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¡EUREKA! DESIGN OF FLOATING LUMINARIES ON WATER: A LEARNING CHALLENGE IN ENGINEERING

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ABSTRACT
The learning space in the 21st Century cannot be limited to a closed space like the classroom. It is important to push the limits of creativity and innovation in the mind of the apprentice. Mixing dissimilar topics, awakening intrinsic motivation, and following a design methodology are the keys to achieve efficient learning. Challenge based learning is an integrative pedagogical approach that combines experience, cognition and behaviour. This approach takes advantage of students' interest in finding practical meaning to education, while developing key skills competencies in a world mediated by rapid technological advance and sustainability. In this paper, a pedagogical strategy is exposed to impact first-year students in the application of a design methodology and the development of competencies in graphic expression, manufacturing, critical thinking. These skills were obtained from the challenge of designing, materializing, and testing a floating luminaire that works from solar energy. These prototypes were manufactured with sustainable materials and processes, considering as an aesthetic/formal referent the work of Ernst Haeckel and as a physical principle, Archimedes' law to achieve buoyancy and stability on the water. The outcome of this learning experience was 56 luminaries that enlightened and floated over the water mirror of the cultural centre of the EAFIT University, the library Luis Echavarría Villegas.

Keywords: Learning challenges, sustainability, solar energy, creativity, luminaire, buoyancy

1 INTRODUCTION
Learning by doing has proven to be an efficient education strategy especially in disciplines related to engineering and design. Active learning is the center of the pedagogical model of Universidad EAFIT [1], the different methodologies that comprise it consider the student at the center of the training process and seek to strengthen applied knowledge without abandoning the importance of theoretical knowledge and reflection on the consequences of doing. Students become protagonists of their own learning process and teachers in the role of counsellors and boosters of the process. Experiential learning, as part of active learning, is an educational approach that seeks to challenge and learn by doing [2]. These types of projects are particularly useful for the development of skills such as critical thinking, autonomy, self-esteem, empathy, collaboration, and reasoning in search of pragmatic solutions. Project 2 is a first-year course, whose pedagogical objective is metacognition, how is it designed when you design? The course is focused on solving challenges around furniture and proposes two exercises, the first is aimed at the student developing a luminaire. This challenge proposes to combine different topics of study such as solar energy, Archimedes' law, and the inspiration around the work of Ernst Haeckel, so that the student summarizes it in a functional prototype integrating the theme of sustainability in six weeks. This challenge introduces the student to the use of alternative energies to design and confronts him with solving engineering problems that may be demanded in subsequent semesters. It also exercises he/she in the use of methodologies and tools to design that are fundamental in design and engineering education. Universidad EAFIT, with its motto - inspire, create, and transform - permeates its entire pedagogical model and in this course, this philosophy is responded to promote responsible innovation in the apprentice. This work shows the process of how students designed and manufactured 56 floating solar luminaires, which were exhibited to the university community as an example of experiential learning.

2 METHODOLOGIES

A five-step methodology was used, which was implemented for 6 weeks. See Figure 1. Its purpose was to develop a functional prototype of a floating luminaire activated by solar energy. In addition, it sought to develop competencies in students on concepts of firmness, utility, beauty, and sustainability [3]. It was also important to promote work in their processes of self-reflection and critical thinking.

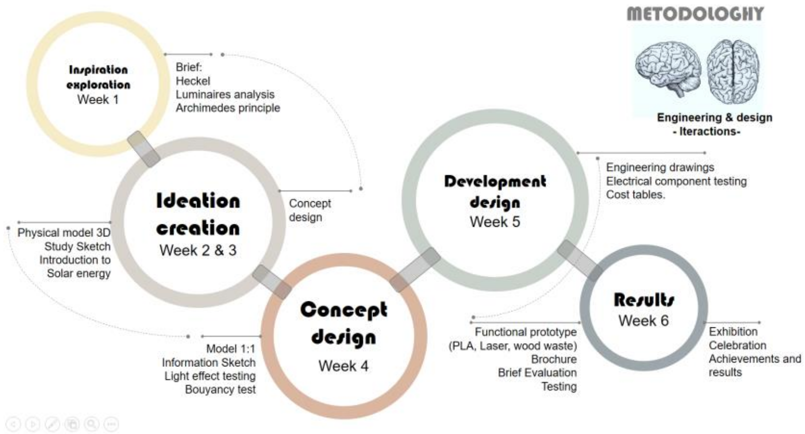

Figure 1. Design Methodology

2.1 Inspiration/exploration

The teachers presented the brief, the luminaire had to be based on the work of Ernst Haeckel, float, and rest on a flat surface, and generate a warm light for the home from solar energy. It began with the presentation of Ernst Haeckel's work "art forms in nature" developed between 1899 and 1904, as an element of formal inspiration [4]. The categories of study to investigate and make a formal exploration by the students were: Thalamophora, Diatomea, Desmidiea, Echinoidea, Acantharea, Spumellaria, Prosobranchias, Teleostéos, Ascidias. Parallel to Haeckel's exercise, they had to understand the operation of 2 luminaries, through the observation and drawing of its components. One luminaire was assigned by the teachers from a design website and the other they were able to choose the model from one physically available at a store or their homes. This stage ended with two activities within the classroom. The first one was the explanation of Arquines's law, and how to use it to calculate the buoyancy force and water line, the appropriate materials selection, and the way to protect the electric circuit. The second one consisted of showing a basic circuit assembled, their components and the range of dimensions available to start generating their design ideas.

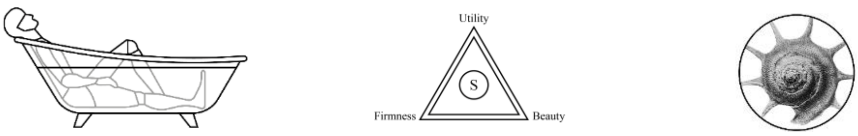

Figure 2. Subjects of inspiration stage: a) Arquimedes law, b) Vitruvio c) Haeckel

2.2 Ideation/creation

Through sketches, students had to present the formal exploration of their proposals from Haeckel's categories. Each had to explore the three dimensions, symmetry, proportion, and views of the concept on different planes. In addition, he had to ask himself: how to make a floating structure that can be a luminaire from the figure explored? How can Archimedes' law be applied to this structure? What materials could work in water? If you need to locate a solar cell, an LED, a transformer, and a switch; how would they be protected from the water? Subsequently, the team of teachers chose a concept for each student, which due to its geometry and aesthetics best suited the established requirements. After choosing the concept, the goal was to delve into the technical aspects of solar energy and the environmental benefit of using renewable energy sources [5]. The operation and calculation of the efficiency of a solar panel and the calculation of the type of battery required for the luminaire to operate for a certain time were explained. In the end, to materialize the ideas, the students had to make three study models in 1:6 scale with their respective sketches. In the following week, the most viable was chosen according to these requirements: cell size, location of the components, and formal reference.

2.3 Concept design

The student presented a 1:1 scale model and a sketch of the luminaire of the selected design concept; He tested some materials, created visual effects using a light source, experimented with the location of components, and did buoyancy tests based on Archimedes' principle [6]. For this test, the waterline of the study model was calculated by following steps as illustrated in Figure 3:

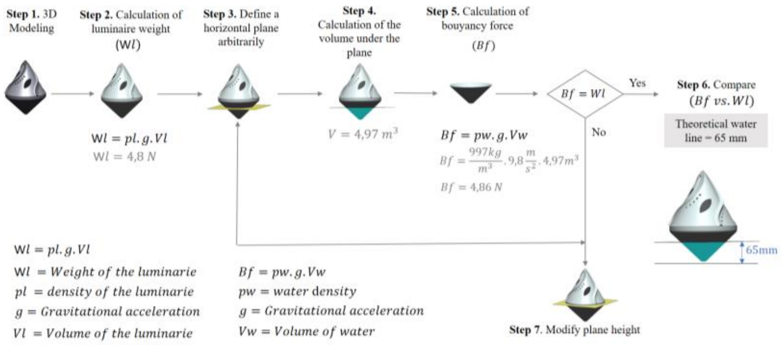

Figure 3. Calculation of buoyancy line

At this stage, students were advised to look for symmetrical shapes, volumes wider than tall, and low-density materials such as balsa, 3D printed parts with low fill density, and thermoformed polystyrene parts. From this exercise, it was possible to make changes of materials and distribution of weights of the components to avoid overturning and achieve better buoyancy.

2.4 Development and detail design

Once the design concept was selected, for each luminaire the circuit was defined according to the model and the studio sketch, to be able to define details for its construction. The corrections made considered aspects such as the scale, size and proportion of the luminaires, the internal circuit and its location, the type of LED and battery to be used and the elements and parts that could be simplified from the design to optimize manufacturing and flotation. A 1:1 scale drawing of the assembled luminaire was required, with section views to illustrate the location of components such as LED, solar cell, controller, battery, switch, and wiring to facilitate construction and assembly of parts.

2.5 Manufacturing, testing and evaluation

Finally, each student defined the electrical components, materials and assembly strategies that would allow them to build their concept in one week, based on the technical drawings, the information sketch, and the 3D sketch. Construction processes included 3D printing, laser cutting, thermoforming, plastic moulding with industrial dryer, plastic welding, and woodworking techniques such as cutting, sanding, carving, serial plane assembly and waterproofing. Once the prototypes were manufactured, they were evaluated under the aspects demanded in the brief. At this stage, slenderness corrections, switching to lighter materials and relocation of components were made. Also, the intensity of the light, its effects and the battery life were evaluated. In this way, some designs were modified and optimized. For the final exhibition, each student prepared a digital brochure with the product name and image in the space, name of the designer, materials used and design process. The catalogues were published on the **Issuu** platform. Those attending the exhibition were able to access the brochure through a QR code that each student had stuck on their shirt. The luminaries were exhibited in the water mirror of the university's cultural center in a celebration with live music and as an achievement of being able to show the results to the university community.

3 RESULTS

In this challenge-based learning project, 56 floating solar luminaires made of sustainable materials and processes were obtained, the results are described below.

3.1 Inspiration/exploration

The brief and Archimedes' law were analysed, two existing lamps were observed, and their components drawn. Also, within Haeckel's categories they selected one and studied its definition, shape, characteristics, and structures to generate a formal exploration and think about manufacturing materials. In the case of the Acqua project, the student selected the category of Prosobranquias, from the gastropod family.

3.2 Ideation/creation

The students selected from the previous stage three figures that were then drawn with volume and materialized with scale models to specify their shape. The exercise proposed the creation of a three-dimensional sketch through the exploration of a linear material [7], a planar material and a material that could be moulded. In this case, the apprentice used materials such as wire, paper and clay. See Figure 4. Care was taken to define shapes that could displace enough volume of water to favour buoyancy and house the solar cell. Model a) in clay was chosen for its symmetry, size, and the feasibility of locating the solar cell and circuit at the base.

Figure 4. Formal exploration, 1:2 scale models of the Acqua project in clay, wire, and paper

3.3 Concept design

To clarify the location of the circuit components, verify the buoyancy of the structure and manufacturing strategies of the final prototype, the students made a study sketch and a 1:1 scale model. Figure 5 illustrates the proposal for the Acqua luminaire.

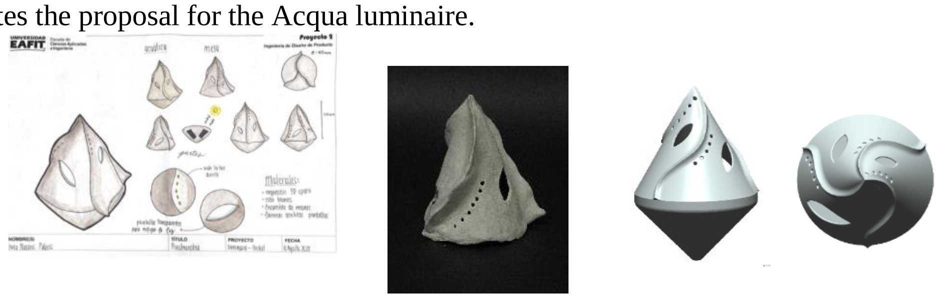

Figure 5. Study sketching and 1:1 scale clay model and modeling. Acqua Project

3.4 Development and detail design

The students developed a sketch with the following information: assembled luminaire with the graphic representation of the real materials, exploded drawing and a technical drawing detailing the location of the electrical components and their assembly, see Figure 6.

Some students generated a technical drawing from a 3D modeling in CAD software, as in the case of Aqua, while others carried it out manually on graph paper. Some students built their prototype modelled in clay, wood or air-dry modeling clay and then digitized it using a 3D scanner. In this way, they were able to export their creations to CAD software and generate a technical drawing.

3.5 Waterline calculation

Most students calculated the waterline from the three-dimensional modeling of their luminaires following the scheme proposed in Figure 3. In the case of Acqua, the total weight was 4.8 N and the volume of water displaced was 4.97 m^3. The water line was 65 mm from the lowest part of the luminaire. The 3D modeling can be seen in Figure 5.

3.6 Manufacturing, testing and evaluation

Once all the technical, formal and construction aspects had been reviewed, the students began manufacturing of their luminaires. Some were fabricated using 3D printing, wood carving, laser cutting and thermoforming. In the case of Acqua, 3D printing was used. Figure 6 shows the entire assembly and the buoyancy test.

Figure 6. Acqua information sketch and model in use,3D printing manufacturing and testing

Each luminaire was evaluated, the most relevant recommendations were related to shape, performance, and buoyancy. In some projects it was necessary to replace the materials with lighter ones, relocate and reduce the height of some parts to lower the center of mass to improve stability and buoyancy and avoid an overturning.

3.7 Exhibition and celebration

"The light is On XIV," is an academic cultural and artistic event conceived for the exhibition of the luminaries to the academic community, family, and friends. It is a presentation that takes place every six months since 2016 as part of the course Project 2. For this edition, the floating luminaries were exhibited in the water mirror of the library Luis Echavarría Villegas University Cultural Center. The students wore a QR code on their t-shirt with the link to the catalogue of each creation published in Issuu. Some of the achievements and results can be seen in Figure 7.

Figure 7. Exhibition at the Library Luis Echavarría Villegas Cultural Centre

4 CONCLUSIONS AND DISCUSSIONS

From **experiential learning** [8], the student was able to make a continuous cycle of reflection, conceptualization, application of knowledge and experimentation to verify the specifications of the design challenge. The exercise of the luminaire confronted him to learn, to be reflective, recursive and to work synergistically with engineering and design tools. It is an exercise to awaken your intrinsic motivation and prepare you for new challenges in topics such as solar energy [9], sustainability, and formalization. They also learned about the importance of following a design process and methodology in complex projects. In the **inspiration and exploration** phase, the exercise combined engineering, design, and art for concept development. Designing with a formal reference when learning to design facilitated the work of creation. Likewise, understanding how a solar circuit and a floating structure works and combining these concepts with the microorganisms that Haeckel researched, made the exercise innovative and stimulating for students' creativity. In the **Ideation and creation** phase, according to Rowena Reed: "all three-dimensional projects must be designed three-dimensionally, you can't design a good three-dimensional design on paper. You must deal with negative space, and you cannot do that in two dimensions". In this exercise, the exploration of three types of materials for the fabrication of the three-dimensional sketches from line, plane and volume was particularly important, it helped the student to find the material that made it easier for him to express the shape of his idea [10]. We consider this practice to be efficient and should be replicated in 3D object design exercises in the ideation and creation stage. In the **design**

concept stage, students had to integrate the parts. The three-dimensional sketch served to make a more precise drawing of the concept, clarify the idea, and then materialize it. The shape of the luminaire had to integrate the electronic components and promote buoyancy from an appropriate water volume displacement. In the **development and detail design** stage, modeling the luminaires using software allowed the waterline to be calculated more quickly, due to the ability to perform iterations using the computer. In addition, having a digital model allowed them to build many parts of their prototypes using 3D printing. The luminaires that were fabricated manually incurred slower iteration processes to find the waterline. In these cases, it was necessary to make changes directly on the physical prototype and test them in the water. Additionally, more time was invested in the fabrication of the models. The manufacturing stage demanded different skills such as modeling, drawing, using measuring instruments and assembling electronic components. On many occasions, the exercise required knowledge that was obtained outside the classroom with the support of the technicians and teachers. In the **testing and evaluation** phase, the tall structures, and the use of materials such as high-density wood caused some luminaires to sag or tip over. To improve the performance of some luminaires, it was necessary to use lighter materials, reduce the height of some structures, redistribute components, and change manufacturing methods. In addition, it was necessary to eliminate unnecessary parts and assemblies. Finally, regarding sustainability, the solar panels worked properly, and all the lamps had an autonomy of approximately two hours. It was important to promote in the students the importance of the use of renewable energies to integrate them in future projects and to make the students aware of the use of recycled or recyclable materials, to use the minimum of finishes and to avoid the project being discarded at the end of the exercise.

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