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The Equilibrium Challenge, a New Way to Teach Engineering Mechanics in Architecture Degrees

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Abstract: Vocation is one of the determining factors taken into account by students when choosing their university studies. However, when the students start their studies, in their first year, they will find a series of basic subjects that barely motivate or stimulate them. In the specific case of mathematics, the problem is aggravated when many of the students already begin the first year showing rejection towards this subject. The lack of motivation for mathematics also affects the subject of physics because "the role of mathematics is to be the language of physics". The EXPLORIA project proposed by the CEU Cardenal Herrera University is a potential solution to this problem. The objective of this project is the implementation of STEAM learning (Science Technology Engineering Art Mathematics) in the Degree in Fundamentals of Architecture at CEU Cardenal Herrera University through the EXPLORIA project. This article focuses on the activities carried out in the subject of physics in the Degree in Fundamentals of Architecture, corresponding to the part of mechanical engineering in order to show that through the realization of different challenges, we can develop creative products, new buildings with their logos and storytelling, as well as connect with the rest of subjects. For its development, students must use everyday objects within their reach, such as forks, spoons, knives, shoes, etc., to build an object or structure that must remain in a "creative balance" and this will serve as an inspiration for new buildings. These new creations are evaluated by an architecture team who fills in a rubric to evaluate the creativity and originality of the products. The number of students included in this project was 24 and the participants' age ranged between 18 and 20 (similarly distributed). At the end of the work, an anonymous ad hoc questionnaire was carried out to show the students' assessment of the new teaching methodology and the challenges developed in the subject of physics.

Keywords: STEAM; active methodologies; equilibrium challenge; challenge based learning; architecture

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Citation: Montés, N.; Hilario, L.; Rivera, J.; López, Á.; Ferrer, T.; Verdejo, P.; Juan, I.; Ábalos, A. The Equilibrium Challenge, a New Way to Teach Engineering Mechanics in Architecture Degrees. *Educ. Sci.* **2023**, *13*, 398. https://doi.org/10.3390/educsci13040398

Academic Editor: Da Yang Tan

Received: 6 February 2023
Revised: 3 March 2023
Accepted: 12 April 2023
Published: 14 April 2023

1. Introduction

As a general rule, one of the determining factors that is taken into account by students when choosing their university studies is vocation. However, when the students start their studies, in their first year they will find a series of basic subjects that barely motivate or stimulate them. The reason is that, in most cases, students do not appreciate the direct application and connection of the general contents with the chosen degree and this generates frustration and demotivation in first-year students.

Among these propaedeutic subjects, which are clearly necessary to develop more complex ones in higher courses, we have physics and mathematics. In the specific case of mathematics, the problem is aggravated when many of the students begin the first year already showing rejection towards this subject [1]. In [2], a study was carried out in which the negative attitude of students towards mathematics from previous courses before starting university was analysed. It was shown that, while primary school students showed a high interest in maths, 87%, this percentage was decreasing as the level increased, reaching 57% when the student entered university. Recently, in [3], a deeper study was carried out in different university degrees, resulting in a 54%, which is very similar to that obtained in [2].

As a consequence, it is evident from the quality evaluation reports of the different Spanish universities [4] that the subjects related to the basic subjects in university studies are ranked among the first places with respect to the number of students who do not pass them, which leads to the increase of apathy and discouragement among students [5].

The student's lack of motivation for these subjects is not limited to the scope of the first year, since failure in the basic subjects also has consequences on the subjects of the higher courses. Although there are no studies that demonstrate the direct relationship, there are other studies, such as in [6], which show the direct relationship between the number of years it takes to finish the career successfully or not in these basic subjects.

In this sense, another of the fundamental basic subjects in technical degree studies is physics, which is also directly related to mathematics since, as defined in [7], "the role of mathematics is to be the language of physics". For this reason, there are studies that are able to predict success or failure in the subject of physics based on how students are dealing with maths [8–13].

This situation gets worse when students start university studies that must necessarily coexist with the acquisition of technical and artistic skills, as it happens for example in the degrees of Engineering in Industrial Design or Fundamentals of Architecture. In these degrees, there is a greater disinterest on the part of the students in the acquisition of knowledge of these subjects, being considered as fundamental for the intellectual development, critical thinking or reasoning of the students.

The search for new teaching methodologies that enable the development of transversality and coexistence between the different areas of knowledge seems to be the right way to solve most of the problems detected. We need to go back in time to find the first experiences that sought to break this classic dynamic. Professor and artist Josef Albers [14] proposed this methodology in his workshops on propaedeutic creativity, which were carried out in the first courses at the Bauhaus (1919–1933) [15]. He named his course Werklehre, (learning by doing), where, in line with his pedagogical philosophy, he understood that students must discover their own solutions by exploring the physical qualities and possibilities of materials. However, from a creative approach, that does not lead directly to any solution, being that the creation of the final product is the student's responsibility. Concepts such as efficiency, effectiveness and economy of means were developed in his workshops; all issues inevitably related to architectural and industrial design.

These types of activities that were carried out almost a century ago are again being reinforced with recent studies on the training of engineers and architects [16], highlighting the need to emphasize the teaching methodologies focused on the student, enhance interdisciplinarity and connect learning with professional reality, issues that even pose a change of roles between the student and teacher with respect to the traditional methodology, thus, teachers adopt the role of advisor and guide of the process [17].

In the 1990s and aligned with these objectives, the STEM methodology (Science, Technology Engineering, Maths) emerged. The idea of this methodology, as indicated in [18], is to educate students in the four specific disciplines: science, technology, engineering and mathematics, 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. Recently, STEM has become STEAM [19], in which A is art. The combination of seemingly opposing scientific and artistic disciplines provides, as indicated in [20], "the variety and diversity necessary for the design of innovative products" and they complement each other because "science provides a methodological tool in art and art provides a creative model in the development of science". In [21] we find that art in STEAM deals mainly with creativity and creativity includes divergent thinking which leads to multiple solutions for a single problem. In the literature, the interventions based on the STEAM educational approach are usually considered as a learning environment used to empower creativity. In [22], a review is presented of the works that relate STEM/STEAM methods and creativity. The researchers support this methodology because it increases the usefulness of the content for daily life, promotes cooperative work and an agreeable classroom atmosphere, makes the teaching–learning process more flexible, develops disciplinary integration and project-based learning and gamifies the teaching–learning process (among others, see [22]). However, the argument in favour of using STEM/STEAM only for promoting creativity is considered an invalid argument due to the difficulty in measuring the creativity related with the STEAM methodologies, ref. [22].

The integration of STEAM projects in pre-university education is a topic of debate among education researchers since it requires the integration of teachers from different areas and subjects, in addition to the collaboration of the school directors [23]. Currently, the curricula of each country are not prepared or designed to integrate these types of methodologies. Recently, curricula analysis methodologies are being proposed in order to implement them, see for example [24,25]. However, they have not been implemented yet in the curricula and teachers have not been trained in their use, nor have they changed their attitude in order to make this integration feasible [26].

In the case of university degrees, the complexity is much greater since they are more specific. There are degrees such as Philosophy, Law, Literature, etc., in which it is very difficult to implement these types of techniques. However, the degrees of Design Engineering or Architecture that have a strong relationship with the creative part and art are the ones most likely to implement this type of methodologies.

The Exploria Project: Previous Works

From the 2019–2020 academic year, a new teaching system (Exploria) was implemented at the Higher Technical School of the CEU-Cardenal Herrera University and whose fundamental objective is to develop teaching methodologies towards STEAM. Its uniqueness lies in the fact that it was proposed in coordination between the university's directive, teaching and management areas, being configured as an approach capable of substantially changing the academic structure without being limited only to teaching methodologies.

The first experience of the Exploria project was carried out in the first course of the Engineering Degree in Industrial Design and Product Development in 2019. Its design was directed by the university professors of the first-year subjects, and by the management team of the Faculty and includes multidisciplinary profiles of mathematics, engineering, fine arts and design. The project makes use of integrated learning and temporal sequences focused on different learning objectives linked to Bloom's taxonomy, see [27]: understanding, application, experimentation and development. The course structure was developed under project-based learning as integrated challenges within the STEAM methodology, in which students organized into groups propose solutions to solve problems for a specific topic in which they must make collaborative use of what they have learned in each subject prior to proposing each challenge.

Although the student's autonomous work is not neglected during the development of each project, we intend to work in teams that change throughout their first-year itinerary, in order to enhance the acquisition of soft skills that emanate from the transversal competencies of the degree, such as decision-making, communication, critical thinking, self-assessment, etc.

In our previous works you can see the results obtained by using this methodology [28,29]. In [28], the effectiveness of integrating various subjects into STEAM learning was demonstrated. This approach led to an improvement in students' interest in mathematics and their understanding of its relevance. Another section of the same project proposed enhancing the learning of physics concepts within the subject by utilizing a similar work scheme based on challenges. In [29], this approach was employed to teach physical concepts within mechanical engineering by using various practical tasks. This evidenced that the use of physics concepts outside their typical context and their integration with other subjects in the course represents a significant improvement in student learning.

2. Purpose of This Article

After the results obtained in the implementation of the new teaching system [28,29], the objective of this article is to demonstrate how, within the framework of the Exploria project in Architecture studies, the content learned in propaedeutic subjects, such as mathematics or physics in degrees that combine the need for technical knowledge with creative skills, can even trigger creative processes and therefore become factors of inspiration and idealization of an architectural project. To do this, the concept of equilibrium challenge proposed in [30] was developed, by adapting it to the subject of physics and to interactions with other subjects. This article describes the development of various equilibrium challenges with the aim of continuing to utilize this model. The challenges involved experimenting with the physical concepts learned and applying different learning outcomes from other subjects such as mathematics, introduction to architecture, drawing, or history of art. As a result, STEAM projects centered around equilibrium challenges were successfully developed.

3. Materials and Methods

3.1. Participants

The participants in the empirical qualitative study, case study method [31] were the students of the Degree in Fundamentals of Architecture from the academic year 2021/2022 at the University CEU-Cardenal Herrera. The number of students included was 24, which was exactly the total number of students registered in the first year of the degree, so we did not need to select any new participants for the study. As this is an international degree, the group was very heterogeneous, from different origins such as Moldova, India, Ukraine, Costa Rica and Spain. The participants' age ranged between 18 and 20 (similarly distributed).

3.2. Scope of Application

STEAM learning has been planned and applied to the first year in which the following subjects are included, see Table 1. All subjects have 6 ECTS (60 h of face-to-face teaching).

Table 1. First-year subjects of Degree in architecture and their classification into STEAM categories (Science, Technology, Engineering, Art, Maths).

Semester 1	STEAM Classification	Semester 2	STEAM Classification
Physics	S,T,M	Physics II	S,T,M
Maths	M	Maths II	M
History of Art I	A	Introduction to Architecture	A
Architectural drawing I	A	Architectural drawing II	A
Descriptive geometry I	A,S,T	Descriptive geometry II	A,S,T

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

Table 2. Syllabus of the physics subject

Item	Contents
1	Newton's laws
2	Moment of forces.
3	Friction
4	Centroid and centre of gravity
5	Free body diagram
6	Equilibrium of a particle
7	Equilibrium of a rigid body
8	Moment of inertia for areas
9	Shear force and bending moment
10	Euler-Bernoulli bending theory

3.3. Method

An empirical qualitative study, (a study carried out under the epistemological view of subjectivism or empirical works conducted from the participants perspective) [31] is proposed in this paper. The design was carried out through multiple-question Likert scale questionnaires. In our empirical qualitative study, data collection was obtained through an ad hoc questionnaire. There are 11 items in the questionnaire.

Eight questions follow a Likert-type scale within a range of five points (from 1 = Strongly disagree to 5 = Strongly agree), there are two Yes/No questions and the last question, item 11, is an open-ended question. The questions are shown below in Table 3.

Table 3. Questions asked in the students' questionnaire. (The LandMark project is explained in Section 4).

ID	Question
1	In the previous year, did you study mathematics?
2	What was your perception of mathematics before the course?
3	With this methodology, you have been able to connect mathematics with physics and architecture.
4	In the previous year, did you study Physics?
5	What was your perception of Physics before the course?
6	With this methodology, you have been able to connect physics with mathematics and architecture.
7	The Landmark project has stimulated my learning process in mathematics.
8	The Landmark project has stimulated my learning process in Physics.
9	Activities like the "Equilibrium Challenge" have changed my motivation through the learning process of physics.
10	This way of learning architecture through concepts and synergies between courses is good and should be used again next year.
11	What is your opinion about the Equilibrium Challenge that you applied in physics during the first semester?

4. Basic Structure of the EXPLORIA Pilot Project in the Degree in Architecture

The main structure of the Exploria project has been based on the experience carried out in the Degree of Engineering in Industrial Design and Product Development, given the good results obtained, see [28,29], adapting it to the conditions and singularities of the architectural studies. As in the previous project, the design of the structure has been carried out in a collaborative manner between the teachers involved in the first-year subjects and the University management, under a multidisciplinary framework composed not only mainly of architects, but also engineers, mathematicians, physicists and art specialists.

By way of synthesis, the learning model based on the hierarchy of Bloom's taxonomy was continued, establishing that in the first course of architecture this model would be limited to the levels of knowing, understanding, analysing and communicating the basic concepts that are part of the architectural fact. During the first year of architecture, it was established that students need a series of tools and previous basic knowledge before starting to create a project. In subsequent years, the complexity towards higher-order cognitive processes will be increased.

Once the level of knowledge to be acquired by the students in their first year was established, the itinerary of the academic year was proposed in a consensual way under six concepts, distributed between the two semesters of the first year. The six concepts were divided into two different blocks that, in some way, summarized the teaching of Architecture and served as inspiration for first-year students: Art + Technology. The first block, under the guiding thread of Art, was structured under the concepts of space (as the first abstract concept defining architecture), beauty and form. The second block, more focused on specificity, concreteness and rigor, was ordered under the concepts of technique, place and use.

These concepts represent a basic sample of architecture and are able to link and relate the contents of each subject of the year, distributed as follows:

Semester I—Art

- Concept I: Space
- Concept II: Beauty
- Concept III: Form

Semester II—Technique

- Concept IV: Technique
- Concept V: Place
- Concept VI: Use

In addition to the common work of the subjects structured under the six concepts, these serve as a basis to propose the development of a project or challenge that is called "Landmark". During the landmark project, the students analyse a building or an architectonical element and, in this analysis, the students need to bring some learning outcomes from all courses to understand the connection between all of them as it is carried out in a STEAM project. At the same time, students work transversal competences of the degree, such as decision-making, communication, critical thinking, autonomous work, etc. Some landmarks are developed by teams and some others are developed individually. The teacher's team will consider how important it is to develop the transversal skill of working as a team and also how a student can take some decisions.

In general, the landmark activity lasts one week and students will submit their work the last day of the week. During the submission day, an oral presentation is given in which they present the storytelling created by the team or student in order to explain the building through all learning outcomes connected to the story.

The landmark is evaluated from different points of view:

- The teacher's team grades their work
- Each student evaluates himself or herself and also each member of the team, which is called auto and co-evaluation
- All classmates grade each team too, which is called post-motorola

All this information is given to each team in a feedback session where the idea is that students receive as much information as they need to grow in their process of being architects. The feedback session is really important because it is organized to give them the option of reaching their right answer. Students develop the skill of listening and respecting their classmates' criteria. The idea is to find out how they grow from their work and from their classmates' work.

5. Physics (Mechanical Engineering) in EXPLORIA

The subject of physics I in architecture, and, in particular, the part related to mechanical engineering, is a key element in architecture studies since it establishes the basic concepts that an architect needs to master in order to design structures in subjects of higher courses.

The sessions of the subject of physics I are divided into two types: theoretical sessions and work sessions in the classroom where the final stage is the equilibrium challenge proposed in this article.

The subject is structured around the three concepts of the first semester following the general approach of Exploria, which proposes the realization of a challenge in each concept, except for the third concept where two challenges are carried out.

5.1. Equilibrium Challenge Fundaments.

The fundamental basis of the Equilibrium challenge is inspired by Albers' experimentation workshops at the Bauhaus (and his intention to verify and test the possibilities of physical concepts (particularly tensile and compressive strength) in a creative way on materials [14]. In doing so, they did not always create "works of art", but what was significant was the process of experimentation that the students developed in order to understand the concepts. The different workshops of Equilibrium challenge try to follow this model, experimenting materially with the physical concepts learned, but approaching them from an active attitude and a creative vision, with the intention that the process of experimentation allows the students, not only to verify the application and the importance of the physical concepts in the creative process, but also to work on the concept of intuition of the material behaviour, a clearly significant skill in the formation of the architect, ref. [30].

During the development of the challenges, the student must understand, apply, experiment and develop the concepts of physics, at the same time using contents of other first-year subjects, such as equations and integrals of mathematics, technical drawing or descriptive geometry. The singular thing about the activity is that it is developed based on architectural references supported by the subject of Introduction to architecture I, which allows the student to relate the abstract physical concepts with built buildings.

The sessions are carried out to develop the workshops of the equilibrium challenges and the subjects included in Concepts I, II and III are shown below.

5.1.1. The Pringles Equilibrium Challenge

The theme of this challenge is inspired by the viral challenge with the same name that can be easily found online: the "Pringles ring", an autonomous ring-shaped structure made entirely of the classic potato crisps. This equilibrium challenge allows students to experiment with the physical concepts of centre of gravity, friction, warped surfaces, in particular the hyperbolic paraboloid and its geometric and physical properties. The whole workshop begins with the verification of how vector geometry is able to become an inspiring source to make a building, using as an emblematic example in this part, the works of experimentation and construction by the Spanish architect Antonio Gaudí, see Figure 1.

Figure 1. Catenary arches used by Gaudí (1852–1926), (**Left**). Museum of Casa Mila (**Centre**), La Pedrera building (**Right**), Barcelona (Spain).

In addition to physics, the subjects involved are mathematics and descriptive geometry with the warped ruled surfaces including the hyperbolic paraboloid, in which its geometry and properties are related to mathematical parametrization. This is important for future architects because in addition to allowing them to experiment with their geometry and physical behaviour, this allows them to understand how forces act in the process of building a structure, given that sometimes these structures behave differently when they have already been built and are stable. In this particular case, if during the construction phase both parts are not balanced, the structure will fall. The scheduled sessions of the different subjects for this challenge are as follows:

- Session 1. Maths session in which the students are told about vectors, vector and scalar product.
- Session 2. Physics session in which they are introduced to the concept of moment of a force and shown how to calculate it.
- Session 3. Mathematics session in which we talk about Gaudí and the Holy Family where we can find different geometries introduced by Gaudí.
- Session 4. Physics session in which we talk about Gaudí and the Holy Family. We talk about the importance of the shape of the arches, the lateral reinforcements, the friction columns and the double helix columns that Gaudí introduced. The physical properties of ruled surfaces are also discussed.
- Session 5. In the descriptive geometry session, we explain the warped ruled surfaces, including the hyperbolic paraboloid, its mathematical and physical properties.
- Session 6. The concept of friction is introduced in a physics session in which a master class is combined with tests carried out in the classroom. A ramp is used and different objects are dropped on it.
- Session 7. Students must buy Pringles cans and they are explained the purpose of the test. They must observe and report how the concepts of friction, centre of gravity and moment work in the construction of rings. In addition, they must report the construction process, the failures they have had and why the structure has fallen.

5.1.2. The Equilibrium Challenge

The objective of this challenge is inspired by the one developed in [30] for the subject of structures that is studied in the second year. For its development, students must use everyday objects within their reach, such as forks, spoons, knives, shoes, etc. . . to build an object or structure that must remain in a “creative balance”. The physical concept that is intended to be evidenced is the importance of controlling the centre of gravity of a construction to avoid becoming unbalanced. It is based on the existence of buildings where architects play with the concept of balance or “visual imbalance” to make them unique, although in fact they are constructions based on their good physical and structural resolution, see Figure 2.

Figure 2. Examples of buildings where the concept of balance is defining their architecture: (**Left**) Bałtyk Building (Poland), Puerta de Europa, Madrid (Johnson and Burgee) (**Centre**), Habitat 67, Candada (J. Brittain) (**Right**).

To solve the challenge, students must calculate the centre of gravity of the structure, as well as the equilibrium equations that govern it and keep it in balance without falling. The subjects that integrate the activity in addition to physics are mathematics for the resolution of equilibrium equations, and descriptive geometry to help draw the simplified structure.

The development of the challenge is specified below:

- Session 1. A physics master session that explains how to calculate the centre of gravity and centroid, both analytically and experimentally. The session continues by explaining how to calculate the centre of gravity of a structure composed of different objects.
- Session 2. A master class in physics explaining Newton's 3 Laws. Upon completion of the master lesson, students go out to the streets and select 4 applications of Newton's laws in architecture, take a photo, and explain how laws work in that particular situation.
- Session 3. A master lesson in physics that explains the concepts of a free-body diagram and the equilibrium equations for a rigid body. After the conclusion, the students go out to the street and select 4 applications of the equilibrium equations in architecture. They take a photo, draw the free-body diagram and calculate the equilibrium equations in that particular application.
- Session 4. This physics session begins with the correction of the exercises from session 3 and the resolution of doubts by the students. After finishing this session, the "equilibrium challenge" exercise is introduced. Each student must choose 10 objects from their home, weigh them and calculate the centre of gravity of each of them. This task should be completed at home and brought in for the next session.
- Session 5. "The training". In this session, students can practice the equilibrium challenge exercise that will be performed in session 6. They choose 5 objects out of 10, put them in balance and calculate the following on that construction:
  - Gravity centre of the structure
  - Free body diagram
  - Balance equations
  - Calculation of the forces and reactions that appear in the joints of the structure

  Students ask questions and the necessary reinforcement is carried out in those concepts that are not clear. Students can work as a team or individually.
- Session 6. "The Challenge". In this case, the exercise is individual and evaluable to pass the subject. The challenge is carried out with 5 objects out of the 10 brought by each student. The student selects 3 out of the 10 initial objects and the teacher selects 2 out of the remaining 7. The student must repeat the equilibrium challenge exercise again. Figure 3 shows several students performing the exercise and its proposed structure.

5.1.3. The Bending Equilibrium Challenge

The challenge posed aims to highlight the concepts of physics that will then be necessary for the development of the subject of structures that is studied in the second year. For its realization, everyday objects will be used again with the intention of modelling one of the fundamental parts of an architectural structure: the beam. The objective is to deepen and physically check the concept of bending and its effects when a beam is subjected to loads. To do this, students must calculate the moment of inertia by areas of the object that is used as a beam, the stress the areas withstand at maximum bending moment, as well as the shear force and bending moment diagrams. The concept of how a beam works is fundamental for the training of the architect, since most types of structures in their different materials use the concept of frame for their idealization, basically composed of columns and beams. To relate the challenge with architectural concepts and creativity, we show architectural projects in which the structure is a singular and visible part that configures the project, see Figure 4.

Figure 3. Students developing "The equilibrium challenge".

Figure 4. Examples of buildings whose structure can be seen: (**left**) Building Cruz del Sur, Chile (architects Izquierdo and Lehmann, (**middle**) Centre Pompidou, Paris (architects. R. Piano, R. Rogers), (**right**) Aspen Art Museum, USA (S. Ban).

The development of the challenge is specified below:

- Session 1. A maths master session in which the integral of the moment is explained. It explains how the first moment integral when using the mass of an object corresponds to the centre of mass and when using the area corresponds to the centroid. Parallelism is also made with data analysis in which the first moment integral corresponds to the mean. The student understands that the centre of mass/centroid is like the average of the masses or areas. The second moment integral is explained and, here, we find also two variants, using the masses and the areas. A parallelism is made with the data analysis in which the second moment integral corresponds to the variance. The student understands that the second moment integral for masses and areas is a value that indicates how mass and area are distributed from the mean or centroid value.
- Session 2. Master lesson in physics in which the differences between the second moment for areas and for masses are explained since in physics, both are expressed with the letter I, but they mean very different things depending on their application. First, the application of the second moment for masses is explained, using the classic example of dropping cylinders on a ramp, see (https://www.youtube.com/watch?v=lvfzdibrUFA, accessed on 11 April 2023). Next, the second moment for areas is

explained and its implication on the bending of objects. Concepts such as medial axis, compression, extension, etc. are introduced in this session.

- Session 3. Master lesson in physics in which calculation exercises of the second moment are carried out for areas of sections composed of simple geometries. Students go out to the streets and select four applications to calculate the moment of inertia according to areas.
- Session 4. This physics session introduces the concept of shear force and bending moment diagrams and explains how to calculate them through the following video (https://www.youtube.com/watch?v=C-FEVzI8oe8, accessed on 11 April 2023), in which the simple case of two loads distributed on a beam is analysed. The concept of bending stress is also introduced and how to calculate it through the Euler-Bernoulli bending theory. At the end of this session, the "bending equilibrium challenge" exercise is introduced. Each student must choose ten plus two objects from their home. Of the objects, four of them will be used as beams in the challenge, six of them will be used as loads and the other two will be used as columns. The students must weigh the objects, calculate the centre of gravity of each of them and the objects used as beams, and calculate their moment of inertia by areas. This task should be completed at home and brought in for the next session.
- Session 5. "The training". In this session, students can practice the "bending equilibrium challenge" exercise that will be performed in session six. Of the ten plus two objects, they select the two objects used as columns, one object that will be used as a beam and two objects that will be used as loads. They will make them balance, so the object that is used as a beam will be resting on the columns and the two loads will be on the beam. On the construction, they will calculate the following:
  - Gravity centre of the structure
  - Free body diagram
  - Balance equations
  - Calculation of the forces and reactions shown in the joints of the structure
  - Shear force and bending moment diagrams
  - Stress at the most critical point

  During the session, students can ask questions and the necessary reinforcement will be carried out on those concepts that are not clear. Students can work as a team or individually.
- Session 6. "The Challenge". In this case, the exercise must be individual and evaluable to pass the subject. The challenge is carried out with the objects that each student brings. Apart from the objects used as columns, the teacher will select the object that will be used as a beam and one of the objects that will be used as a load. The student will select the other object that will be used as a load. The student must repeat the "bending equilibrium challenge" exercise again. Figure 5 shows several students performing the exercise and its proposed structure.

Figure 5. Students developing the bending equilibrium challenge.

5.1.4. The "Last" Equilibrium Challenge

The last challenge is carried out following the dynamics of the previous ones by using everyday objects for the construction of a structure, but in this case, it aims to put into practice all the knowledge acquired in the subjects of physics, architectural drawing, descriptive geometry and introduction to architecture.

From the area of introduction to architecture, they have to put into practice their search skills for architectural references with characteristics similar to those in the exercise (and in turn linked to case studies seen in the subject) and also exercised the way of communicating and explaining these skills in a coherent and orderly way, both graphically and orally. As a complement, from the subjects of Architectural Drawing and Descriptive Geometry, students participate by practicing and working with the skills of representation of the object in balance; choosing the representation system, the projections of the object in proportion, the expressiveness of the drawing, the selected technique, etc.

For its development, first of all, students must search for buildings that include in their design and the use of basic and unique geometries as a generating element of their design; see, for example, the buildings in Figure 6. Subsequently, they will select two examples they find most interesting in order to extract and schematically redraw the principles of their design.

Once this first phase of search for information and synthesis has been carried out, students must be inspired by the concepts analysed in order to propose a building design, but using everyday objects for its construction in which creativity and the physical concepts of balance already experienced in previous challenges will prevail. The level of the students' creativity is evaluated according to the creativity of the product, ref. [32]. This fact is evaluated by architects filling in a rubric with different items, evaluating the creativity and originality of the logo, the storytelling and the building proposed.

Figure 6. Examples of buildings whose original idea could involve the use of an equilibrium challenge, Oscar Niemeyer International Cultural Centre (Spain), Niterói Contemporary Art Museum, Brazil (Oscar Niemeyer).

Finally, students must draw their building, give it a name, design a logo and generate the storytelling of their project, to finally record a video in which they present the designed building and its main qualities. As it is a more complex and elaborate challenge, students will have two weeks to develop it.

The tasks to be performed in this challenge are the following:

- Build your equilibrium challenge
- Draw your building
- Name your building, design its logo and generate the storytelling of your building
- Record a video showing the designed building

This challenge will be carried out on Christmas holidays and therefore, students have two weeks to design their building. Figures 7–9 show three examples of the students' proposals.

Figure 7. The Hanging Garden Conservatory.

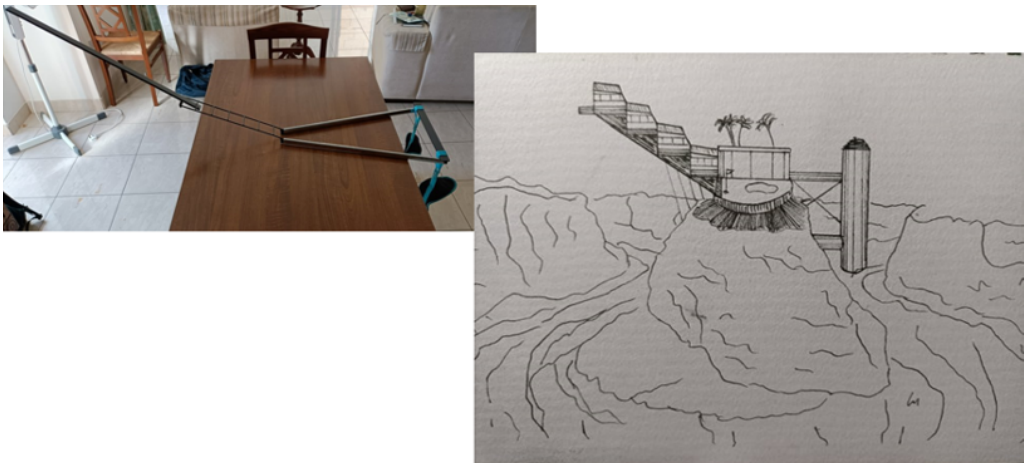

Figure 8. HorseHoe Bend Resort.

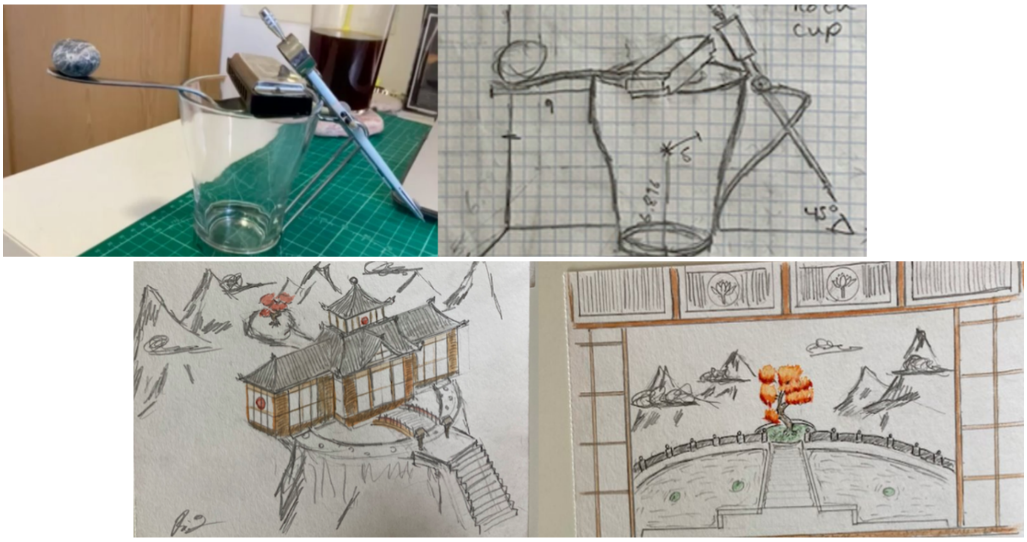

Figure 9. Thenjou.

6. Results

Table 4 shows the answers to the Likert-type questions and Table 5, the answers to Yes-No questions.

Table 4. Students' questionnaire responses, Likert-type questions. (Strongly Disagree (SD), Disagree (D), Neither agree nor disagree (N), Agree (A), Strongly Agree (SA))

Question	SD	D	N	A	SA
2	1	2	7	7	3
3	0	1	5	10	4
5	2	3	8	7	0
6	0	1	3	12	4
7	0	2	4	11	2
8	0	2	2	12	3
9	0	1	8	7	3
10	0	1	4	11	4

Table 5. Students' questionnaire responses, Yes-No questions

Question	Yes	No
1	18	2
4	16	6

The questionnaire was answered by 87.5% of the enrolled students.

If we focus on the mathematics questions at the beginning of the course, 90% of students had studied mathematics in the previous course and their perception of mathematics was not entirely positive. A total of 35% of students showed a neutral attitude and 35% of them were positive. The rest of the students were divided between a negative or very positive perception, 15% each.

If we focus on the questions related to physics at the beginning of the course, there were 20% of students who had not studied physics in the pre-university phases, and in which 40% of students showed a neutral attitude or perception of physics, 35% showed a positive attitude and 25% a negative one.

Regarding the question of whether with this methodology they had managed to connect the subject of mathematics with physics and architecture, 80% considered that they did manage to connect the subject of physics with mathematics and architecture.

Regarding questions related to the landmark, 65% of students considered that it had been useful in stimulating their learning of mathematics while 75% considered that it had been useful in stimulating their learning of the subject of physics.

As for the question of whether students would recommend this learning methodology, 75% consider it to be a good methodology for higher courses.

Regarding the specific question about the activity of the equilibrium challenge and whether this activity had changed their perception of physics, 75% agreed or strongly agreed while 20% showed a neutral position. Only 5% disagreed. In response to the open question about their opinion on the activities related to the equilibrium challenges, these were some of the answers:

- *"I actually loved experimenting on my own and discovering different structures by myself"*
- *"Well, I think it is a great way to study physics. The only thing I would change is maybe the analysis of some examples in complex buildings"*
- *"It was a good way to test students without it being an actual test"*
- *"Fun"*
- *"Many activities done outside the classroom helped in understanding the concept"*
- *"Really interesting and really easy to understand the concept"*
- *"It was a great challenge and fun to work with"*
- *"I liked analysing the structure that we make ourselves"*
- *"It is a good practical example in order to understand general concepts when you don't know them"*

7. Discussion

The EXPLORIA project implemented in the first year of the architecture degree has caused a great methodological impact when it comes to addressing the subjects and knowledge, both for teachers and students. This break with the traditional way of teaching lessons, by encouraging learning based on experimentation and application of content instead of memorizing it, has been a real achievement to encourage active student participation in their learning [33], as seen in Table 4. Being able to connect the content studied in physics and mathematics with architecture in their first year of the degree (80%), has already been a success due to this new methodology. Moreover, active learning based on the STEAM methodology promotes a positive attitude towards learning [34], and consequently, greater motivation towards the subjects of physics (75%) and mathematics (65%). In addition, the research carried out both individually and in groups in the projects developed by the students will encourage the creative process in architecture and their capacity for observation [35], thus verifying that the STEAM format allows students to benefit from the integration of technical and artistic aspects in order to encourage creative solutions [36,37], which is evidenced in the products developed from the equilibrium challenge. However, as commented in [22], creativity is difficult to measure and the relationship between the STEAM methodology and the creative process has not been scientifically evidenced yet. In this article, we have examined the perceptual aspect of creativity by asking whether creative individuals are more likely to perceive recognizable forms (buildings) in ambiguous stimuli (objects in equilibrium), a phenomenon known as pareidolia, see [38]. However, although the student's perception is positive (75%) regarding the use of this teaching methodology by the student, it must necessarily be adjusted after its first year of implementation. It is necessary to reconsider and optimize the time and resources of teachers and professors, taking into account the feedback from the students, in which, as seen in Table 4, there is no total success in the complete integration of the basic subjects with the specific ones in an environment linked to architecture (20%), or that this methodology has stimulated them in the study of basic subjects.

As a general evaluation, during the new learning experience carried out in the first year of Exploria, we have been able to contrast the hypothesis that the learning based on the STEAM pedagogical model helps to understand basic concepts through its implementation with problems of the real world, thus being able to increase the competence in project-based work and the motivation for student learning [39] and also verifying as a contrasted result the integration of the contents of the different subjects for the resolution of projects.

8. Conclusions and Further Developments

This article shows the design and evaluation of the EXPLORIA project, based on STEAM learning for the Degree in Fundamentals of Architecture. In this project, the subjects are no longer considered as isolated from one another, but, instead, we are trying to generate an integrated learning process in which the competences and learning results of the subjects are considered as a whole. In this paper, we have shown how through different variants of the equilibrium challenge, the different learnings of the subjects of drawing, fundamentals of architecture and mathematics can be integrated with the learning of a part of the curriculum of the subject of physics. The equilibrium challenge also has the peculiarity of enhancing intuition and creativity in future architects, something very relevant for the development of their profession.

The results obtained show the effectiveness of the methodology and how students perceive these exercises, as a fun way of learning through experimentation, distancing themselves from the traditional methodology, not only in class dynamics, but in the way of evaluating the subject.

In future works, we intend to extend the equilibrium challenge to higher courses, in particular to the subject of structures, as originally defined in [30], giving continuity to these exercises within the EXPLORIA project.

Author Contributions: Conceptualization, I.J. and A.Á.; Methodology, N.M., L.H., J.R., Á.L., T.F., P.V., I.J. and A.Á.; Validation, N.M., T.F. and P.V.; Investigation, N.M., L.H., J.R., Á.L., T.F., P.V. and A.Á.; Resources, I.J. and A.Á.; Writing—original draft, N.M., L.H. and P.V.; Writing—review & editing, N.M. and J.R.; Supervision, L.H. and I.J.; Project administration, L.H. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Institutional Review Board Statement: The study did not require ethical approval. All the students agreed to be part of the study, all participants were fully informed that their anonymity is assured, why the research is being conducted, how their data will be used and that there are no risks associated with the exercises proposed in the paper.

Informed Consent Statement: Informed consent was obtained from all subjects involved in the study.

Data Availability Statement: Not applicable.

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

Abbreviations

The following abbreviations are used in this manuscript:

STEM	Science Technology Engineering Maths
STEAM	Science Technology Engineering Art Maths
ESET	Technical School of Engineering

References

1. Minte, A.; Sepúlveda, A.; Díaz-Levicoy, D.; Payahuala, H. Aprender matemática: Dificultades desde la perspectiva de los estudiantes de Educación Básica y Media. *Espacios* **2020**, *41*, 30.3
2. Hidalgo, S.; Maroto, A.; Palacios, A. ¿ Por qué se rechazan las matemáticas? Análisis evolutivo y multivariante de actitudes relevantes hacia las matemáticas. *Rev. Educ.* **2004**, *334*, 75–95.
3. Pedrosa, C. Actitudes Hacia Las matemáTicas en Estudiantes Universitarios. Ph.D. Thesis, Universidad de Cordoba, Cordoba, Spain, 2020.
4. Ministerio de Ciencia, Innovación y Universidades. *Datos y Cifras del Sistema Universitario Español Publicación 2019–2020*; Ministerio de Ciencia, Innovación y Universidades: Madrid, Spain, 2020.
5. Martin, A. Dime qué carrera estudias y te diré cuántas asignaturas suspenderás. *El español*, 30 December 2016.
6. Perdigones, A.; Gallego, E.; Garcia, N.; Fernandez, P.; Perez, E.; del Cerro, J. Physics and Mathematics in the Engineering Curriculum: Correlation with Applied Subjects. *Int. J. Eng. Educ.* **2014**, *30*, 1509–1521.
7. Ataide, A.R.P.D.; Greca, I.M. Epistemic views of the relationship between physics and mathematics: Its influence on the approach of undergraduate students to problem solving. *Sci. Educ.* **2013**, *22*, 1405–1421. [CrossRef]
8. Bishof, G.; Zwolfer,A.; Rubesas, D. Correlation between engineering students' performance in mathematics and academic success. In Proceedings of the 2015 ASEE Anual Conference & Exposition Seattle, Seattle, WA, USA, 14–17 June 2015.
9. Adebisi, A.; Olanrewaju, O. Mathematics Skills as Predictors of Physics Students' Performance in Senior Secondary Schools. *Int. J. Sci. Res.* **2013**, *2*, 391–394.
10. Kamal, N.; Rahman, N.N.S.A.; Husain, H.; Nopiah,Z.M. The Correlation Between Electrical Engineering Course Performance and Mathematics and Prerequisite Course Achievement. *Soc. Sci. Humanit.* **2016**, *24*, 97–110.
11. Rossdy, M.; Michael, R.; Janteng, J.; Andrew, S.A. The Role of Physics and Mathematics in Influencing Science Students' Performance. In *Proceedings of the Second International Conference on the Future of ASEAN (ICoFA) 2017-Volume 1: Business and Social Sciences*; Springer: Singapore, 2017; Volume 1, pp. 399–406.
12. Ojonugwa, T.; Umaru, R.; Sujaru, K.O.; Ajah, A.O. Investigation of the Role of Mathematics on Students'Performance in Physics. *J. Res. Educ. Sci. Technol.* **2020**, *5*, 101–108.
13. Pospiech, G. Framework of Mathematization in Physics from a Teaching Perspective. In *Mathematics in Physics Education*; Springer: Cham, Switzerland, 2019; pp. 1–33.
14. Albers, J. Creative Education. In *The Bauhaus*; Wingler, H., Ed.; MIT Press: Cambridge, MA, USA, 1969; Volume 142.
15. Fiedler, F. *Bauhaus*; Ullmann Publishing: Potsdam, Germany, 2013.
16. UCL Center for Engineering Education. *Innovations in Engineering Education. Inspiring and Preparing Our Engineers for the 21st Century*; UCL Center for Engineering Education and Lloyd's Register Foundation: London, UK, 2017 .
17. Blank, W. *Authentic Instruction. Promising Practices for Connecting High School to the Real World*; Blank, W.E., Harwell, S., Eds.; University of South Florida: Tampa, FL, USA, 1997; pp. 15–21.
18. Irwanto, I.; Saputro, A.D.; Widiyanti; Ramadhan, M.F.; Lukman, I.R. Research Trends in STEM Education from 2011 to 2020: A Systematic Review of Publications in Selected Journals. *Int. J. Interact. Mob. Technol.* **2022**, *16*, 19–32. [CrossRef]
19. Yakman, G.; Lee, Y. Exploring the exemplary STEAM education in the U.S. as a practical educational framework for Korea. *J. Korea Assoc. Sci. Educ.* **2012**, *32*, 1072–1086. [CrossRef]
20. Kim, E.; Kim, S.-H.; Nam, D.-S.; Lee, T. Development of STEAM program Math centered for Middle School Students. *Des. Technol. Educ. Int. J.* **2012**. Available online: https://www.semanticscholar.org/paper/Development-of-STEAM-program-Math-centered-for-Kim-Kim/7a48fe7e5d58c7303175853dc7cb1032cec3a3f0 (accessed on 11 April 2023).
21. Sousa, D.A.; Pilecki, T. *From STEAM to STEAM: Using Brain-Compatible Strategies to Integrate the Arts*; Corwin: Thousand Oaks, CA, USA, 2013.
22. Aguilera, D.; Ortiz-Revilla, J. STEM vs. STEAM Education and Student Creativity: A Systematic Literature Review. *Educ. Sci.* **2022**, *11*, 331. [CrossRef]
23. Mills, J.E.; Treagust, D. Engineering education—Is problem-based or project-based learning the answer. *Australas. J. Eng. Educ.* **2003**, *3*, 2–16.
24. Sumiyoshi, T.; Matsui, G. *Wood Joints in Classical Japanese Architecture*; Kajima Institute: Chofu, Japan, 1991.
25. Ruiz-Vicente, F.; Zapatera, A.; Montes, N. *Como Extraer áreas de Oportunidad Para Diseñar Proyectos STEAM a Partir del Curriculum de Bachillerato*; Mc Graw Hill: New York, NY, USA, 2022.

26. Pospiech, G.; Eylon, B.S.; Bagno, E.; Lehavi, Y. Role of Teachers as Facilitators of the Interplay Physics and Mathematics. *Math. Phys. Educ.* **2019**, *12*, 269–291.
27. Jose, J. An Exploration of the Effective Use of Bloom's Taxonomy in Teaching and Learning. *Int. Conf. Bus. Inf. (ICBI)* **2021**, *1*, 100.
28. Romero, P.D.; Montés, N.; Barquero, S.; Aloy, P.; Ferrer,T.; Granell, M.; Millán, M. EXPLORIA, a new way to teach maths at university level as part of everything. *Mathematics* **2021**, *9*, 1082. [CrossRef]
29. Montés, N.; Aloy, P.; Ferrer, T.; Romero, P.D.; Barquero, S.; Carbonell, A.M. EXPLORIA, STEAM Education at University Level as a New Way to Teach Engineering Mechanics in an Integrated Learning Process. *Appl. Sci.* **2022**, *12*, 5105. [CrossRef]
30. Vrontissi, M.; Castellón, J.J.; D'Acunto, P.; Monzó, L.E.; Schwartz, J. Constructing equilibrium: A methodological approach to teach structural design in architecture. In Proceedings of the IV International Conference on Structural Engineering Education, Madrid, Spain, 20–22 June 2018; pp. 1–10.
31. Montero, I.; León, O.G. A guide for naming research studies in Psychology. *Int. J. Clin. Health Psychol.* **2007**, *7*, 847–862.
32. Altan, E.B.; Tan, S. Concepts of creativity in design based learning in STEM education. *Int. J. Technol. Des. Educ.* **2020**, *31*, 503–529. [CrossRef]
33. Salemi, M.K. An illustrated case for active learning. *South. Econ. J.* **2002**, *68*, 721–731.
34. Smith, K.A. From small groups to learning communities: Energizing large classes. In Proceedings of the 30th Annual Frontiers in Education Conference. Building on A Century of Progress in Engineering Education. Conference Proceedings (IEEE Cat. No.00CH37135), Kansas City, MO, USA, 18–21 October 2000.
35. Alba Dorado, M.I. Architecture and creativity. Reflections on the creative process of the architectural project. *Arquitetura Rev.* **2016**, *12*, 125–139.
36. Henriksen, D. Full STEAM ahead: Creativity in excellent STEM teaching practices. *STEAM J.* **2014**, *1*, 15. [CrossRef]
37. Conradty, C.; Bogner, F.X. STEAM teaching professional development works: Effects on students' creativity and motivation. *Smart Learn. Environ.* **2020**, *7*, 26. [CrossRef]
38. Bellemare, A.; Harel, Y.; O'Byrne, J.; Mageau, G.; Dietrich, A.; Jerbi, K. Processing visual ambiguity in fractal patterns: Pareidolia as a sign of creativity. *iScience* **2022**, *25*, 105103. [CrossRef]
39. Lin, C.L.; Tsai, C.Y. The effect of a pedagogical STEAM model on students' project competence and learning motivation. *J. Sci. Educ. Technol.* **2021**, *30*, 112–120. [CrossRef]