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Integrative project in engineering education for the design and manufacturing of a solar tracker prototype as a mean to learn and develop soft skills

Proyecto integrador en ingeniería para el diseño y fabricación de un prototipo de seguidor solar como medio de aprendizaje y desarrollo de habilidades blandas

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Abstract
The given research aims to inform about Integrative Projects at University context and its respective impact on the learning of soft skills in education. For this purpose, it has been proposed a solar tracker design that can take advantage of the energy in a more efficient way. Design (CAD) and programming software were used as static analysis and material choice also did. Results given were both positive in the learning field an in the construction and functionality of the prototype.
Keywords: Solar panel, educational integrative project, energy, soft skills

Resumen
La investigación dada tiene como objetivo informar sobre proyectos integrativos en el contexto universitario y su respectivo impacto en el aprendizaje de habilidades blandas en la educación. Para este propósito, se ha propuesto un diseño de seguidor solar que puede aprovechar la energía de una manera más eficiente. El diseño (CAD) y el software de programación se utilizaron como herramientas de análisis estático y para la selección del material. Los resultados obtenidos fueron positivos tanto en el campo de aprendizaje como en la construcción y funcionalidad del prototipo.
Palabras clave: Panel solar, proyecto educativo integrador, energía, habilidades blandas

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1. Introducción

Nowadays, Higher Educational Institutions (HEI) are in search of new ways to inspire their students in the acquisition of new knowledge and competencies. Among the most plausible proposals, the Integrative Project Learning Method is presented. This method comments to be a theoretical-methodological approach that allows, through a specialized and investigative research support, to guarantee the scientific scope with the exclusive intention to generate knowledge which enriches solely from the experience that the student acquires during its development (Moreno, 2019).

In this context, Medina Nicolalde, et al. (2017) agree with the statement discussed previously. However, their point of view goes hand in hand with the statement of a didactic-methodological approach where both the teacher's performance and students relate with the formative structure, where new learning strategies can be implemented.

This new method has not only begun to be put into practice in Ecuadorian Educational Institutions but in many other countries. Colombia, as an example, has also used this strategy since 2007, as (Hewitt Ramirez, 2007) claims, this investigative exercise tends to be developed by the students at the end of the semester. During that period, they must to apply all their knowledge learned to solve the problem proposed according to their academic level.

During the development of such projects, a very essential factor can be found implicitly: the learning and development of soft skills. Without them, there is any project could be made correctly. According to Reyes (2020), they can be defined as the soft skills are "skills that have to do with the integrated implementation of aptitudes, personality traits, knowledge and acquired values". (Ortega Santos, 2017) indicates that such skills require a high level of experience in order to form them correctly and the only way to achieve it is by practicing and relating with teammates. Integrative Projects help to amplify knowledge beyond the inside classrooms as students acquire their own judgment while working in the design and construction of their prototype takes place.

Following the information given by Gorrochategui, (2016) and Ingoos, (2017), to improve soft skills some steps need to be taken:

- Getting out of the comfort zone: Helps to know oneself.
- Establish a clear objective: The first big step in which creativity, communication, critical thinking, leadership, etc. are involved.
- Dividing and overcoming: Skills need to be prioritized, and then an extra step needs to be made
- Search for experts and knowledge sources
- Be patient: Developing and improving such skills take time
- Practice

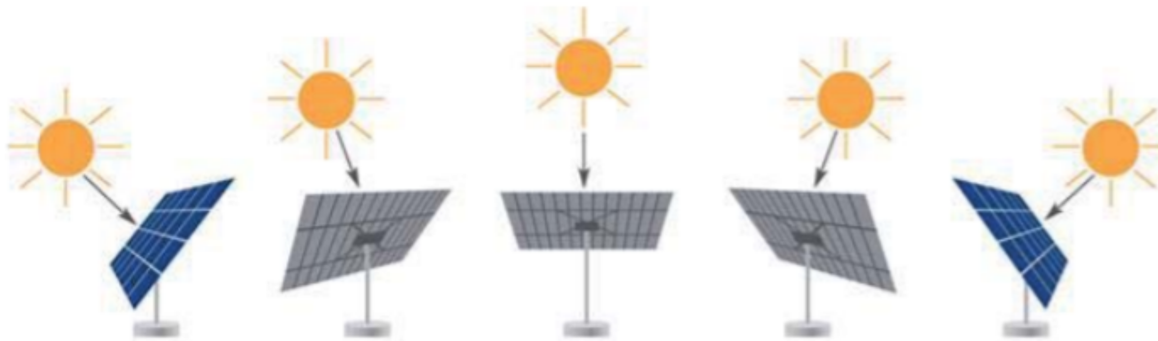
During the process of development of Integrative Projects all these steps are put into practice. This was mainly done as a method of Integrative Learning through the application of soft skills which will be mentioned later Integrative Projects allows the development of practical and group skills which allows the development of a series of skills that cannot be developed in a personal way (Llanes et al. 2018; Moreno et al. 2019).

Their application will be introduced below concerning the assigned research topic that consists in the design and manufacturing of a Solar Tracker:

1.1. The Project: Design and Manufacturing of Solar Trackers

One of the best-known methods for the use of solar energy is the implementation of photovoltaic cells to generate electricity from solar radiation since it represents a clean way of obtaining electricity as it does not generate waste or emissions and practically the source of energy is inexhaustible (Escobar Mejía, Holguín Londoño, & Osorio, 2010). By placing the panels directly in the direction of solar rays, they can capture maximum radiation and thus take better advantage of sunlight throughout the day (see *Fig. 1*) (Romero, 2015).

Figure 1
Tracking of solar rays. (Bermal, 2016)



Implementing the correct technology to achieve this task will allow the design to be more efficient and, considering that it must be economically accessible to be able to implement it in different cities of Ecuador (Gaona et al. 2017). The ideal materials used for its construction should be analyzed, followed by a design suitable for a multitude of applications (Espinoza et al. 2018). To meet the proposed requirements, the design will have to be subjected to static analysis, especially of live loads, with wind speed being the main one.

Due to its operational and constructive characteristics, the given project turns out to be a viable option for students who attend engineering matters since it covers a wide variety of subjects that, through its application, will help to reinforce the knowledge acquired throughout the course while everyone's soft skills will flourish. In this article, for example, study over material selection from the subject Materials *Science*), the design of its structure and behavior (CAD and Static respectively) and its operation (Electrical Engineering and Programming) will be made.

It should be emphasized that, for higher academic levels, the design could even be improved and further deepened in its operation and limitations. For example, if teachers wish, they can integrate extra subjects such as Mechanics of Materials, Mechanisms, Dynamics, Electronics or even Design of Machine Elements.

Summing up, what this research seeks is to analyze the impact of the Integrative Projects on students´ soft skills learning and development through designing and building a solar energy capture and monitoring device. We seek to evidence the level of learning acquired during the academic semester was taken.

This prototype must be able to be placed perpendicularly to the solar rays during the day, be economical and versatile to implement it in different cities of Ecuador.

2. Methodology

The process made of on the design and building of a solar tracker in which engineering subjects were covered to reinforce the knowledge learned throughout the Second Semester of Automotive Mechanical Engineering (Acurio et al. 2018). This was mainly done as a method of Integrative Learning through the application of soft skills which will be mentioned later (Llanes et al. 2018; Moreno et al. 2019). The current section will cover the outline, evaluation, verification, and construction of the prototype. The materials used, its costs, static analysis, design in CAD software, the programming that will allow its automated operation and finally a section of soft skills will be presented.

2.1. Material Selection

The selection of materials seeks to reduce the cost of construction of the element by compensating it with greater structural integrity to increase its functional efficiency (Acurio et al. 2019). The steel was selected for the base area considering that it has a moderate weight to help maintain the fixed structure (Kastillo et al. 2017; Villacis et al 2015). Also, it has a high resistance to being exposed to the weather and a high degree of toughness.

On the other hand, wood was chosen for the upper structure because of its low weight and a relatively good degree of toughness, to have a much more accessible project cost. It should be noted that acrylic was also considered as an option. However, this material did not have a good degree of toughness and could not withstand the weight of the structure of the panel, the shaft and the motors on it. For this reason, it was decided to discard this material.

2.1.1. Material Selection Criteria

Steel

Has a series of highly praised mechanical properties. This material is very efficient since it will allow the base structure to be firm and avoid fracture. It is also possible to unleash its great malleability, hardness, toughness, and moderate plasticity (Kastillo et al. 2015).

Wood

Its characteristics vary according to its moisture content, the duration of the load and its quality (such as its hardness, density, defects). Its mechanical characteristics can be analyzed through parallel fibers and perpendicular fibers. Fiber wood will be used in the parallel direction since its resistance is greater than perpendicular. It is important to highlight some of the qualities that make it one of the ideal materials, among them are three main strengths: flexion, traction, and compression.

2.1.2. Material and Costs for the Prototype Manufacture

The elements used with their respective specifications are shown in *Tables 1 & 2*.

Table 1

Specifications of a) electric motors, b) solar panel zw-50p

DC Motor	
Torque	7.08 kg*in
Frecuency	80 rpm
Weight	190 gr
Ty	7,08 kg*in
Servomotor	
Torque	10 kg*cm
Weight	55gr
Tx	3,93 kg*in

Parámetros / Tipo		50P Silicio Poli cristalino
Potencia máxima (watt)	W	50
Tolerancia de potencia		0 ... +3%
Voltaje óptima (Vmp)	V	17.68V
Corriente óptima (Imp)	A	2.83A
Voltaje máxima (Voc)	V	21.68V
Corriente máxima (Isc)	A	3.01A
Dimensiones		540x670x30 mm
Marco (tipo, material y gruesor)		Aluminium anodizado. Alloy 35mm
Voltaje máxima externa permitida		715V
Coeficiente de temperatura de Isc		±0.05%
Coeficiente de temperatura de Voc		-0.33%
Coeficiente de temperatura de P		-0.23%
Coeficiente de temperatura de Imp		+0.08%
Coeficiente de temperatura de Vmp		-0.33%
Resistencia a cargas mecánicas		200kg/m2
Eficiencia de conversión		>15.75%

Source: Self-made

Table 2
Materials & costs

Materials	Unit Cost	Quantity	Total Cost
Arduino UNO R3	$ 10.00	1	$ 10.00
Solar Panel	$ 50.00	1	$ 50.00
Screw	$ 0.25	6	$ 1.50
Bolt	$ 0.25	6	$ 1.50
Photoresistance	$ 1.50	4	$ 6.00
Servomotor	$ 13.99	2	$ 27,98
Rechargeable Battery	$ 18.00	1	$ 18.00
H Bridge	$ 2.75	1	$ 2.75
Electric Box	$ 1.00	1	$ 1.00
Metallic Structure	$ 80.00	1	$ 80.00
USB Power Outlet	$ 1.00	1	$ 1.00
Rowlock	$ 8.00	4	$ 32.00
Motor Support Axles	$ 8.00	2	$ 16.00
DC Motor	$ 35.00	1	$ 35.00
		Total	$ 282.68

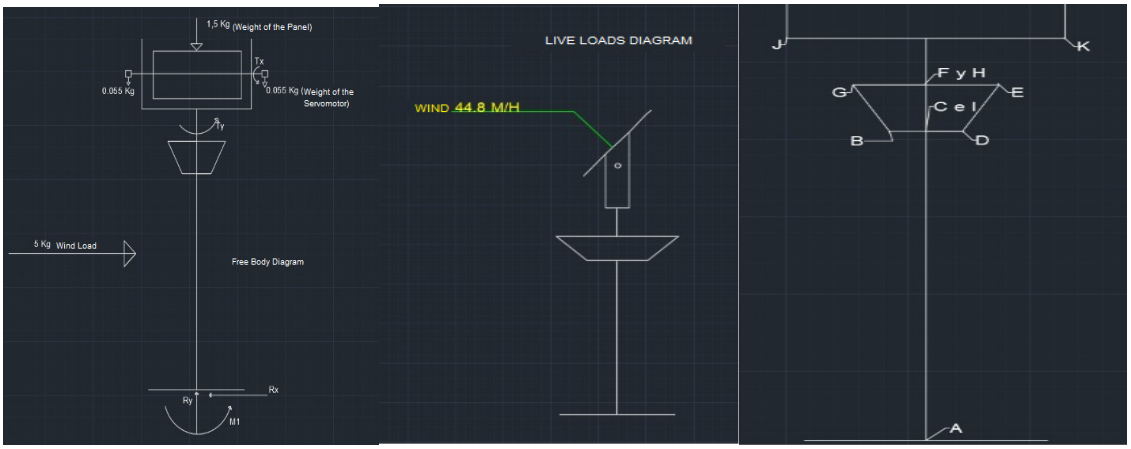
Source: Self-made

The overall cost of the solar tracker, as seen before, is very accessible taking into account its characteristics and elements proposed (Chingo et al. 2020; Villacreses et al. 2017).

2.2. Static Basis

By the implementation of Statics, it is possible to determine the loads that the solar tracker will have to bear, in order not to succumb to them and yield (Villacreses et al. 2017). As seen in *Fig. 2a)* analysis will be carried out with the forces that exist in the structure and the existing reactions due to the embedding in the lower part of the solar tracker, this to be able to identify all the variables that affect the operation and integrity of the structure. Likewise, *Fig. 2b)* shows one of the variables that will most affect its behavior: wind speed; since being a live load, it will tend to vary. Finally, *Fig. 2c)* will be associated with the calculation of stresses, reactions, and deformations using matrix methods to obtain more reliable data.

Figure 2
Free Body Diagram of a) Solar Tracker structure, b) live loads, c) for matrix calculation of stresses, reactions, and deformations



a) b) c)

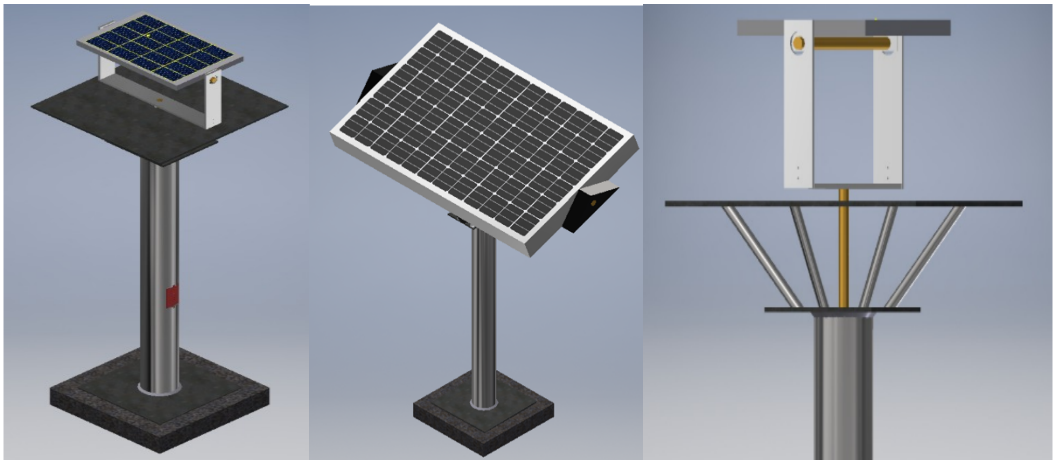
Source: Self made

2.3. CAD Design

Autodesk Inventor was used to sketching the structure to have a clear idea of the design that was decided to implement before the construction of the tracker (Aldas et al. 2019; Villacreses et al. 2019). Thanks to this software it is possible to schematize or sketch different types of structures, lowering the costs of material in its subsequent construction (Beltran et al. 2019, Martínez-Gómez et al. 2018). Its accuracy when modeling different mechanisms is flawless as it allows to give a clear idea and improve any fault that is detected throughout the development and construction of the project (Godoy et al. 2017).

Steel materials were used in the base such as a 4-inch tube and steel plates for the supports. For the drive mechanisms, a DC motor was placed in the base anchored to a half-inch transmission shaft, its operation can be 180° of rotation to place the panel at 45 ° to obtain the rays perpendicular to it and in this way get more use of it. The drive mechanism that will place the panel at 45° will be operated with two servomotors determined at the ends of the panel anchored to a U-shaped platform and in turn anchored to a transmission shaft that will rotate 45° in the direction of the sun. An angle of 45° is used since it is a standardized angle of installation of the panels. Below it is shown the different concepts for the design in *Fig. 3*.

Figure 3
a) Conceptual design using CAD, b) Structural design of the solar panel
c) Side view of the drive mechanisms of the tracker. Source: Self made



a) b) c)

2.4. Electric Circuit

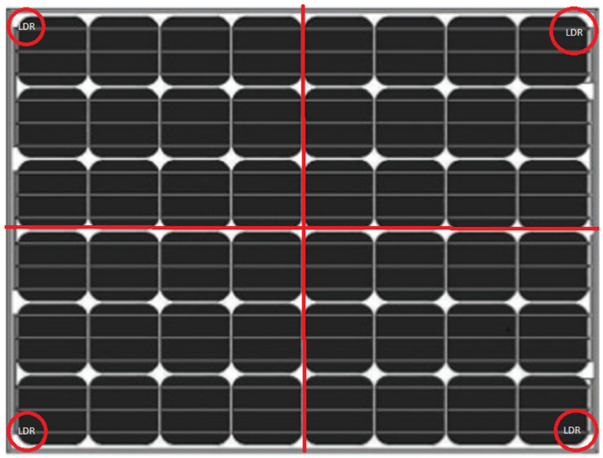
The design will consist of an electrical circuit (*Electrical Engineering* subject) that will enable the tracker to operate by its means and, in addition to the programming that will be seen in the following section, will facilitate its solar energy collection efficiency through its automation (Martínez-Gómez et al. 2017; Muñoz et al. 2012). This tracker will consist of photoresistors, resistors, Arduino board, motors, and panel. The present design differs, for example, from Escobar Mejía, Holguín Londoño, & Osorio, (2010) since those researchers decided to implement more sophisticated sensors and mathematical models of a greater degree of complexity to predict the position of the sun without the need for photoresistors. However, as this project is directed for learning purposes, it was decided to use them, thus avoiding further complicating its design and programming.

2.4.1. Programming the Algorithm for Automation

For the Programming section, Arduino will be used for the automation itself and, consequently, the best energy collection (Martínez et al. 2017). Servomotors will be controlled by this device. The operating mechanism will have two degrees of freedom in which a servo motor will be located on the main axis that will rotate the panel 360° and in turn, there will be a second axis on which another servo motor will be located that will rotate the panel in 45° to position at different angles of sunlight during the day.

The algorithm that will be developed in Arduino will aim to program what the two motors come to be, the code developed will focus mainly on the sending of signals by the photoresistors, which will detect the degree of luminosity and will send this information to the engines so that they perform the respective movements. It will also be developed in such a way that through a visualization software its performance can be determined.

Figure 4
Distribution of photoresistors on the panel



Source: Self made

By distributing the photoresistors on the panel (as seen in *Fig. 4*), the motors will act and transmit movement towards the structure in such a way that it will move according to the area in which a greater luminosity is detected. The program will be designed in such a way that the servomotors can place the panel in 3 different positions 0°, 90°, and 180°, while the DC motor that is at the base of the upper structure of the panel focuses on making movements from left to right.

2.5. Evaluation of Soft Skills

During the development of the previous paragraphs, the presence of soft skills observed in students is evident in the development of the previous phases (LLanes et al. 2018; Moreno et al. 2019). To assess them, the Google Drive platform will be used. A survey was designed in its Surveys section, with 7 questions will be asked that will be answered by impartial teachers. Such questions should be answered according to the level of scope of the students during the development of the project (from 1 to 5 going from less satisfactory to more satisfactory). The soft skills to evaluate will be: responsibility, teamwork, ability to solve problems, self-certainty, assertiveness, self-organization, and leadership. The selection of these skills was based on practical and group skills developed in Integrative Projects.

3. Results

This section will analyze the results obtained for the subjects of CAD (plans), statics (load analysis), electronics/programming (automation) and soft skills (tabulation of surveys). Also, the problems and difficulties encountered during its development will be mentioned.

The final structure obtained can be seen in *Fig. 5* below with their respective materials, where the layout of each element is observed. Likewise, the main plans are presented in *Fig. 6* below.

Figure 5
Solar tracker design (left), final model (right) with the students

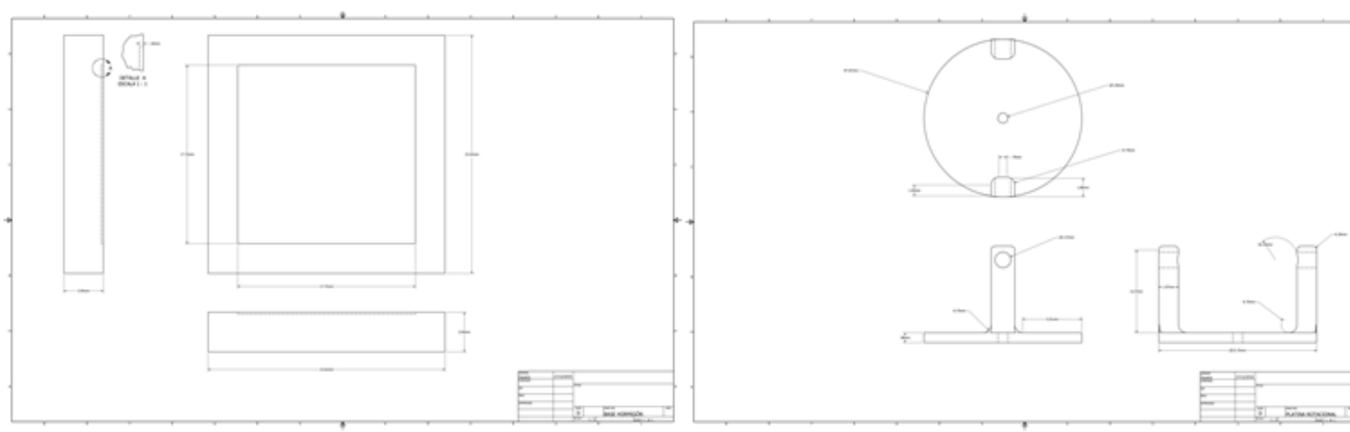
Source: Self made

3.1. CAD

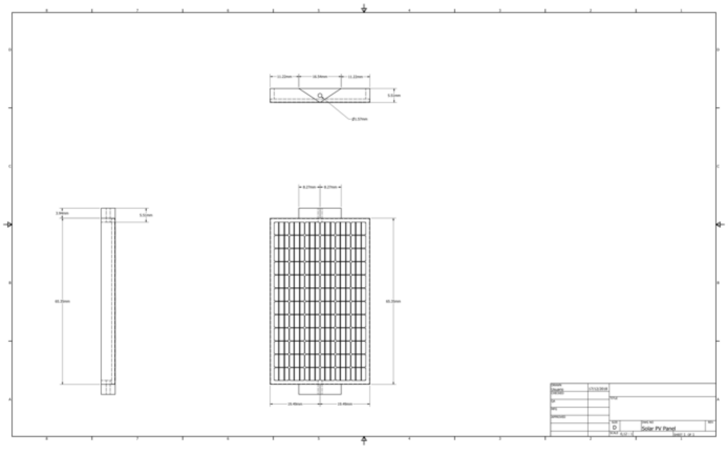
The concrete base (Fig. 6a)) allows the weight of the other plates to fall directly and uniformly and prevents the fracture due to the movement of the solar panel when capturing sunlight. The rotational stage (Fig. 6b)) supports the weight on the second level of the structure while it allows movement along the entire axis.

The panel (Fig. C)), as is known, helps to capture sunlight and generate enough electrical power to charge a mobile device. Finally, the main support (Fig. 6d)) represents the lower support of the small structure of the solar panel, it is the one that supports the axis of the rotation next to the DC motor.

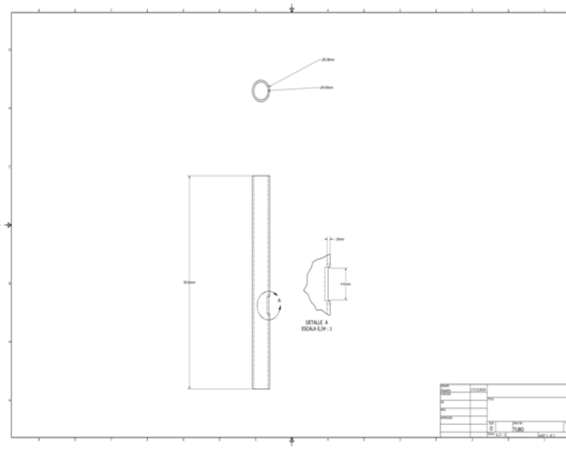
Figure 6
a) Concrete base, b) Rotational stage, c) Panel, d) Main support



a) b)



c)



d)

3.2. Statics

Analyzing the results shown in Table 3, it is determined that in its entirety the structure will support its main operation, considering that dimensions can be reduced and have the same result. This is because the loads obtained are insignificant compared to the structural integrity of the tracker. The analysis of live loads could determine that due to the wind's force, the system will not have any inconvenience and will support it without any problem, in the same way as the moments and the torque presented on the axes.

Table 3

Results a) live loads, b) matrix calculations

LIVE LOADS RESULTS	
Wind speed	44,8 M/H
qz *windward panel*	$2{,}20\ lbf/ft^2$
Pz *windward panel*	$0{,}561\ lbf/ft^2$
qz *windward tube*	$1{,}79\ lbf/ft^2$
Pz *windward tube*	$1{,}22\ lbf/ft^2$

a)

Displacements	Loads
0	0
0	0,82775
-7,10E-11	0,00447905
-7,10E-11	-0,00478795
-7,10E-11	0,00447905
-7,10E-11	-0,8324197
-7,10E-11	-0,02931155
-7,10E-11	-0,06780355
8,35E-11	0,05853655
8,35E-11	0,06780355
8,35E-11	-0,00447905
8,35E-11	0,00478795
8,35E-11	-0,00447905
8,35E-11	0,00478795
8,35E-11	0,00219625
-7,10E-11	0,0315078
-7,10E-11	-0,02702875
-7,10E-11	-0,0315078
2,30E-02	12,19
2,30E-02	0
2,30E-02	-12,19
2,30E-02	0

b)

3.3. Electronic section

The diagram of the electrical connection between the photoresistors and the nodes of the Arduino board is shown in *Fig.7*:

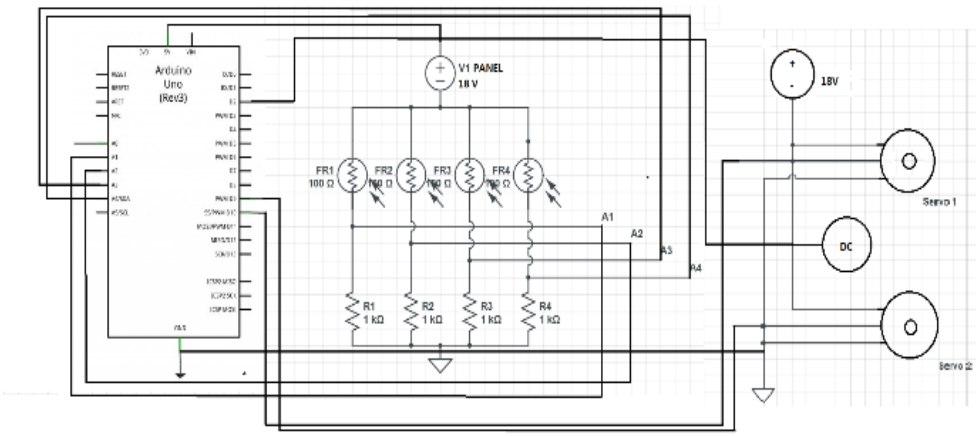


Figure 7. Diagram of panel connections and motor control via Arduino

The panel provided a maximum voltage of 18V, which will energize according to the light intensity that the sun will provide.

Resistors connected in parallel were analyzed. Starting with the fixed resistors:

$$R_{eq} = \frac{1}{1000} + \frac{1}{1000} + \frac{1}{1000} + \frac{1}{1000} = \mathbf{250}\ \boldsymbol{ohms}$$

Next, the equivalent resistance of the photoresists was calculated

$$R_{eq} = \frac{1}{100} + \frac{1}{100} + \frac{1}{100} + \frac{1}{100} = \mathbf{25}\ \boldsymbol{ohms}$$

Then both were added

$$R1_{eq} + R2_{eq} = \mathbf{275}\ \boldsymbol{ohms}$$

Which is also connected in parallel with both resistances of 1M and 220 ohm

$$R_{eq} = \frac{1}{1M} + \frac{1}{220} + \frac{1}{275} = \mathbf{125}\ \boldsymbol{ohms}$$

Then, the current intensity was calculated:

$$V = I * R$$

$$I = \frac{V}{R} = \frac{18}{125} = \mathbf{0.144}\ \boldsymbol{amp}$$

The voltage divider that will be seen below was performed to determine the necessary amount of voltage that is needed in each part of the circuit. In this case, it was carried out for the resistors and the photoresistors since they are the main elements of it.

$$V_s = V_o \frac{R1}{R1 + R2}$$

$$V_s = 18 \frac{100}{1000 + 100}$$

$$V_s = 1.63\ V$$

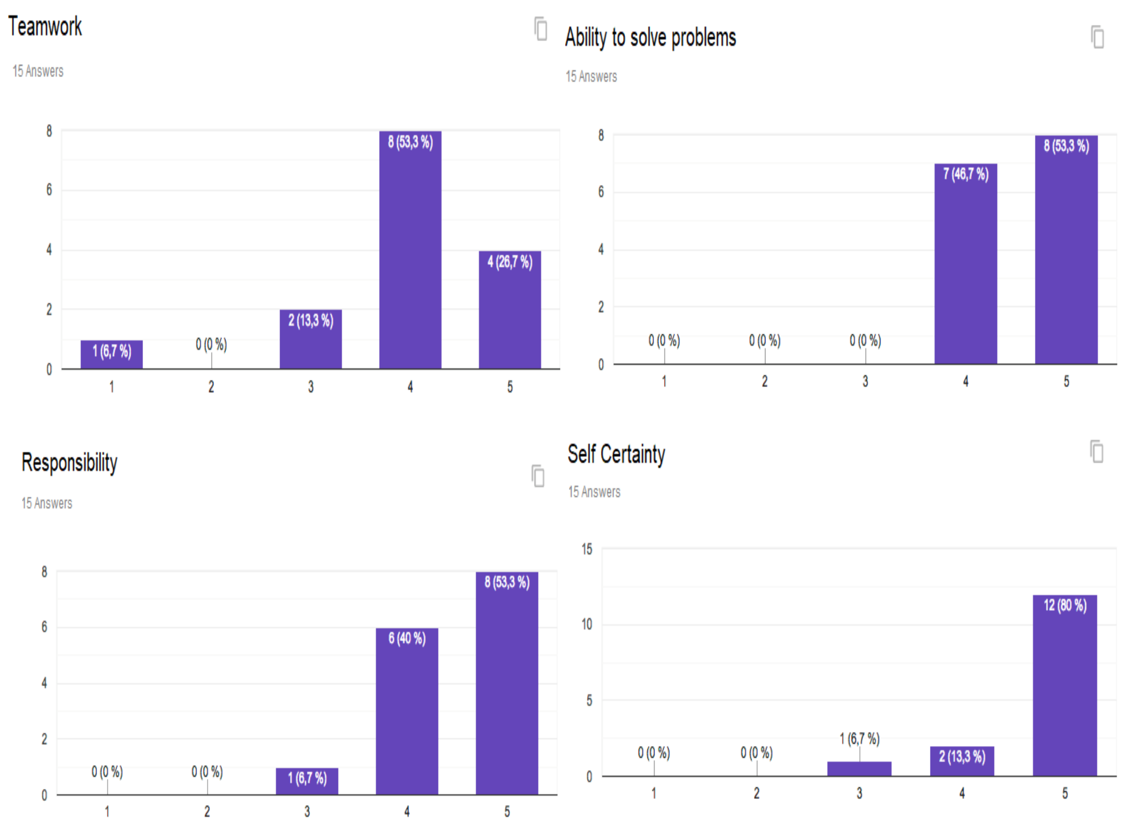
By obtaining a small current and voltage, it can be determined that the circuit is safe and there will be no overload on any of its elements.

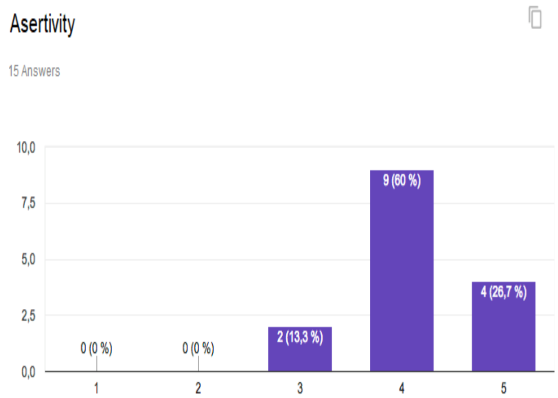
3.4. Soft Skills

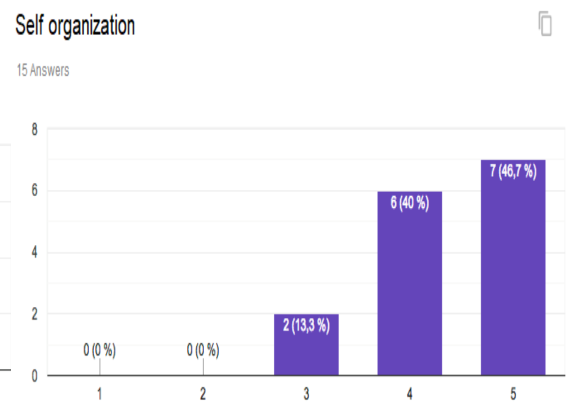
In the first instance, teamwork played the most important role, which allowed the members of the group to divide their tasks during the planning and construction of the tracker, in conjunction with critical thinking ability used in material selection, equipment layout and decision making. Leadership related to good communication skills, needed for tasks distribution, which favored a correct order and distribution of occupations. Those skills are usually found intrinsically in all types of integrating projects.

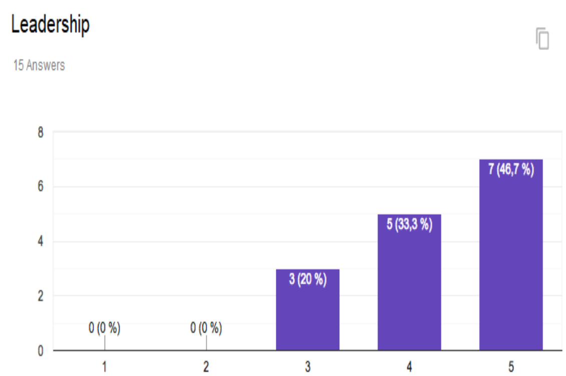
Additionally, emphasizing the issue of Integrative Projects, it can be said that thanks to them, engineering students were able to strengthen their judgment skills through teamwork, ability to solve problems, responsibility, self-certainty, assertiveness, self-organization, and leadership, all of them being soft skills put into practice, as mentioned in previous sections. As the results of the surveys shown in *Fig.8* below, the project presents a remarkable development in terms of the enrichment skills of its soft skills.

Figure 8
Surveys' results









To evaluate the soft skills of the *Solar Tracker Integrative Project*, 15 responses were obtained on a scale of 1-5, with 5 being the highest and 1 the lowest. One of the main skills that have been acquired is self-certainty leading the surveys with the highest score of 80%. However, teamwork despite presenting positive results, is the only one that has a rating of 1, which could lead to further reinforcement in future projects. Responsibility, leadership, and self-organization maintain a similar development among themselves, denoting the assimilation by the project participants.

3.5. Correlation Between Similar Projects. Results Discussion.

As it was observed, favorable results were obtained in all cases. (Bernal Spain, 2016) unlike the present project, it had a greater number of drawbacks because its design presented slowness in obtaining data during its construction, which slowed down the movement of its solar tracker. It should be noted that his prototype, like the one of (Eslava & Olaya, 2015) had a higher cost because it was a Degree Project, which resulted in more sophisticated software design. On the other hand, (Escobar Mejía, Holguín Londoño, & Osorio, 2010) had appropriate results where a correct response was evidenced by the panels. That said, the development and validation of this project was satisfactory, making it suitable for small applications in any city in the country (as long as it is located in areas covered by external agents such as rain or by having the circuits and wooden section well insulated).

4. Conclusions

The search for knowledge is always linked to commitment and self-dedication. Therefore, executing methods such as Skills Learning through Integrative Projects is a very successful alternative for current education institutes. Based on the present Solar Tracker Project was proposed, and a striking and fully functional final product was obtained.

These types of projects help to train students in the field of engineering as they allow them to strengthen their criteria (soft skills) at the same time while reinforcing their knowledge acquired throughout the course.

The proposed design resulted from the project, can be implemented in all kinds of structures or buildings in the country (as long as the electrical part is properly insulated from humidity and dust), reducing space needs and considerable costs due to the correct choice of materials, as it could be evidenced in *Table 2*.

In addition to cost reduction, these types of systems can meet different needs by solving environmental pollution problems, providing clean and efficient energy thanks to the automation provided.

The results of the final prototype were satisfactory both in its operation and in the personal development of each student (soft skills); this can be evidenced in the results obtained from the surveys present in the previous section, where they mostly have satisfactory grades of 4 and 5. It is also worth noting the overall performance of the prototype against similar projects which, after their respective bibliographic review, turned out to be thesis projects where they had appropriate results but which took a greater amount of development time. The evidence is overwhelming soft skills also called “non-cognitive skills” are important drivers of success in school and in adult life. In case of teacher´s performance, crucial skills of the most effective teachers today are very different from those of twenty years ago. Long gone are the days of one room schoolhouses with a handful of students where reading, writing and arithmetic were enough. It takes more than expertise in one academic field to be an effective teacher. Knowledge is still important, but today’s teachers must also possess the right soft skills to be successful.

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