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Problem-based learning as a strategy for teaching parabolic motion of particles

Aprendizaje basado en problemas como estrategia para la enseñanza del movimiento parabólico de partículas

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Abstract

In this paper an application of problem-base learning to support students in the subject of parabolic motion of particles by means of a home experiment is proposed. To encourage learning in students, is used a tower-tank system with an output water flow , which can be studied in a theoretical way to analyze it using the equations for dynamics of a particle, considering a steady output flow of water, in other words, without pressure or velocity changes. Subsequently, is given to know the way in which students can represent the scaled water system tower-tank using a few materials that all students have at home: a water carafe and a glass, exemplifying as they must carry out the experiment to obtain measurements that allow estimate the speed of the water outlet. Finally, through a survey applied to the students participating in the experiment, gets his perception in the improvement of learning topic.

Problem-based learning, Parabolic motion, Practical example

Resumen

En este trabajo se presenta una propuesta de aplicación del aprendizaje basado en problemas para apoyar a los estudiantes en el tema de movimiento parabólico de partículas por medio de un experimento casero. Para incentivar el aprendizaje en los estudiantes, se utiliza el flujo de agua en un sistema torre-tanque, el cual puede ser estudiado de manera teórica al analizarlo con las ecuaciones que describen la dinámica de una partícula, tomando considerando un flujo constante, es decir, sin cambio de presión o velocidad. Posteriormente, se da a conocer la forma en que los estudiantes pueden representar a escala el sistema de agua torre-tanque utilizando materiales que tienen en casa: jarra de agua y vaso, ejemplificando como deben llevar a cabo el experimento para obtener las mediciones que permiten estimar la velocidad de salida del agua. Finalmente, mediante una encuesta aplicada a los estudiantes que participaron en el experimento, se obtiene su percepción en la mejora del aprendizaje del tema.

Aprendizaje basado en problemas, Movimiento parabólico, Ejemplo práctico

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Introduction

When a student is presented with the subject of parabolic particle movement, it is often difficult for them to understand the resulting movements since they must be imagined. [Flores García et al, 2008]. This problem is due, in most cases, to the fact that the professors first present the theoretical information of the subject and then seek to apply it in the resolution of an exercise, failing in the teaching-learning didactics [Hyslop Margison y Strobel, 2007], [Campelo Arruda, 2013][Barragán Gómez, 2011] [Fagundez y Castells, 2012]. This failure is reflected in the students when they intend to solve an exercise, since they erroneously use the knowledge acquired recently, because they have not fully understood the subject [Elizondo Treviño, 2013].

The above can be solved using the methodology of problem-based learning as a didactic technique, since it has been shown to work effectively in areas such as computers [Guevara Mora, 2010], nursing [Kong et al. 2014], physiotherapy [Morral et al, 2002], geography [Maldonado Sánchez, 2016], education [Lozano et al, 2012] and engineering [Fernández and Duarte, 2013] [Kolmos and de Graaff, 2014], to mention a few.

The methodology consists of posing a real problem, or practical, to later identify the learning needs of a particular topic [Morales Bueno and Landa Fitzgerald, 2004] and finally collect the necessary information to solve it. This motivates students to work collaboratively [Davidson, Major and Michaelsen, 2014] and encourages coexistence with their classmates, allowing them to improve the teaching-learning process [Alvarado, 2015] [Parra Bermudez and Ávila Godoy, 2015] at the same time that you change the traditional professor into a facilitator or tutor of learning [Loyens et al, 2015].

This document presents a typical engineering problem, related to a tower-tank water system, which is analyzed in two cases from the perspective of parabolic particle movement, to be later emulated at home by means of a water jug and a common glass. In addition, the procedure to be carried out by the students as well as an example and the data they can obtain to compare them with what was obtained analytically is disclosed.

Finally, the results of the survey applied to a group of students who carried out the experiment and their perception of the knowledge acquired using the problem-based learning methodology are presented.

Methods

As indicated in the methodology of problem-based learning, the first thing that should be taken into account is a real problem that generates interest in the students and that after being analyzed can be solved by the students. The proposed steps to carry out this are the following:

1. Description of the system under study
2. Mathematical analysis of the system
3. Represent the system at scale
4. Exemplify the procedure using the scale system
5. Discuss the results

Next, the proposed method is developed.

Description of the system under study

A problem that can be used in the teaching of the parabolic movement is that of the tower-tank water system, constituted by a container located on a tower and a water tank located on the floor level, as shown in figure 1.

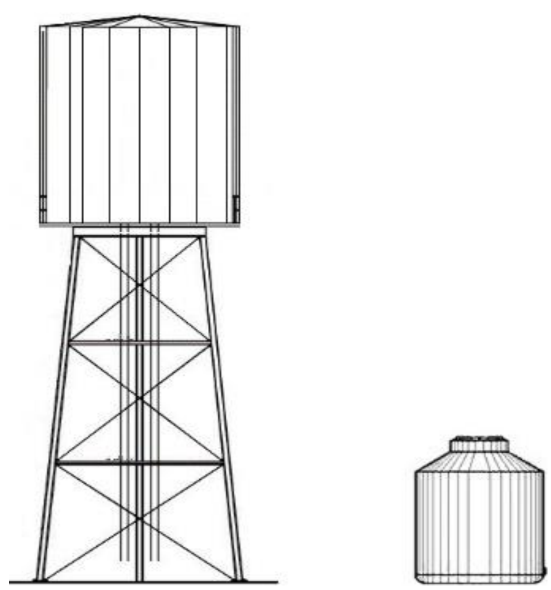

Figure 1 Tower-tank system
Sourse: Own Elaboration

The water container is raised a certain height by a tower, has an outlet nozzle that is not connected to any pipe, which allows a free flow of water to the outside with enough pressure to form a curvature similar to the of the parabolic movement. This flow of water must fall into a tank of known measures, which is located at ground level and away from the tower, so it is necessary to carry out a mathematical analysis of the behavior of the water that leaves the container.

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Mathematical analysis of the system

To analyze the problem, it is taken into account that the water outlet pipe of the elevated container is inclined at an angle Θ with respect to the horizontal, causing the water to exit with an initial velocity v_0. The vertical distance existing from ground level to the nozzle is h and the horizontal distance from the outlet pipe to the left inner wall of the inlet nozzle to the tank is d, while a is the internal diameter of the inlet nozzle of the tank and b is the height of the tank, as shown in figure 2.

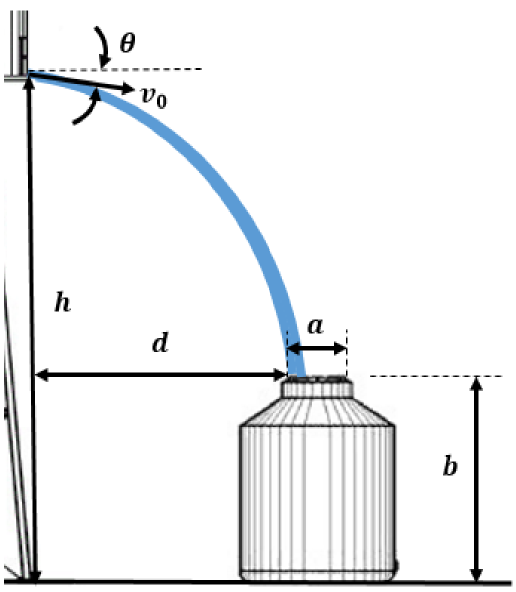

Figure 2 Dimensions of the system
Sourse: Own Elaboration

It is taken into consideration that, due to the volume of water inside the container, the water outlet forms a parabolic path, so it can be studied as a parabolic movement of particles, taking into account the following considerations:

– There are no gusts of wind that alter the path that forms the water.
– The friction of the air is not taken into account.

Once explained the above, two cases must be taken into account, the first corresponds to the minimum height that the container must have for the water to fall into the tank, while the second corresponds to a variation of the height so that the water Do not touch one of the walls of the tank inlet nozzle.

Case 1. Minimun height

This height is with which the water touches the left inner part of the tank's nozzle, so according to Beer, Johnston, Cornwell and Self (2017) we have that:

$$d = v_0(cos\theta)t \tag{1}$$

$$b = h - v_0(sin\theta)t - \frac{1}{2}gt^2 \tag{2}$$

where t represents the time it takes for water to move from the outlet tube to the tank inlet nozzle.

When you solve t from (1) and replace it in (2) you get

$$b = h - dtan\theta - \frac{gd^2}{2v_0^2\cos^2\theta} \tag{3}$$

If from (3) the initial velocity is cleared, the

$$v_0 = \sqrt{\frac{gd^2}{(2\cos^2\theta)(h - dtan\theta)}} \tag{4}$$

By means of (4) it is possible to estimate what is the initial velocity of the water when leaving the pipe of the elevated container.

Case 2. Variation of height

For this case, the height of the container is varied above the minimum required, keeping the angle of the outlet pipe constant and the initial velocity of the water flow. This produces a variation x in the horizontal distance that runs through the water, obtaining, according to Hibbeler (2017), the following

$$d + x = v_0(cos\theta)t \tag{5}$$
$$b = y - v_0(sin\theta)t - \frac{1}{2}gt^2 \tag{6}$$

Clearing t from (5) and substituting it into (6) you get the expression for the required height

$$y = b + (d + x)tan\theta + \frac{g(d+x)^2}{2v_0^2\cos^2\theta} \tag{7}$$

If you now replace (4) in (7) you get the following expression for the height of the pipe

$$y = b + (d + x)tan\theta + \frac{1}{d^2}(d + x)^2\cos^2\theta\,(h - b - dtan\theta) \tag{8}$$

It is observed in (8) that the height depends exclusively on the horizontal and vertical distances, as well as the angle of exit of the water, because there is no change in the initial velocity of the water flow.

Verifying the two cases in a real tower-water system would not be possible because the height of the tower is fixed. However, by means of a scale system that roughly represents the tower, the container and the tank, these experiments can be carried out.

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System under study at scale

To emulate the container a jug of water is used, which is an element that all students can have at home, without having the need to acquire a. It must be considered that the elevation of the tower is represented by the elevation that is given manually to the jar, while the tank's outlet pipe is represented by the outlet nozzle of the pitcher. On the other hand, the storage tank, which is at ground level, is emulated by a glass vessel of known dimensions, which is also an element that students can obtain with great ease, thus having all the elements necessary to be able to carry out the experiments.

Figure 3 shows a picture of the emulated system, as an example, so that students can get an idea of how they should develop the experiment.

The distances and dimensions can be obtained using a photograph of the jar-glass system, since knowing the dimensions of the glass can approximate the other values.

Figure 3 *Equivalent system*
Sourse: Own Elaboration

Application of the procedure.

Using a photograph of the scale system, the measurements of the exit angle of the water and the distance it runs are carried out, as shown in figure 4. Care should be taken to use a line parallel to the plane where it is supported the glass.

It is observed that the water does not fall right into the left wall of the glass, this is because it is difficult to keep the jar level, at the same angle and with a constant flow of water.

Table 1 shows the average values obtained experimentally by the students, which are approximate due to the way in which the measurements are taken, in addition to the difficulty of maintaining the jar without variations in height, angle or water flow.

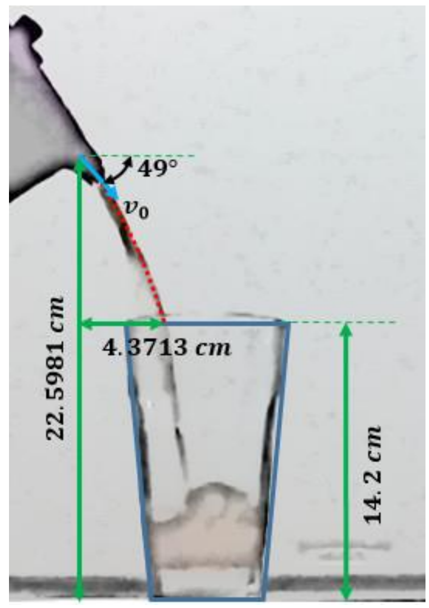

Figure 4 First experiment
Sourse: Own Elaboration

Parameter	Value	Units
d+x	4.3713	cm
a	8.2	cm
b	14.2	cm
h	22.5981	cm
q	49	Degrees
g	981	cm/s^2

Table 1 Experimental values
Sourse: Own Elaboration

By means of measurements of the photograph the students obtained, on average, a horizontal separation between the water outlet and the left wall of the glass of d = 2.3578 cm, so the horizontal distance between the water flow and the inner part of the the wall was x = 2.0135 cm. Using the values shown in table 1 and substituting them in (4), it was obtained that the initial water velocity when leaving the jar was 80.3905 cm / s.

Variation in the height of the jar.

To verify experimentally if there is any change in the magnitude of the water exit velocity, another experiment must be carried out, where the height that the pitcher initially had was modified only, trying to maintain the water exit angle in θ = 49 ° as well as the same separation distance d between the nozzle of the jug and the left wall of the glass. Table 2 shows the average values obtained for the second experiment.

Parameter	Value	Units
d	2.3578	cm
b	14.2	cm
h	22.5981	cm
d+x	6.3317	cm
y	38.2287	cm
q	49	Degrees

Table 2 Values of experiment 2
Sourse: Own Elaboration

Figure 5 shows the photograph of the second experiment for the variation of the height of the jar and the resulting measurements.

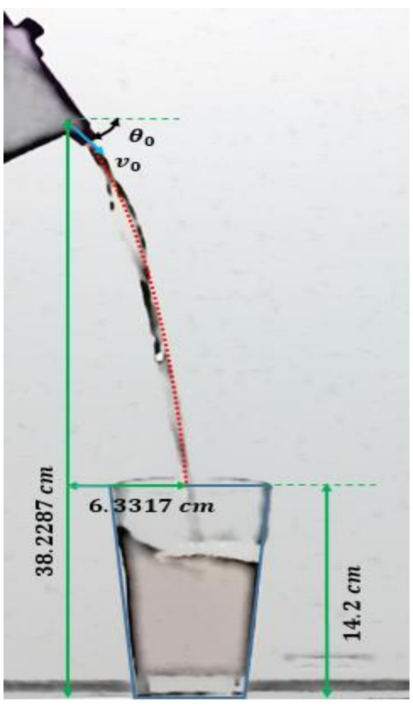

Figure 5 Second experiment
Sourse: Own Elaboration

Substituting the values of table 2 in (8) it is obtained that the height that the jug must have is 39.1381 cm, obtaining a difference of 0.9094 cm with respect to the experimental, which represents an error of 2.3236%.

All students used the described procedure to perform their own experiments, which showed variations in the measurements they obtained, mainly due to the elements (jar and glass) used by each of them. However, the main objective of this article is not to compare the results obtained, but to verify that the experiment serves to improve learning, so a survey of 9 questions was conducted to the 16 students who participated in the exercise. Table 3 shows the questions asked.

No	Question
1	Is the purpose of the experiment clear?
2	Is it difficult to reproduce this experiment at home?
3	Does this experiment support you to understand the concepts of parabolic particle movement?
4	Was the time invested in carrying out the experiment adequate to understand the concept?
5	Does what is analyzed in class differ from what you obtained experimentally?
6	Did you find the way to obtain the measurements complicated?
7	Do you consider that variations in measurements are affected by the conditions in which they are made?
8	Do you consider that these types of experiments are an adequate way to check what you learn in class?
9	Did teamwork prove helpful for your learning?

Table 3 Questions to evaluate problem-based learning
Sourse: Own Elaboration

This set of questions is divided in such a way as to partially identify students' ability to understand and manage their time. On the other hand, it also allows you to identify if you can apply the knowledge acquired during the theoretical development of the topic and its interpretation. Finally, the student's perception of the use of problem-based learning can be measured.

Results

The answers of the students are shown in table 4, where it is observed that each question has 4 possibilities of response: broadly (A), moderately (M), little (P) and nothing (N). It also shows the percentage and number of students that responded to each of the segments that make up a question.

	Percentage (Answers / Participants)			
No	A	M	P	N
1	93.75 (15/16)	6.25 (1/16)	0 (0/16)	0 (0/16)
2	0 (0/16)	6.25 (1/16)	37.5 (6/16)	56.25 (9/16)
3	68.75 (11/16)	31.25 (5/16)	0 (0/16)	0 (0/16)
4	62.5 (10/16)	37.5 (6/16)	0 (0/16)	0 (0/16)
5	6.25 (1/16)	25 (4/16)	37.5 (6/16)	31.25 (5/16)
6	6.25 (1/16)	50 (8/16)	31.25 (5/16)	12.5 (2/16)
7	18.75 (3/16)	56.25 (9/16)	18.75 (3/16)	6.25 (1/16)
8	75 (12/16)	25 (4/16)	0 (0/16)	0 (0/16)
9	37.5 (6/16)	56.25 (9/16)	6.25 (1/16)	0 (0/16)

Table 4 Answers to evaluation questions
Sourse: Own Elaboration

The analysis of the answers obtained shows that for the vast majority of participants it is clear that the purpose of the experiment (question 1) is to support the learning of the parabolic particle movement theme (question 3) using the problem-based learning methodology, which is done at an appropriate time (question 4) and which is a relatively low degree of difficulty (question 2).

In addition, in the comparison between what was analyzed during the course and what was obtained experimentally (question 5), it is obtained that the perception changes, this because the experiment is not done in a completely controlled environment (questions 6 and 7), with variations in the way to hold the jar and even maintain the angle when changing the elevation of the same which can lead to erroneous measurements.

On the other hand, a large majority of students say that this type of experiment is useful to learn the topics seen during the course (question 8), however the opinion regarding teamwork (question 9) this perception is varied, since that it is not usual for them to carry out activities in this way.

From the results obtained, it can be verified that the students thought the problem posed to analyze together with the materials used to study it at scale was adequate. In addition, they approve the use of the problem-based learning method as they considered that it was of great support to improve the understanding of the parabolic particle movement theme. However, the main problem they had was when trying to control the movement of the jug and maintain the water level, since to be changing constantly, this modified the water jet.

One of the requests made by students, in the comments attached to the survey, was to carry out the experiment in the classroom to be able to express questions directly to the professor, since at the time of realizing it in their homes, the doubts that they had regarding the procedure were not resolved.

Finally, to improve the experimental form, a system must be designed to maintain control over the jug, its height and water flow, which represents a new challenge for students, which would be related to other issues.

Conclusions

Using the problem-based learning method is a viable option within the classroom, promoting student participation and awakening their interest in the different topics usually seen in a particle dynamics course. In addition to this type of activities supports the professor to change the traditional teaching method, achieving that there is a simple way to transmit their knowledge to students and allowing them to improve communication with them.

However, great care must be taken when carrying out the experiments, since when carried out manually and at home, there is no control or exact measurement of the variables of interest, since everything obtained is approximate and you are not exempt from making some mistakes.

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