SOCIETY OF PHYSICS STUDENTS
An organization of the American Institute of Physics

SPS Chapter Research Award Interim Report

Project Title	FOUCAULT PENDULUM
Name of School	Universidad Autonoma de Ciudad Juarez
SPS Chapter Number	3291
Total Amount Awarded	$1,980.00
Project Leader	Julio Lopez-Ibarra

Abstract

Physics students from the Universidad Autonoma de Ciudad Juárez present a proposal to design and build an interactive Foucault Pendulum based on a real time traking-system. Motivations behind the proposal are: Earth's rotation properties in a science museum, development teaching tools of Classical Mechanics and valuable scientific skills.

Statement of Activity

OVERVIEW OF PROPOSED PROJECT

Research question

What effects related to cognitive activity and scientific curiosity will produce a Foucault Pendulum in both physics' students and community people through the use it inside physics curriculum and museums?

Motivation

Regularly in elementary schools, science teachers tell children that earth rotates on its own axis. However, student's scientific interpretation and conceptual understanding is fundamental to develop important knowledge. Students need a demonstration process through the visualization of this phenomena. We believe that design and the implementation of physical demonstrations, suggest a Foucault Pendulum could help in the cognitive process during academic life.

A Foucault Pendulum could be a good alternative to: **i)**. Help UACJ's physics students during the process of conceptual understanding, and **ii)** encourage community to enjoy and achieve scientific knowledge.

Brief description

This research project is based on the design, construction and implementation of a Foucault Pendulum. Design elements built will achieve technology-hardware process. This technology will incorporate not only trajectory tracing sensors, but also the necessary software for graphing the corresponding data on an integrated screen.

Research goals of the project

1. Develop a functional prototype for several academic activities in the Universidad Autonóma de Ciudad Juárez.
2. Make investigation related with the electronic components and materials for the construction of the Foucault Pendulum.
3. Implement a high technology Foucault Pendulum at "*La Rodadora"* Science Museum.
4. Raise the scientific divulgation, interest and curiosity in Juárez City Community. SPS connection to strengthen the objectives of the SPS this project will also consist in the creation of a web page with free access for anyone who wants to interact and acquire the data provided by the Foucault Pendulum at any time.

SPS connection

To strengthen the objectives of the SPS this project will also consist in the creation of a web page with free access for anyone who wants to interact and acquire the data provided by the Foucault Pendulum at any time.

BACKGROUND FOR PROPOSED PROJECT

Currently in science museums and universities it's common to find a Foucault Pendulum as an exhibition piece. This type of pendulum was introduced firstly in 1851 by Michael Foucault given the experimental proof Earth´s rotation, hence these devices has a utility in the physics laboratories to the undergrad students because it can useful to demonstrate this fact and the physical principles that government the Foucault Pendulum behavior.

The Foucault pendulum consists of a large weight suspended on a cable attached to a point two or more floors above the weight. As the pendulum swings back and forth its plane of oscillation rotates clockwise in the northern hemisphere, convincing the rotation of the Earth. The motion of the Foucault pendulum is the coupling of two periodic motion, the rotation of the Earth and the oscillation of the pendulum leading to a precession. Depending on the relevant parameters, the motion differs in varied conditions, showing periodic or non-periodic motion consequently. With gravity, tension and Coriolis force applied on the cable, the motional equation, due to Newton's Law, is difficult in solution.

Up to now, a lot of researches were focused on the Foucault pendulum, they assumes that the weight could be seen as moving in the horizontal plane and not moving in the vertical direction due to its low-amplitude oscillation and propose the motional equations of the pendulum which can get analytical answer to them. However, we want mainly concentrated on is how the Foucault pendulum moves in varied relevant conditions, doing a comparison between the theory and experimental results.

EXPECTED RESULTS

Once this project is executed, the following results are expected: It is expected that a interactive Foucault Pendulum with a tracking system in real time, in orter to show the rotation of the Earth at the "La Rodadora Science Museum", in Cd. Juaréz, Mexico, in the border area with Texas (Scientific divulgation purposes for all the people en our city). This is a result that we believe is very important to promote scientific culture in our city, so that society values and promotes the development of physics and its applications. This type of projects contributes to the development of physics because it motivates future physicists. The expected pendulum will be interactive, well instrumented and very beautiful that will allow visualizing on a screen its trajectory and its explanation in a visual way. From the academic point of view, this project will be a very useful didactic tool for the Classical Mechanics course, specifically to help to understand the topics of

Mechanical of Lagrange and Mechanical of Hamilton, this is because any student of physical can validate their theoretical knowledge with our experimental proposal, which will allow us to validate the theoretical solutions with the experimental observations. Additionally, we will elaborate a list of academic activities that allow to challenge or improve the knowledge of Classical Mechanics of physics students, in order to achieve a more proficient knowledge of Classical Mechanics. The electronics (tracking system in real time) that we will develop to obtain the precise position of the trajectories of our Pendulum (3D), can be incorporated into other experiments of classical mechanics, the previous due to the small and high degree of precision that we expect.

Finally, as a result of the execution of this project we hope that our scientific skills and those of the rest of our classmates will improve, that we gain experience in order to be able to face the study of more challenging problems in physics.

DESCRIPTION OF PROPOSED RESEARCH - METHODS, DESIGN, AND PROCEDURES

- Review of the State of the Art abaut Foucault Pendulum
- Meetings to determine the the specific design of the pendulum.
- Made theoretical calculus for experimental design.
- Buy all materials necessary.
- Build a prototype of the interactive Foucault pendulum.
- Looking additional financing.
- Design an artistic concept for the pendulum, through industrial designers.
- Meeting with advisors for feedback, and Write and submit interim report (May 31)
- Meetings to determine the the specific design of the real time traking-system.
- Characterization and optimization of the Foucault pendulum.
- Build final Foucault Pendulum, for "*La Rodadora*" science museum in Mexico. Present and announce this project in our city.
- Verify if results match with expected findings, if not, solve technical problems.
- Diffusion of the project.
- Write and submit the final report (Dec 21).

PLAN FOR CARRYING OUT PROPOSED PROJECT

- Personnel. Four SPS members will be involved in the research of activities: Fernando, Julio, Gabriel and Raúl are the ones who assume the responsibility of the project, designing and executing the activities of the project. Additionally, in January-2019 two more students of physics and two students of Electronic Engineering will be integrated that support with electronics and instrumentation. All the team will be under the supervision of Dr. Abdiel Ramírez-Reyes and Dr. Sergio Flores-García. Finally, there is the support of the personnel in charge of laboratories and workshops of the UACJ.
- Expertise. Fernando, Julio, Gabriel and Raúl has necessary background completion of courses like General Physics, Classical Mechanics and Instrumentation which are helpful to achieve success in the proposed project.
- Research space. The work of this research will be carried out in the Physics Laboratories of the UACJ and in their respective workshops. The final stage of this project will be held at the "La Rodadora Science Museum", in Cd. Juaréz, Mexico, in the border area with Texas

- **Research question:** What effects related to cognitive activity and scientific curiosity will produce a Foucault Pendulum in both physics' students and community people through the use it inside physics curriculum and museums?

- **Brief description of project:** In addition to the general overview already presented (previous section), this project has been a great challenge for us, at the beginning we knew it would be complicated, but the interest in challenges impelled us to do it, we have been able to count on great support from our Professors. One of the most promising challenges we have had is the variation and calculations of the displacement of the pedicle; after a series of tests against time we get an idea of the proper height that we should use as well as the weight. The decision was made to put it in the paleontology area in "*La Rodadora*" museum, and adapt a design of the same theme, we have had great challenges but each one of them we have overcome and they have helped us to be more enthusiastic about this project. Fortunately, we have been able to incorporate Design students from our university who support us with the artistic concept of our project, because aesthetics is of the utmost importance, something that we had not previously considered.

  We could know that the link with the rest of society is not easy, it takes many efforts and skills to involve more people in the project who join efforts. This makes the project take more risks, but we believe this will strengthen the project, because we can finish with a more beautiful project with great potential for positive social impact in our community and in our development as physicists.

- **Some our achievements.**

✓ We have managed to make two prototypes of the pendulum mass, to be able to realize that it would be what is missing or what is to be inculcated.
✓ We also take a great step forward in the design that will be given to you, as well as the material that will make it interactive and popular.
✓ A functional prototype has been developed for several academic activities in the Universidad Autonóma de Ciudad Juárez, specifically data calculations for a complete plane oscillation, angle rotation, and motion equations.
✓ We have raised the scientific divulgation, interest and curiosity in the Juárez City Community (mostly students) by creating a specific design of the pendulum which adapts to one of "La Rodadora" museum section assigned for this project.
✓ We have the approval of the project by the museum "La Rodadora" (see letter in next page).

- **Changes in the scope of project.**
  Really if it was more difficult than we expected, but that has not been cause for discouragement, but on the contrary, it has been very important because we realized that this is a very promising challenge and of great importance in our city. Another of the challenges we had, and we stopped a bit was the fact that we had little knowledge in design sofwere and struggled in realizing animations and schemes of the pendulum.

- **Personnel**
  All the members of the Project have had a great participation and dedication for this work, we have managed to work as a team and promote more links and exchange of information among the

members, each one of them carries out different theoretical and experimental activations. All the participants are members of the SPS and are very happy to be part of the SPS.

- **SPS connection.**
  Unquestionably this activity will be very strengthening in our chapter because it will awaken the scientific and experimental interest of more physics students, as well as to want to be part of the SPS, this will be the first pendulum in the state and it will be of great pride that it will be put by alumnus of the UACJ through the great support that the SPS has granted. It is the door to a great series of activities and projects that will surely continue to be proposed, as well as the great bond that will be made between these two institutions and two large countries.

Updated Background for Proposed Project

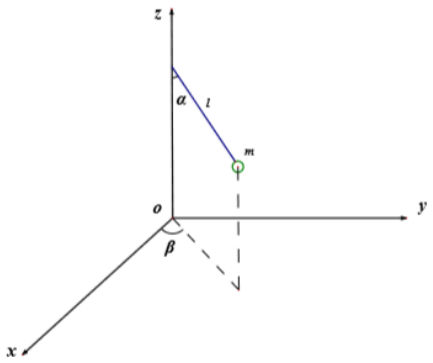
The model giving some assumptions of the pendulum itself and the property of the earth will be first built up and then with the theoretical result and some analysis. Finally, the numerical analysis and simulation will be used to analyze different motion types; we consider a massless cable with its length l tied between the weight and the fixed point, the weight is treated as a mass point ignoring its influence of size and shape with mass m, the range of the motion can be neglected compared with the size of the earth. Therefore, we neglect the variation of the latitude and the gravitational field of the weight. Finally, we consider the earth as a sphere, with its uniform gravitational field g on its surface, rotating with a uniform angular velocity w around its geometrical axis.

Then doing the corresponding analysis the motion equations are:

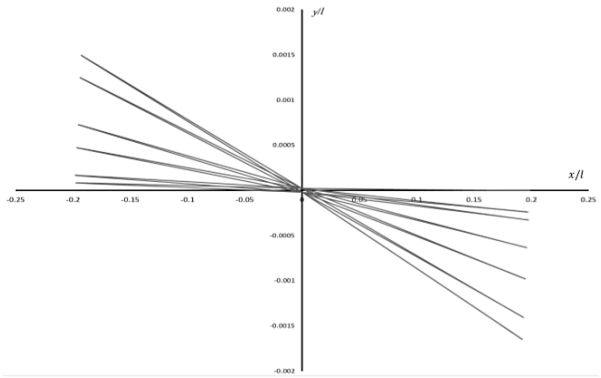
$$\ddot{\alpha} - \sin\alpha\cos\alpha\dot{\beta}^2 - 2w\sin\alpha(\cos\varphi\sin\alpha\cos\beta + \sin\varphi\cos\alpha)\dot{\beta} + \frac{g}{l}\sin\alpha = 0$$

$$sin\alpha\ \ddot{\beta} + 2cos\alpha\dot{\alpha}\dot{\beta} + 2w(cos\varphi sin\alpha cos\beta + sin\varphi cos\alpha)\dot{\alpha} = 0$$

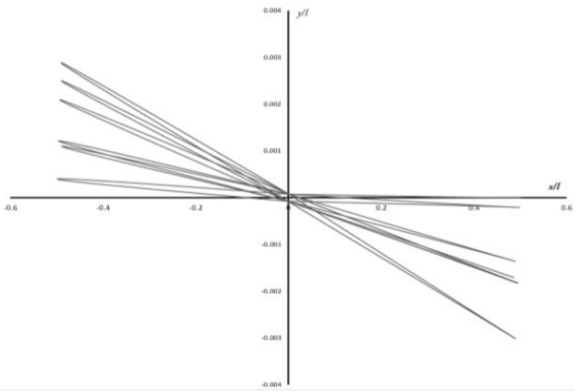
The angles, α, β, are the intersection angles between z axis and the cable, x axis and the projection on x-y plane respectively. And φ is the latitude locating the pendulum; w is the angular velocity of the earth rotation.



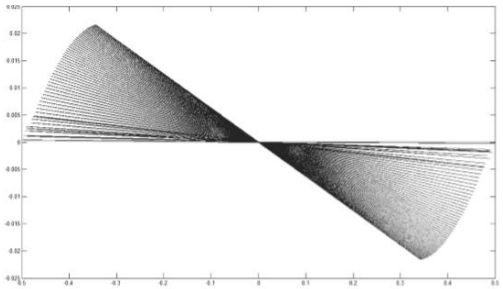
The next images are the results of the numerical analysis extracted from a paper research:



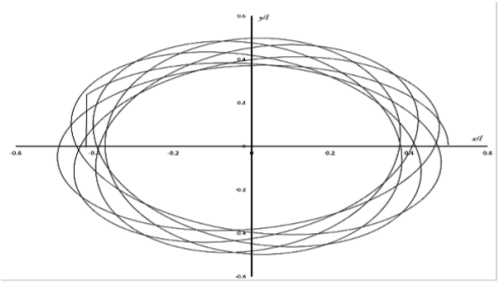
The motion trail projected on the horizontal plane for 100 s with the initial parameters: l=67m, $\alpha_0 = 0.2rad, \beta_0 = 0, \dot{\alpha_0} = 0, \dot{\beta_0} = 0.$



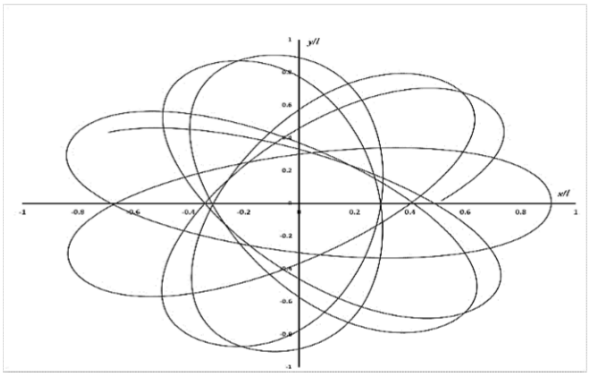
The motion trail projected on the horizontal plane for 100 s with the initial parameters: l=67m, $\alpha_0 = \frac{\pi}{6}rad, \beta_0 = 0, \dot{\alpha_0} = 0, \dot{\beta_0} = 0.$



The motion trail projected on the horizontal plane for 1000 s with the initial parameters: l=67m, $\alpha_0 = 0.2rad, \beta_0 = 0, \dot{\alpha_0} = 0, \dot{\beta_0} = 0.$



The motion trail projected on the horizontal plane for 100 s with the initial parameters: l=67m, $\alpha_0 = \frac{\pi}{6}rad, \beta_0 = 0, \dot{\alpha_0} = 0, \dot{\beta_0} = 0.3.$



The motion trail projected on the horizontal plane for 100 s with the initial parameters: l=67m, $\alpha_0 = \frac{\pi}{6} rad, \beta_0 = 0, \dot{\alpha_0} = 0.3, \dot{\beta_0} = 0.5$.

We consider that our research project will have an important impact related to the Experimental Physics, due when finished in this research, we get a product in which there will be implemented the necessary technology to make the physical analysis of several mechanical systems (not only Spherical Pendulums as the Foucault Pendulum) by means of the elaboration of comparisons; contrasting the theoretical models based on the Classical Mechanics with the acquired data through the design of experiments that let perform a realistic physical analysis and get a deeper understanding about the variables involved in the movement of the objects. So, when this project is finished, we could evaluate the validity or the reach of the several theoretical physical models existing about Spherical Pendulum or another and more complex mechanical systems that are used to describe the reality.

Description of Research - Methods, Design, and Procedures

Methodology

This work begins with an exhaustive investigation on the state of art of Foucault Pendulums, the physics associated with the subject, the pendulums existing in Mexico and the type of sensors and technologies around the data collection of the corresponding sensors. In a parallel manner, management will be carried out to achieve linkage with the La Rodadora Museum, and the search for funding will begin. Subsequently prototypes and tests will be developed in the UACJ, experimental protocols will be developing to understanding the system and define the final design. Parallel to this last activity, students specialized in design will be incorporated to support the development of the artistic concept of the project. Finally, with a resulting design, it will be built and installed in the Dome of Paleontology of La Rodadora. The results will be disseminated in specialized magazines and disseminated within the state of Chihuahua. The stages can be simplified as follows.

1) It will design a support structure of the Dome: For the support of the metal sphere of the pendulum with very particular features. We already have an advance related to the design.
2) It will design a metal sphere of the pendulum of high density, with a lead nucleus and brass finish.

3) It will send to fabricate a railing and security system related to some subject in syntonic with the Museum, for example, some thematic about dinosaurs, due to that the area of Paleontology will be the place where the Pendulum will be located. We already have an advance in design.
4) The art of the Plane Projection in agreeing to the Paleontology theme in the Museum. We already have the final artistic design.
5) It will send to fabricate an aluminum and template glass structure as security system.
6) We will create and design the instrumentation and software necessary to acquire the data position of the metal sphere which will be visualized in a LED technology screen.
7) It will design an informative module in relation with the thematic of the Pendulum.
8) Prototyping and fellowship for the all participates in the project.
9) Finishing, illumination, final ensemble, final calibration proofs and maintenance for a period of 12 months.
10) Travel expenses, supervision and linkage executed by the authors of the present propose.
11) Divulgation of the finalized project through publications in a technical magazine or another communication channel of divulgation more suitable.

In the next section we present the general design for the Pendulum, artistic concept and sphere. We are working very hard in the tracking system. It will be ready at the final summer.

Initial Results

1. We have the institutional support of the UACJ and the museum "La Rodadora", see the next letter please.

March 7, 2019

Dear members of the Physics Students Society

This letter is to confirm that "La Rodadora" Interactive Science Public Museum wishes to participate in the proposed project entitled *Foucault Pendulum*, led by SPS Chapter students from the "Universidad Autónoma de Ciudad Juárez".

We are willing to offer support for the Foucault Pendulum installation and exhibition in our museum expecting to share with visitors an interesting physical demonstration. We appreciate SPS students and physics adviser the effort to share their scientific knowledge and abilities to help people through this significant science interactive learning process.

Please do not hesitate to contact me if you need any further information.

Best regards,

Karen Alamo Castro

Executive Director

la rodadora

www.larodadora.org
Tel. (656) 257-0909

Av. Teófilo Borunda 6632 - Col. Jardín del Norte - C.P. 32652
Interior Parque Central Poniente - Hermanos Escobar
Ciudad Juárez, Chihuahua, México

2. Prototype of the pendulum with lead core and plastic exterior type PLA 3D printing. It has a mass of approximately 17 kg, diameter of 21 cm and length of 9 m (See figure 1). Note: The final pendulum will be steel with lead nucleus (in the form of pellets). Chrome-gold finish, and a length of approximately 20 meters in height, supported by a dome inside the museum.

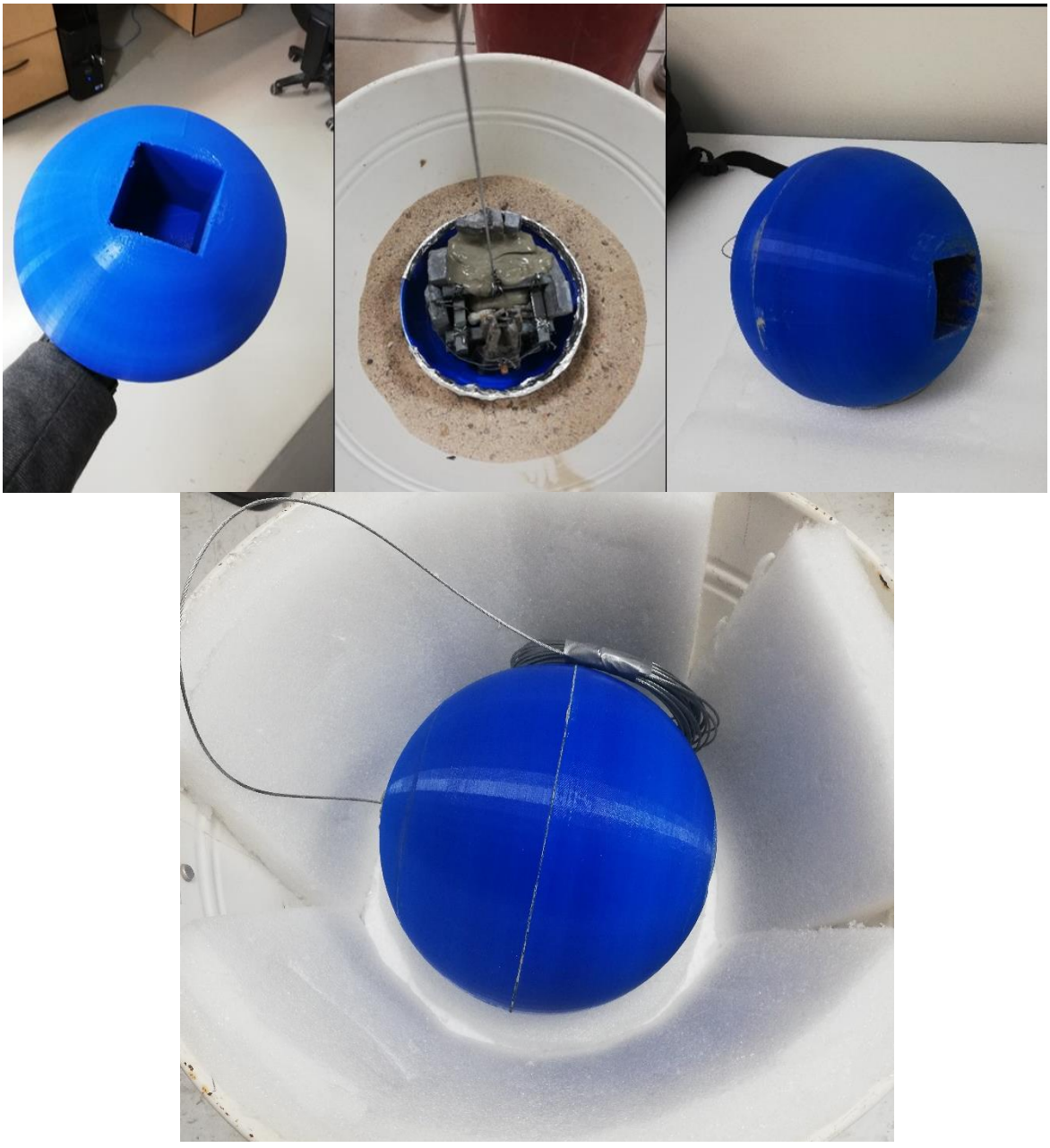


Figure 1. Prototype printed in PLA 3D, Lead and concrete core; the square cavity is for the traking sensor.

The design of the sphere that will form the pendulum is outlined in Fig. 2, it consists of an A36 steel shell with anchor and position position sensor container. Inside this sphere will be filled with a very high density material. It will be supported with a steel cable to the upper structure of the "La Rodadora" dome.

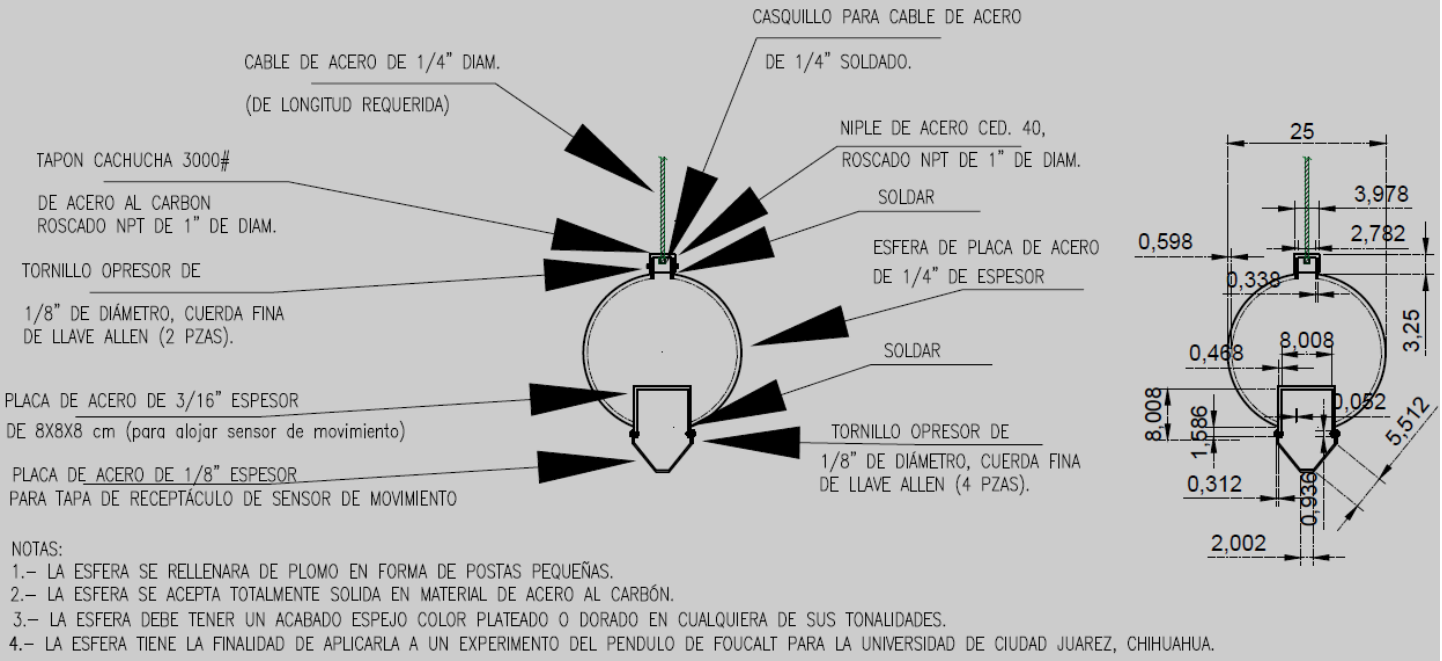
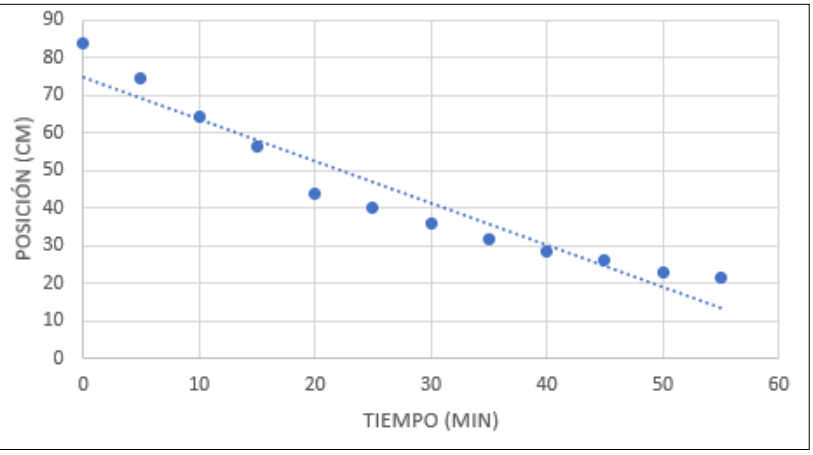


Fig. 2. Preliminary technical detail of the sphere that will be part of the Pendulum, steel core A36 and interior of Lead. The lower part will house position sensor.

3. Based on the test of our prototype, where 84 cm from the origin was displaced, we obtained the following results, clearly showing us the loss of energy, where its amplitude decreases with time (see below).

Tiempo(min)	Posición(cm)
0	84
5	74.5
10	64.5
15	56.5
20	44
25	40
30	36
35	31.5
40	28.5
45	26
50	23
55	21.5



It is important to mention that the conditions in which the test site was found were not adequate, due to the bad weather condition which could have produced greater air resistance (friction) besides the provisional support structure (Figure 3) that we guarantee it did not count on a free movement, thus granting more friction to the System. We are working in the final support design.

Figura 3. Provisional support of the prototype. The blue point at the center is the sphere.

4. The "La Rodadora" museum provides the place for Foucault's Pendulo (Figure 4).

Fig. 3. “La Rodadora” museum (sección de Paleontología).

5. With the support of colleagues belonging to the Institute of Architecture Design and Art, the artistic design for the Foucault pendulum was chosen, the space provided by "La Rodadora" is in the area of paleontology, therefore the chosen design has characteristics belonging to this area, is shown in the following figures.

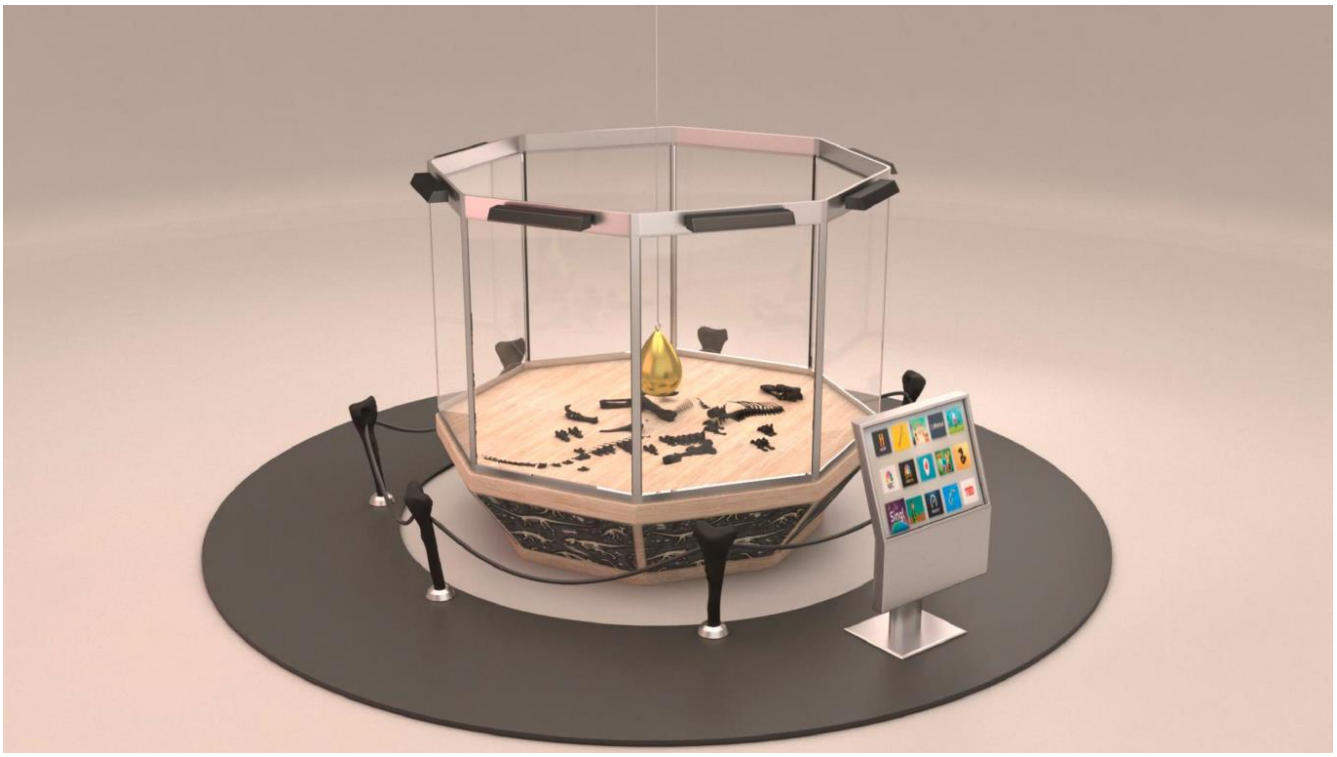


Fig. Oblique view of the Artistic Concept of the Pendulum.

Fig. Lateral View of the Artistic Concept of the Pendulum.

Fig. Top View of the Artistic Concept of the Pendulum.

Statement of Next Steps

Plan for Carrying Out Remainder of Project (including Timeline)

The previous Project plan had significant updates due to new plan review for project success.

	Tasks	Date
1.	Review of the State of Art.	Jan (2019) - Feb (2019)
2.	Resources research.	Feb (2019) - May (2019)
3.	Pendulum Design.	Feb (2019) - Mar (2019)
4.	Gather prototype materials.	Apr (2019) - May (2019)
5.	Prototype construction.	Apr (2019) - May (2019)
6.	Electronic construction.	May (2019) - Aug (2019)
7.	Write first Interim Report.	Apr (2019) - May (2019)
8.	Milestone (Deliver first Interim Report).	Predecessor: 7
9.	Possible app design.	Jul (2019) - Sep (2019)
10.	Device adjustment and calibration.	Aug (2019) - Oct (2019)
11.	Final pendulum construction and installation.	Sep (2019) - Dec (2019)
12.	Milestone (Final Pendulum built)	Predecessor: 11
13.	Technical report to publish.	Nov (2019) - Dec (2019)
14.	Perform optimization.	Nov (2019) – Jan (2020)
15.	Write Administrative final report.	Dec (2019) – Jan (2020)

Personnel:

Task 6:

- Ramirez is in charge to gather the proper electronics materials for construction.
- Hidalgo will design the electronic structure for the sensor and data communication device.
- The electronic will be constructed Between Raul Quiñones and Gabriel.

Task 9:

- The app design and functionality will be coded by Fernando Hidalgo.

Task 10:

- Raul Quiñones, Gabriel Murgia and Julio Lopez, are going to adjust the device and make sure it has proper calibrations for better data extraction.

Task 11:

- The construction of the pendulum (sphere structure) will be managed by Dr. Abdiel Ramírez-Reyes and Dr. Sergio Flores-García.
- The pendulum concept design will be constructed with the help of "La Rodadora" museum since they have their defined procedures and tools.
- Assembly of the electronic device will oversee Gabriel Murgia, Julio Lopez, Raul Quiñones and Fernando Hidalgo.
- Installation of the pendulum will be managed with the help of "La Rodadora" museum, since it is their structure and count with professionals to do so.

Task 13:

- The technical report oversees all the participants since most of the process involves technical issues.

Task 14:

- Each participant of the project will be in charge to seek for optimization of the final pendulum.

Task15:

- A total of 6 participants are members of the SPS.
- This project counts with two members of the SPS with special expertise on the pendulum goal topics that will ensure success.

Activities	Jan 2019	Feb 2019	Mar 2019	Apr 2019	May 2019	Jun 2019	Jul 2019	Agu 2019	Sep 2019	Oct 2019	Nov 2019	Dec 2019	Jan
-Review of state of art													
-Search for resources													
-Pendulum Designs													
-Prototype materials													
-Prototype construction													
- Electronics construction													
-First report (May 30)													
-Possible APP Design													
-Adjustments and calibration													
-Construction and installation of the final pendulum													
-Technical report to be published													
-Optimization													
-Administrative Final Report													

Bibliography

- Aczel, A. D. (2004). PENDULUM-Léon Foucault and the Triumph of Science.
- Marion, J. B. (2013). Classical dynamics of particles and systems. Academic Press.
- Goldstein, H., Poole, C., & Safko, J. (2002). Classical mechanics.
- Von Bergmann, J., & von Bergmann, H. (2007). Foucault pendulum through basic geometry. American Journal of Physics, 75(10), 888-892.
- Chapra, S. C. (2012). Applied numerical methods with MATLAB for engineers and scientists. New York: McGraw-Hill,.
- Wilson, J. D., & Hernández-Hall, C. A. (2014). *Physics laboratory experiments*. Nelson Education.
- Norman, S. F., & Anthony, G. E. (1999). Measurement, Instrumentation and Sensors Handbook, Edited by John Webster. *Florida: CRC Press LLC. Section*, 71-1.
- Koch, W. (2013). *Tracking and sensor data fusion: methodological framework and selected applications*. Springer Science & Business Media.
- Matthews, M. R., Gauld, C. F., & Stinner, A. (Eds.). (2005). The pendulum: Scientific, historical, philosophical and educational perspectives. Springer Science & Business Media.
- Crease, R. P. (2002). The most beautiful experiment. Physics World, 15(9),19.
- IPN. (2017). Gaceta Instituto Politécnico Nacional. 2 de mayo del 2019, de IPN.
- SPS. (2019). Chapter Research Award Recipients. Disponible: https://www.spsnational.org/awards/chapter-research/recipients/2019
- Prikhodko, I. P., Zotov, S. A., Trusov, A. A., & Shkel, A. M. (2011, January). Foucault pendulum on a chip: Angle measuring silicon MEMS gyroscope. In 2011 IEEE 24th International Conference on Micro Electro Mechanical Systems (pp. 161-164). IEEE.