10
6	0	0	4	15	4
7	0	2	5	9	7
8	0	0	0	4	19
9	0	0	1	6	16
10	0	0	1	5	16
11	0	1	3	12	7
12	0	0	5	8	10
13	0	0	0	5	18
14	0	0	4	15	4
15	0	0	5	12	5
16	0	0	6	9	8
17	0	0	3	13	7
18	0	0	0	10	13
19	0	0	0	9	14
20	0	0	3	9	11

With regard to learning related to other subjects, in questions 7 and 15, related to the usefulness of integral calculus in product design, 69% and 73%, respectively, agreed or strongly agreed. In question 8, related to knowledge of traditional joints and their physical restrictions, 100% agreed or strongly agreed, and in questions 9 and 20, related to cutting and graphic representation, 95.6% and 86.9%, respectively, agreed or strongly agreed. In questions 10 and 19, related to the aesthetic and added impact of the joints, 95.6% and 100%, respectively, agreed or strongly agreed.

Here are some of the answers given to open question 21:

- "These are exercises that help you understand the syllabus in a very dynamic way. It's a good way to learn theory while putting it into practice".
- "When we carry out this type of projects, we are learning and understanding the lesson explanations".
- "The most interesting exercise is the Pringles ring since with common food you can realize the importance of shape for calculating balance. On the other hand, the balancing exercise was more about calculation of structure. Finally, the letter seems to me a very complete exercise to bring together all the subjects in the same work".
- "When it comes to doing it in a practical way, you learn better".
- "They are examples that perfectly convey the theory taught".
- "They help us to really realize the usefulness of physics in any type of project".
- "I think it was an exercise that allowed us to understand in a practical way how friction and gravity act and how to use these factors to our advantage".
- "These exercises are a very good way to learn, since you understand what you are studying because you can check it at the same time".
- "Very useful exercises, since you can see how to apply physics and mathematics in specific things such as for example the pringles exercise, this helps you see how the content taught in class is reflected in reality and helps you understand the contents much better".

8. Discussion

The EXPLORIA project implemented in the bachelor of Engineering in Industrial Design and Product Development produces a great impact on the learning process. As can be seen in the questionnaire results, the vast majority of students agree or strongly agree that learning all the subjects in an integrated way through challenges and milestones has been very helpful and above all, being participants in the learning process through knowledge discovery.

The feedback given by the students in the questionnaire reinforces the idea that steam-based learning improves the understanding of basic concepts through their implementation in projects and challenges. We can see that a first-year student has not yet received a project subject and therefore he/she will need more knowledge to be able to develop a project, although we think that the students are able to develop their own ideas and put into practice what they have learned so far. So, this is where they are able to apply what they have learned, and their knowledge can be consolidated.

The evaluation of this type of project is an important handicap since, in the end, teachers must assign grade reports for each subject. In this case, in each project or challenge, teachers must independently take the part corresponding to their subject and grade it. The hardest part found by teachers is separating the subject grading from the project applicability or, being able to qualify it as a design project itself. It is important to know how to grade students at the point of learning in which they are. It is not the same grading a first-year student who develops the trip challenge as grading a final-year student. Regarding student evaluation and grades, in our previous work [37], we compared the grades obtained by students in mathematics from the first semester with respect to last year when the improvement was significant, not only in the number of pass grades, but also in the grades obtained. The results of the physics subject are similar compared to those of the previous year: only one of the students failed, and there was an increase in the level of grades obtained. However, this comparison is not included as a result in the paper since the teacher for the year 20/21 was a different one. Understanding the concepts of mathematics and physics applied to projects should solve the problems noted in the research studies by [23,26,27,34,35]. As demonstrated in our previous work [37], the inclusion of this methodology improves students' perception of mathematics by solving the problem indicated in [23,26] and indirectly in the subject of physics, as indicated in [27]. The improvement in physics and mathematics has direct consequences in the rest of the subjects of the same course, and so will have in higher courses, as demonstrated in [34,35].

Regarding the results of the post-test, it can be noted that the proposed challenges help students to understand the concepts of physics, see questions 11–14, 18, and to apply them to design, questions 1–6. As can be seen also in the post-test results, with the questions related to the letter challenge, which involved all the subjects, it has not only served to help in learning the concepts of physics, but also for the rest of the subjects, see questions 15–20. However, although questions 1–20 show how useful the proposed challenges can be, the most important thing is their perception of the activities, see question 21, since, as demonstrated in our previous work [37], the affective domain is key to generate knowledge that is maintained over time and that students do not forget what they have learned. Observing the comments they make, this positive attitude can be denoted with respect to the challenges proposed since they see the physical concepts reflected in the product designs, generating a positive reinforcement that strengthens their learning.

The construction of the learning process could be a problem for the university because a significant effort is required on the part of the teachers since in order to carry out the integration of subjects, a broad knowledge of the rest of the subjects is needed. In this paper, the challenges of the pringles ring exercise and the letter exercise have required the physics teacher to understand ruled surfaces and wood joints. The latter are especially relevant since to achieve an integration of the physical part with the design part, the concept of traditional joints explained in rigid solid mechanics has been adapted to the wood joints used in design.

Another important limitation of the present methodology is that the teachers' schedule is not fixed and is determined by the learning sequence. Additionally, if a student fails a part of the test, it is not easy to pass that part because the whole learning process is intertwined. This could lead to organizational problems for the university.

9. Conclusions and Further Developments

This article shows the design and evaluation of the EXPLORIA project, based on STEAM learning in the bachelor of engineering of product design. The development of an integrated competency map of the learning process, in which the subjects are no longer considered as isolated contents and the elaboration of an integrated learning process in which the competencies and learning outcomes of the subjects are considered as a whole, that is, a global and complete learning, have allowed a comprehensive learning of the basic and specific subjects of the first year, which has offered great advantages. Students can see the application of basic subjects in problems related to their profession which generates positive emotions and reinforces the learning process and the motivation to continue learning.

On the negative side, this integral learning process requires an extra effort from the teaching staff since to be able to achieve perfect integration they need to know the rest of the subjects and we also find problems at organizational level, since the schedules are not fixed but influenced by the learning sequence.

As future works, we intend to implement the EXPLORIA methodology in other bachelors related to STEAM learning, such as Architecture.

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Abbreviations

The following abbreviations are used in this manuscript:

STEM	Science Technology Engineering Mathsi
STEAM	Science Technology Engineering Art Maths
AGV	Automated Guided Vehicle
AMR	Autonomous Mobile Robot
ESET	Technical School of Engineering

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