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Effects of Philosophical Reflection on the Teaching of the Concept of Force in Newton's Second Law

By

Wilder Guerrero
Universidad Nacional de Agricultura (Honduras)
Email: hermogenes92@gmail.com

Gilberto Castrejón
Instituto Politécnico Nacional, CICATA-Unidad Legaria (Mexico)
Email: gcastrejon@ipn.mx

Abstract

The article presents the results of an educational project in which a didactic sequence was applied under the theoretical approach of conceptual change and linked to philosophical reflection to teach the concept of force in Newton's second law. This was carried out with a sample of 78 students of the General Physics course of the National University of Agriculture, using a mixed method and combining Socratic dialogues and essay composition in the qualitative part, while a pre/post instrument was applied in the quantitative part, to make a comparative analysis of the academic results between the control group and the experimental group. Before this application, it was applied twice with smaller groups of students to validate its relevance and ensure a favorable reaction concerning the students. The quantitative results show that the experimental group's performance was 25% higher than the performance of the control group, which is supported by the qualitative analysis in which a greater overcoming of previous ideas is reflected in the experimental group. From all this, it has been inferred that philosophical reflection in teaching the concept of force in Newton's second law contributes significantly to better learning.

Keywords: Teaching, concept of force, Newton's law, philosophical reflection.

Resumen

El artículo presenta los resultados de un proyecto educativo en el que se aplicó una secuencia didáctica bajo el enfoque teórico del cambio conceptual y vinculado a la reflexión filosófica, para enseñar el concepto de fuerza en la segunda ley de Newton. Éste se realizó, con una muestra de 78 estudiantes del curso de Física General de la Universidad Nacional de Agricultura, empleando un método mixto, y combinando diálogos socráticos y composición de ensayos en la parte cualitativa, mientras que se aplicó un instrumento pre/post en la parte cuantitativa, para hacer un análisis comparativo de los resultados académicos entre el grupo de control y el grupo experimental. Antes de esta aplicación, se aplicó dos veces con grupos más pequeños de estudiantes, para validar su pertinencia y asegurar una reacción favorable, respecto a los estudiantes. Los resultados cuantitativos muestran que el rendimiento del grupo experimental fue un 25 % mayor al rendimiento del grupo de control, lo cual se respalda por el análisis cualitativo en el cual se refleja una mayor superación de las ideas previas en el grupo experimental. De todo esto se ha inferido que la reflexión filosófica en la enseñanza del concepto de fuerza en la segunda ley de Newton, contribuye notablemente a un mejor aprendizaje.

Palabras clave: Enseñanza, Concepto de fuerza, según ley de Newton, reflexión filosófica.

Introduction

The concept of force is vital in understanding classical mechanics and physics in general, so it plays an essential role in the teaching and learning process of physics and engineering students. However, as the concept is presented in physics, it is difficult for students, who tend to associate force with motion and believe that when two bodies interact and motion occurs, it is because one is stronger than the other (Maloney, 1990). Because of this, there are several epistemological and ontological obstacles that students have to face in order to understand the concept of force (Mora and Benítez, 2007). Such obstacles are due to different causes, among them students' preconceptions, of which one of the most common and persistent is associating force with motion and not the change of motion. This is emphasized by Sebastià (1984) when he mentions that studies carried out in France and England show that students' alternative frameworks are related, in some cases, to the Aristotelian theory of motion, and in other cases, to medieval concepts related to momentum. This coincides with Leymonié (2009), when he states that preconceptions or "alternative frameworks" continue, in many cases, to be held even when a scientific education has already taken place, which shows much tenacity and resistance in such previous ideas, which is not easy to overcome, even at the university level. McDermott (1991) points out that although students learn to solve exercises and can find the acceleration of a system such as the modified Atwood machine, they have difficulty explaining qualitatively why such a result is obtained.

Now, Jung (2012) has shown those aspects of science where philosophy plays a fundamental role, highlighting that the philosophy of science cannot be separated from the history of science. Therefore, the author accounts for scientific theories and their interpretations, the different epistemological positions throughout history, and the evolution of the historical relationship between physics and philosophy. In addition, he describes a series of examples where science and philosophy are necessarily intertwined in the structure of science and scientific activity, but above all, in the teaching of science. And it is about that linkage that this article is about, which refers to the result of an educational project that was carried out with students of General Physics at the National University of Agriculture[1], to whom a didactic sequence based on the theory of conceptual change, and linked to philosophical reflection, was applied, measuring its impact on the overcoming of previous ideas about the concept of force. This was achieved by comparing the sequence results with traditional teaching unlinked to philosophical reflection.

The project consisted of three phases, with different groups of students in three different academic periods. The first application was carried out during the third and fourth week of classes of the second academic period of 2019. This time, it was only done with an experimental group since the intention was to see how the students reacted to the experiment and the relevance of the designed instruments. The second application was carried out during the third and fourth weeks of classes of the third academic period of 2019. On this occasion, it worked with both the experimental and control group; and the third application was made during the third and fourth week of classes of the first academic period of 2020.

It is important to clarify that it was intended to repeat the experiment two more times, but with the covid-19 pandemic, it was impossible to continue with the repetitions of this experiment. However, even though it was only applied three times, it is considered that the

[1] This is a Honduran university.

results have been satisfactory and show the importance of linking philosophical reflection with the teaching of physics.

Among the possible solutions to problems of this type, according to Matthews (2017), introducing historical and philosophical aspects in the Teaching-Learning Process (PEA) is stimulating for students and, therefore, makes the process more effective. It is worth mentioning that according to what Matthews raises, didactic proposals guided by History and Philosophy of Science (HFC) have been made, as is the case in Teixeira, Freire and Greca (2015), who propose a didactic sequence to teach universal gravitation in the light of HFC; however, they do not get to apply their proposal.

Faced with this problem, the present research aimed to show how significant is the contribution of philosophical reflection in achieving the learning of Newton's second law.

Theoretical Framework

The theoretical support of this project had a triple focus: Axiological, in terms of the key concepts in Newton's laws; methodological, in terms of the didactic theory under which the didactic sequence was designed; and epistemological, in terms of the philosophical implications of the concept of the second law, and especially in the concept of force, whether of an ontological or methodological nature. In its ontological aspect, several questions arise: does force exist, is it an entity or a concept, what conditions would give rise to its existence as an entity and what others to its existence as a pure concept if it is conceived as a concept, then to what extent does it express reality, are not concepts a human tool to account for reality, if it is conceived as an entity, what are the premises that lead to infer its existence in itself, what are the premises that lead to infer its existence in itself?

In addition, the concept of force gives rise to many philosophical questions that, although they may remain unanswered, propitiate criticism and self-criticism in the student. As for the methodological aspect, some questions lead to reflection in the classroom: if it is taken for granted that force exists, how can its existence be demonstrated, and what level of approximation do the results obtained in the solution of a problem have with the phenomenon itself, represented in the problem?

On the other hand, within the methodological scope, the Force Concept Inventory (FCI), proposed and applied by Hestenes, Wells & Swackhamer (1992), consists of a set of questions asked to students before and after the learning process to measure their understanding of the concept of force, has been essential for this project.

Force

As Newton conceived it, the concept of force was, to some extent well, accepted in his time. However, in the nineteenth and twentieth centuries, questions began to be raised as to whether the equation could be demonstrated experimentally, and whether the force existed $\vec{F} = m\vec{a}$. These questions led many authors to deny the existence of the force and others to avoid its inclusion in their scientific proposals on classical mechanics, who admit the force from an ontological point of view, but not as an object of knowledge since it cannot be observed (Coelho, 2010, pp. 91-95).

Newton called the action of changing the state of rest or uniform motion in a straight line of an object 'impressed force,' a term that had been in use long before the Principia and which he stated had several sources such as percussion, pressure or centripetal force (Cohen, 2013, p. 62). In current textbooks, the second law is mathematically expressed as:

$$\overrightarrow{F_x} = m\overrightarrow{a_x};$$
$$\overrightarrow{F_y} = m\overrightarrow{a_y}$$
$$\overrightarrow{F_z} = m\overrightarrow{a_z}$$

in its vector form or in its differential form, either

$$\vec{F} = m\frac{d\vec{v}}{dt}$$

or in terms of the time[2]

$$\vec{F} = \frac{d\vec{P}}{dt}$$

According to Cohen (2013), Newton stated the second law for an impulsive force, or momentum force, acting instantaneously or nearly. From his point of view, moving to the continuous form of force was very easy. However, Cohen explains the reasons why Newton expressed both separate laws. For Maudlin (2014), they are two complementary laws, which would reduce their explanatory scope if expressed as one. The fact is that Newton's laws are very useful for performing calculations and predicting the behavior of a 'classical' phenomenon; however, they are based on a mathematical concept with no observable epistemological hold, such as the concept of force. Given all this, it must always be taken into consideration that force is a mathematical concept whose existence is not possible to observe in reality; although, according to Jammer (2011), it is the culmination of a process of demystification, which is detached even from its metaphysical connotations, to move to a strictly mathematical and scientific plane, of course, always with certain deep philosophical implications; for it is a concept as abstract as Schrödinger's wave function, from which certain phenomena can be explained, even when there is no apodictic definition of it.

Didactics and philosophy of physics

Didactics cannot be alien to the epistemology of the content taught because if we do not want a vertical and dogmatic transmission, it will be necessary to explain the nature and validity of such knowledge. Hence, in the case of didactics of science, the philosophy of science is an inseparable component. Suppose it starts from neopositivism, Klein (2012) considers science as a structure of empirical and objective knowledge, experimentally validated independently of the observer and independent of the theory it intends to corroborate. After neopositivism, more critical epistemological approaches emerged, such as those of Kuhn, Lakatos, Feyerabend and Toulmin,"which question' reality' understood as what is observable 'by the senses and experimentation as the judge of what is correc" (Klein, 2012, p. 9).

For Kuhn (2019), (normal) science is governed by paradigms manifested in texts, classes and laboratories. In the same way, the didactics of physics have their own, which lay the foundations of the teaching-learning processes and evolve together. Because although Kuhn speaks of scientific revolutions as paradigm shifts, according to Rovelli (2018), the cumulative nature of science is undeniable; hence, instead of recognizing paradigm shifts, an evolution of paradigms is recognized. Nevertheless, the fact is that paradigms exist, both in science and in its teaching, and for the latter to be differentiated from simple indoctrination processes, the nature and validity of its content must be demonstrated. Here, the philosophy of science plays

[2] In the General Physics class at the National University of Agriculture, the Second Law is introduced in both its vector and differential forms.

a crucial role and brings together the paradigms of science with those of didactics, a union impossible without philosophical reflection and epistemological scrutiny of both. This brings to the dual character of didactics of science that Klein (2012) emphasizes: on the one hand, it must be seen as scientific knowledge, and on the other, as an instrument of scientific literacy committed to both science and society. Thus, the didactics of science must, to some extent, appropriate the philosophy of science because the latter has to broaden its horizons and significantly enrich its theoretical and epistemological structure, giving rise to a self-criticism within didactics itself in such a way that it is framed in the process of continuous rectification. Likewise, the philosophy of science plays a crucial role in the classroom to clarify the nature of knowledge and awaken greater motivation in students. In this way, physics teaching will provide stimulating experiences at the cognitive and affective levels, and"attending classes will be a pleasure for the studen" (Klein, 2012, p. 28).

The didactics of physics are not only an academic instrument but also a social instrument that transforms collective thinking; therefore, if this transformation does not include philosophical reflection, it can end up being a process of indoctrination, which makes the individual go from a faith in myth to a faith in physics, which applies to the classroom. According to Leymonié (2009): "Much work has been done in researching the mechanisms by which students conceptualize a studied natural phenomenon... and their understanding of the scientific and mathematical concept*"*. From such research, it has been observed that when presented with the study of a particular phenomenon, it is natural for children to have preconceived ideas about that phenomenon or preconceptions, very different from those held by the scientific community" (p. 34-5). This is one of the most common problems that prevent 'true learning' because these preconceptions are dogmatically ingrained in the students. Therefore, the teacher must implement many didactic strategies within an active learning environment so that students can internalize the scientific concept and replace their previous beliefs, which are generally mistaken. Likewise, it should be considered that the teaching-learning process, as García (2014) points out, is carried out as a horizontal and multidirectional didactic dialogue. This leads to magnifying communication in the teaching-learning process, which for Moltó (2003) should have the following functions: informative, regulatory, persuasive and effective.

Conceptual change

The conceptual change learning approach was born in the heart of constructivism coupled with active learning schemes, where the student must manage his or her learning. However, this approach faces great challenges. For example, Campanario *et al.* (1999) point out that one of the problems and obstacles to PEA is the fact that, many times, students do not know that they do not know. Thus, regardless of the strategy to be followed in the PEA, it is essential to make preconceptions evident, either with a Socratic maieutic or by other means, so that the student is motivated by self-knowledge apart from the concept of the course itself.

From this point of view, the first step to unlearning wrong preconceptions is for students to enter into a "didactic struggle" with the scientific concept to be taught. Moreover, this can be achieved through a moderated Socratic dialogue[3] (mayeutics), which leads them to be fully aware of their mistakes, and allows them to open their minds for a critical and deep internalization of the new scientific ideas; and at the same time, it provides them with a more realistic explanation of the phenomena in nature. Unlearning the "alternative frameworks" in

[3] A type of conversation in which questions are asked in order for the student to self-discover his own conceptual errors or ignorance about a specific subject. It was the method used by Socrates, and may also be called Socratic maieutics.

their totality is impossible since human beings tend to 'balance between contradictions' and hold contradictory ideas with similar tenacity, without intellectual confrontation, in our minds' logical and psychological fields. Furthermore, this 'dialectical nature' of the human mind makes it challenging for the teaching-learning process to replace these 'alternative frameworks' acquired in the cultural and social environment or inferred from ignorance or a naive vision.

Preconceptions about strength

Previous ideas about the concept of force have been studied in different contexts; this has been evidenced by different researchers, among which it is worth mentioning: Maloney (1990); Mora and Benítez (2007); Steinberg, Brown and Clement (1990); Hewson (1990); whose conclusions show that students associate force with motion, momentum and as a property of objects. However, what there is no certainty about is what is the most appropriate way to overcome these previous ideas; and although everything points to the fact that philosophy and history of science are crucial in their teaching, there is still a lack of research regarding the way they should be linked, according to the degree of effectiveness found for different topics and possible types of linkage, because there is not only one way to link the history and philosophy of science with the teaching of science, there is a range of possibilities, and it is important to investigate what are the most viable and effective alternatives. This project has sought to add to that effort, specifically for the concept of force.

Methodology

This educational research focused on measuring whether philosophical reflection affects the learning of the concept of force in Newton's second law, following the theory of conceptual change. This implies that the evaluation instrument should be designed to measure whether there has been an overcoming of previous ideas on the part of the students. In this sense, the quantitative analysis has been reinforced by the qualitative analysis of the Socratic dialogue, added to two short essays written by the students themselves, where they exposed their conceptions about force, both at the beginning and the end of the application of the didactic sequence.

In the qualitative area, a series of questions were designed to build a Socratic dialogue in the class, which would lead the students to put their previous ideas into evidence to have an effect that would allow them to realize their conceptual errors. In the dialogue, Bianchini (2008) highlights the importance of waiting times of at least three seconds between the teacher's question, the student's response, and the teacher's response. As Gellon et al. (2005) suggested, qualitative analysis has revealed details lost in quantitative statistical analysis. The importance of Socratic dialogue in the classroom is supported by research such as those of Soto Restrepo (2018) and Camargo and Useche (2015), who gather enough evidence to show its contribution to learning. It is important to point out that, in the didactic sequence on the concept of force, it started from a series of assumed phenomena and mental experiments, which lead to the concept of force.

In the quantitative area, the results of the evaluation instrument applied to both the control group and the experimental group before and after developing the didactic sequence were analyzed. This was done in Excel. We call the pre-application"Pr" and the post-application"Pos". The evaluation of the sequence started from the beginning of the sequence since the means of the previous"*Cpr*" ratings of both groups were compared in order to ponder whether there was any degree of uniformity in their alternative conceptions; this degree of uniformity was reinforced with the qualitative analysis of the Socratic dialogue and the essay.

In addition, the standardized gain formula of the strength concept inventory, proposed by Hestenes, Wells, and Swackhamer (1992), was used.

$$\langle g \rangle = \frac{Cpost\,\% - Cpre\,\%}{100 - Cpre\,\%} \qquad (1)$$

Where *Cpre* is the pre-sequence rating, and *Cpost* is the post-sequence rating.

The qualitative part analyzed which of the most common alternative conceptions about the strength of the students' previous ideas fit and if there was uniformity in them. In the final test, it was observed which ideas had been overcome and which persisted.

Different educational researchers have used quantitative analysis. Rajapaksha and Hirsch (2017) used it to measure the impact of competency-based learning; Savinainen and Scott (2002) analyzed research conducted with the strength concept inventory to show that, indeed, standardized gain $\langle g \rangle$ measures student learning; Henderson (2002) concludes that the prior application of the force concept inventory does not influence its subsequent application, so this remains valid for the instrument used in this research; and Planinic, Ivanjek and Susac (2010) use it to measure the level of Newtonian mechanics of pre-university students, and Wang and Bao (2010) analyze it with a sample of 300 students. Although researchers such as Coletta, Phillips, and Steinert (2007) analyze how an instrument's normalized gain should be interpreted, in this case, the qualitative analysis is reliable as a support for the quantitative results.

Class 1 dialogue model

Socratic dialogue in education is not new. Already "in the 1920s, Leonard Nelson, a German philosopher (1882-1927), adapted the Socratic method to the educational context and promoted it as an important means to renew education and politics, as he was convinced that it would serve to create more reflective and critical citizen" (Van Rossem, 2009, p. 2). The Socratic dialogue model was designed to consider the generation of an active learning environment and a method that favors reflection processes, where the student brings to judgment each of his ideas and intuitions during the study of a topic (Huber, 2008). The dialogue model is as follows:

1. Suppose that a sled loaded with sand travels freely on a horizontal ice surface and maintains a constant speed, then the sled begins to throw sand behind it, then the speed of the sled: increases, decreases or remains constant. What do you think happens? (Approximately 5 minutes were dedicated to this question; an ideal case is proposed because what is hoped to test is if the force is associated with the movement, it is more of a mental experiment since later the discussion will be taken to the real case where friction is present, but at this moment the friction force has not yet been studied).
2. Suppose the students, as expected, since almost all studies show that motion and force are associated, answer that velocity increases. In that case, they are asked: what parameters do we need to know to calculate this increase in velocity? Which of the equations we have seen in kinematics can we use to calculate this change in velocity when the mass of an object moving freely with constant velocity decreases?[4] (Approximately 6 minutes were dedicated to this question).

[4] In this study there were no students who answered question 1, that the velocity decreases. However, if some students did give that answer, then one of the questions is rephrased by substituting decrease for increase: What parameters do we need to know to calculate such a decrease in velocity, the other question remains unchanged.

3. Regardless of whether students answer the first question correctly or incorrectly, restate this one for an inclined surface, as follows: Suppose the same sled as above when enters a downward slope. If it starts to throw sand, its acceleration increase, decrease, or remain constant? What do you think? (5 minutes were dedicated to this question).
4. Based on the studies conducted, it is to be expected that the majority believe that acceleration increases. So the teacher should ask why and take note of the answers. Then he/she should do a lecture demonstration with two carts loaded with sand in conditions of almost negligible friction and set up the system so that one loses sand and the other does not[5]. (In developing the topic, the teacher shows them that in conditions where friction cannot be negligible, the acceleration will increase, but it will always be less than gravity). The teacher should dedicate 10 minutes to this question and demonstration.

The dialogue took about 26 minutes. The teacher should not give answers because his objective is to uncover and confront the students' previous ideas so that the cognitive conditions are created to make them evolve with the development of the didactic sequence. The intention is that the student discovers by himself that he is wrong and why he is wrong.

Written instrument

This pre/post instrument was designed considering the updated strength concept inventory of Hestenes and Halloun (1995) and translated by Macia-Barber *et al.* (1995). Its application took about 20 minutes. In this research, the concept of force in the second law was evaluated, so our instrument has only five single-choice questions. Each question was dictated to the students, giving them two minutes to answer it[6] .

Question one is a variation of question 13 of the translated questionnaire, and it assesses whether the student associates force with motion or whether he/she considers it an internal property of objects. Question two assesses whether the concept of force is associated with mass and motion. Question three is similar to question one, but the options and context are different, although the correct answer is the same in both cases. This was intended to ratify the answer to question one, and the way it is posed prevents the student from associating both questions. On the other hand, question four is a synthesis of questions 25, 26 and 27 of the inventory; this is key to identifying if the force is associated with the movement; therefore, question five was designed, where the forces present are asked to be identified, in order to ratify the answer given.

1. Suppose you flip a coin and, just as it reaches the highest point, the force(s) acting on it is/are:
a. An internal force on the coin pointing upward and another force of equal magnitude pointing downward.
b. The force of gravity pointing downward.
c. No force acts on the coin just at the instant it stops at its highest point and changes direction.
d. None of the above.

Which of the equations we have seen in kinematics can we use to calculate such a change in velocity when the mass of an object moving freely with constant velocity, decreases?

[5] This was done by sliding two little boxes with grit on an oil-filled ceramic surface, one box had a small hole opened at one end, and both were released at the same time from the upper end of the inclined plane.

[6] Although it may be impractical to dictate the questions, in addition to being more time-consuming, this allows students to be aware of what they are being asked while copying each dictated question, since in previous diagnostic tests, several students chose answers at random without even reading the question. It was to avoid this that we resorted to dictation.

2. If at the same time a coin and an iron ingot are thrown vertically upwards from the ground and reach the same height, then the following can be stated:
a. The initial velocity of the ingot is greater than that of the coin.
b. The force impressed on both, at the moment of launch, is the same.
c. The initial velocity of both is the same.
d. None of the above.
3. Regarding the force(s) acting on either of the two objects in the previous problem, it can be said to be (are):
a) A downward force due to gravity together with a continuously decreasing upward force.
b) An upward force that decreases continuously until it becomes zero at the highest point and a downward force of gravity that is constant.
c) A gravitational force that points downward and is constant.
d) None of the above.
4. A man pushes a massive box with constant velocity of 2.5 m/s in a straight line on a flat surface, when the man stops pushing it:
a) The box stops immediately.
b) The box continues to move with the same speed.
c) The box begins to stop until it then comes to rest.
5. The force(s) acting on the above box, in the horizontal plane, are:
a) The force exerted by man in the same direction of motion.
b) The force exerted by man in the direction of motion and a frictional force, in the opposite direction of motion, approximately equal in magnitude.
c) A frictional force opposing motion.

Didactic sequence

Class 01

The objective of this first class was to know the students' previous ideas and the nature of these ideas. For this purpose, the pre/post instrument was applied during the first 20 minutes, and the Socratic dialogue was developed in the following 30 minutes. The class lasted 50 minutes, and before finishing, the students were instructed to check their e-mail, where they would receive the educational task to be done for the next class. During the Socratic dialogue development, the teacher noted the students' answers, who answered what, and how many students seconded them.

Educational homework assigned to students

They were sent via e-mail the article "Historical evolution of the concept of force" by Rivera-Juárez *et al.* (2014). Moreover, they were asked to write an essay where they placed their ideas about the concept of force in some historical moment. The essay had to be handwritten with an extension of two or three letter-size pages.

Post-class teacher activity

Review the pre/post instrument and assign a score[7], identify what preconceptions the students' responses relate to. Then, compare the Socratic dialogue responses with those of the pre/post instrument.

[7] This did not affect the students' final grade; it was only a research resource.

Class 02

The objective was to motivate students' dissatisfaction with their previous ideas. To this end, based on the previous class, an air-rail with its carousel and a bag of sand was brought to the classroom to be placed on top of it.

In the first 30 minutes, an open dialogue was held based on the questions of the pre/post instrument. Each question was formulated without mentioning the answer or the distracters. This dialogue was multidirectional; given the answer of one student, the opinion of the others was asked regarding that answer so that the students could interact with each other. The teacher did not tell the students if they were wrong or not. He just made them justify their answer and took notes.

In the next 20 minutes, a demonstration related to question 4 was performed, which provoked much discussion among the students. Finally, the teacher ended the discussion with a reflection on the importance of putting what is believed into judgment, especially questioning whether what we affirm coincides with reality. The activity was then assigned for the next class.

Educational homework assigned to students

Read the text "On Newton's Law" by Gómez *et al.* (1983), and write a paragraph on whether the second law is a concept or a relation between concepts. Then, answer the questions: how do we know that a force is present? How do we know that the force exists?

Class 03

The purpose of this class was to present and discuss Newton's second law within its context of validity.

To begin with, Newton's definition and his vector mathematical expression were presented, emphasizing that the current mathematical expressions are the consequence of a long transition from geometrically expressed mechanics to mathematical mechanics as it is known today. This was done in the first 10 minutes. In the next 10 minutes, there was a discussion about what force is and whether or not force is something that exists in reality. Finally, in the next 10 minutes, it was discussed why the second law is a relation of concepts and not a concept itself.

In the last 20 minutes, free-body diagrams were made on the following cases:

- A sled sliding down a steep slope.
- A vehicle braking to a standstill.
- The Atwood machine.
- A sled that slides bouncing sand down a slope.

The diagrams were made on the board, and students were asked to point out the forces involved in each case. They were then asked if the forces correctly identified in the diagrams were all the forces that existed for each case or only those that had a bearing on what we wanted to find? The teacher pointed out that science works with approximations, and although we identify all the forces involved in each system when they are calculated, the result will always be an approximation.

Educational homework assigned to students
Study section 4.4 of Giancoli (2008), from page 86 to 88.
Review sections 9.3 to 9.6 of the book by Feynman *et al.* (2011).
Review sections 3.1 to 3.3 of the book by Gánem *et al.* (2009).
Solve the following exercises:

A 0.140 kg baseball traveling at 35.0 m/s hits the catcher's glove, which, when brought to rest, moves back 11.0 cm. What was the average force applied by the ball to the glove? (Giancoli, 2008, p. 104).

A sportsman pulls a fish vertically out of the water with an acceleration of 2.5 m/s2, using a very light fishing line, which withstands a maximum tension of 18 N (L 4 lb) before it breaks. Unfortunately, the fisherman loses his prey because the line breaks. What can you say about the mass of the fish? (Giancoli, 2008, p. 104).

When solving the exercises, they were instructed to change the data at their discretion, at least four times, answering the question: what happens if I change this parameter or this one? The student had to justify each change in the data.[8]

Class 04

The purpose of this class was to present and solve problems within a context familiar to the student, where the second law is applied, following a series of steps where the possible assumptions and the level of approximation implied by such assumptions are evidenced. Two problems were solved. The first was simple, the second more complex. In the first problem, the teacher identified the data, the known parameters, and the assumptions. He then explained the solution to the students (Giancoli, 2008, p. 105):

1. What is the average force required to accelerate a 9.20-gram bullet from rest to 125 m/s over a distance of 0.800 m along the barrel of a rifle?

After arriving at a solution, the teacher proposed some questions to the students: if you have noticed they talk about average force, not the net force or the force at a specific point, what does that mean? How could we do it if we wanted to know the force at a given point? With these questions, a brief multidirectional dialogue was initiated in the class, which generated an environment conducive to capturing the students' attention and involving them in solving the other problem.

The time used for this first exercise was approximately 15 minutes.

2. The locomotive of a train pulls two cars of the same mass behind it. Determine the ratio of the tension in the coupling (as if it were a rope) between the locomotive and the first car (FT1), concerning the tension in the coupling between the first car and the second car (FT2), for any non-zero acceleration of the train.

Students were invited to identify the data, known parameters and assumptions for this problem. One student was then asked to go to the whiteboard to draw the free-body diagrams with the help of any other classmates who wanted to support him or her. The problem was explained and solved while the students were asked questions at each step. They were then

[8] Although it may seem like an excessive burden for the student, at the National University of Agriculture, the General Physics class only consists of 3 hours of class per week, normally distributed on Monday, Wednesday and Friday. Given this, the students had the entire weekend to complete their homework, as it was due in class 04.

asked what would happen if the parameters were changed and the masses of the cars were different? In this way, a wide participation of the students was achieved. Then they were asked: if we knew all the parameters except for the mass, could we calculate the mass from the stresses and acceleration, just as we can if we clear the mass from the second law equation? Now, will be able to calculate one parameter from another to validate the fact of defining the concept of that parameter from the one that allows us to make the calculation? That is: will the fact of calculating the mass from the force validate the fact of pretending to define the concept of mass as a function of the concept of force?

Problem-solving and discussion took approximately 30 minutes.

Educational homework assigned to students

- Resolution of five problems related to the second law, taken from page 105 of Giancoli's textbook (2008).
- Write a paragraph after each problem arguing about the relationship between each problem and the reality it represents.
- Answer the following questions for each problem: Why do you think your results are correct? How close do you think your results are to reality? What elements affect the real phenomenon posed in the problem and what has the solution method not considered?

Class 05

To evaluate if the students have understood the concept of force in Newton's second law. In the first 20 minutes the pre/post instrument was applied. Then the problem's solution was written on the blackboard, and it was proposed to conceptualize the problem from its solution. Here almost all students participated, and it took 30 minutes.

Educational homework assigned to students

One-page essay mentioning those aspects of nature where the second law is present. The student is instructed to mention how he/she understands the concept of force, with which concepts it relates and how it manifests itself.

Class 06

The purpose was to discuss some of the students' arguments in the essay, provide feedback and show opportunities for improvement in their argumentation development. This took about 15 minutes. Likewise, the five questions about the instrument were discussed again for 20 minutes, and notes were taken. Finally, a conversation was held with the students about their impressions of the educational experiment.

Analysis

Qualitative: Prior ideas were identified before the sequence and classified according to their type. Predominant prior ideas: force is associated with motion, force is an intrinsic property of objects; historical stage of coincidence with prior ideas; isolated ideas and spontaneous ideas invented *ipso facto*.

To identify the prior ideas in the essay, a checklist and an identifier were used for each student so that the first could be compared with the second. The checklist was as follows:

- Your ideas about strength are correct
- Associates strength with movement

- Conceives force as an internal property of objects.
- There is no clarity to identify their ideas about strength

After the sequence, in the last day's dialogue, the persistent preconceptions and the ideas that were overcome were noted down. This classification was made in both groups, and after the sequence, we analyzed which were overcome and which were not in each group, by comparing the checklist of the first trial with the second and the answers of the final Socratic dialogue.

Quantitative: means and standard deviations were calculated for both groups. These results were then compared. The normalized gain was obtained $\langle g \rangle$ for both groups, and a comparison is made.

Tables and Charts

Results of the first application.

Table 1: *Quantitative results of the first application.*

No. of students	Average Cpre	Average Cpost	DE Cpre	DE Cpost	Average ⟨g⟩
22	34.33	75	4.64	11.08	0.62

Table 1 shows the averages of the instrument application before and after; it also shows the average of the normalized gain, which has a value of 0.62; whose value does not change if the calculation is made based on the averages of Cpre and Cpost. DE Cpre and DE Cpost refer to the standard deviation of each series of results. It should be clarified that the first application was based on 100 points. However, the subsequent ones were based on 10 points, with the sole objective that the students would not be negatively impressed by an evaluation whose value is 100 points, which could generate unnecessary stress in them when they answer the instrument.

Results of the second application.

Table 2: *Quantitative results of the second application.*

	Sample	Average Cpre	Media Cpost	Average g	DE Cpre	DE Cpost	DE of (g)
G. C.	30	24.60	65.60	0.54	2.92	4.21	0.050
G. E.	32	24.28	80.16	0.74	3.59	9.96	0.13

Results of the third application

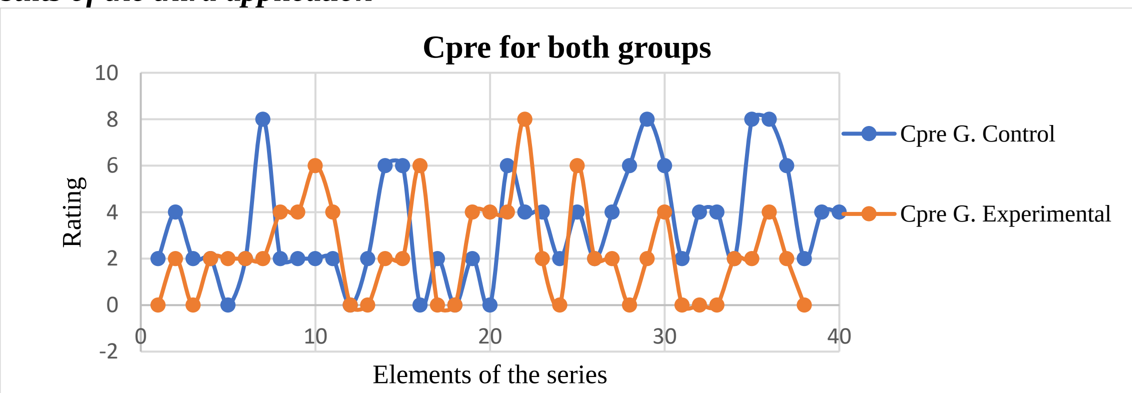

Figure 1: *Cpre results for both groups in the third application.*

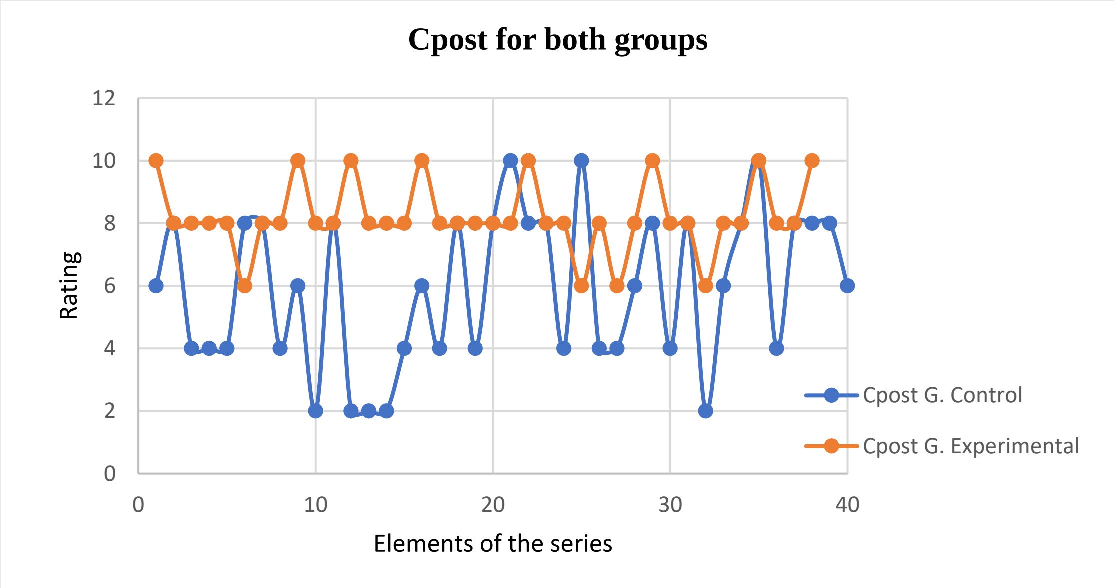

Figure 2: *Shows the Cpost results for both groups in the third application. The orange dots represent the experimental group and the blue dots represent the control group.*

Figure 1 shows the *Cpre series* for both groups. Although it seemed that the control group had a better performance, when talking with the students about the subject, it was noticed that the previous ideas were similar. The differences in the averages are due to some spontaneous answers since, except for five students, all of them considered that when throwing an object upwards, the force decreases as the object goes upwards; this seems to be an unrooted conception since it comes from an automatic intuition, since immediately, upon careful reflection of the problem, they concluded that their premises were erroneous. This was repeated in the three scenarios of the application of the didactic sequence, and the results are similar. When posed with the question of a box being pushed on the floor with constant velocity, all students considered that the box would come to a complete stop when they stopped pushing it. The preconceptions were similar in both groups. However, on the second day of class, the experimental group students visualized how their ideas failed, and they all seemed to be aware of their mistakes, showing some enthusiasm.

In quantitative terms, the students in the experimental group had a 25% better average performance than the control group, and this was ratified by the qualitative analysis, where it is seen that the ideas of force associated with the movement have been overcome, as well as force as a property of objects, while in some members of the control group, these ideas persisted after the subject was developed.

In *Figure 2* it can be seen that the experimental group's performance is significantly higher than that of the control group. The superior performance of the experimental group can also be seen in *Figure 3* which shows the normalized gain for both groups.

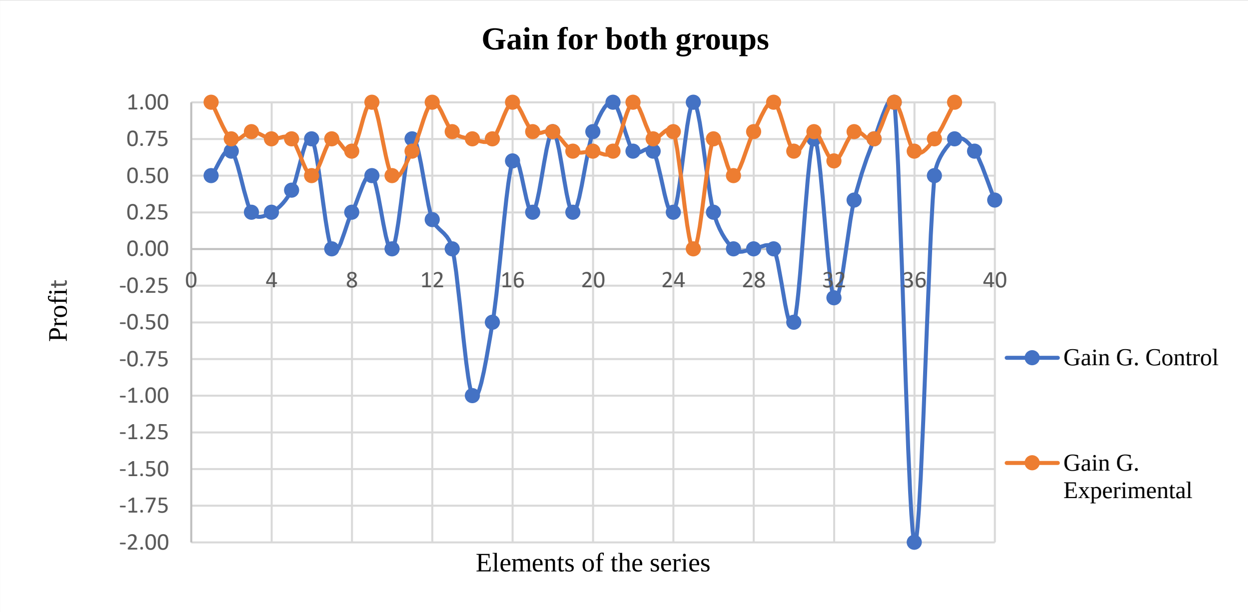

Figure 3: *The results of the normalized gain for the third application are shown. The orange dots represent the experimental group, while the blue dots correspond to the control group.*

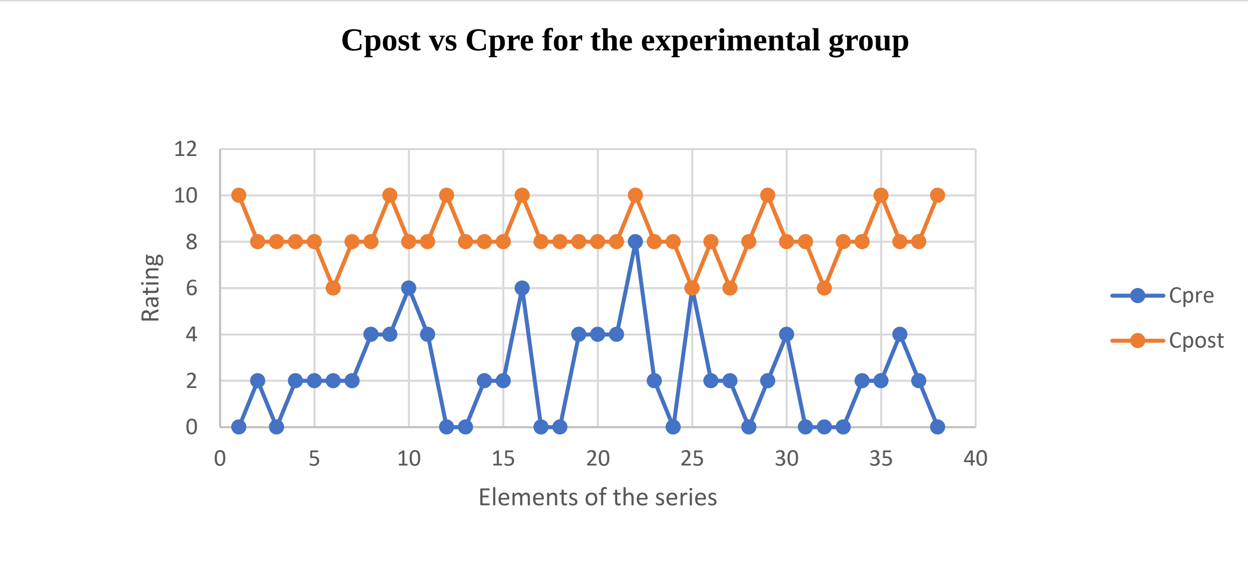

Figure 4 *shows the results of Cpost vs Cpre for the experimental group in the third application. The orange line corresponds to Cpost and the blue line to Cpre.*

In the experimental group, only one student obtained the same grade in the *Cpre* and the *Cpost* while the others obtained a notably higher grade in the *Cpost*, which is consistent with the qualitative results.

Results And Discussion

The students' main preconceptions associated force with motion and attributed force to an internal quality of objects. These prior ideas were similar, and the differences in the averages are due to some spontaneous responses since, except for five students, all of them considered that when throwing a ball upwards, the force decreases as the object rises; however, this seems to be a conception without roots, since it comes from an automatic intuition, which Kahneman (2011) defines as system 1, which response quickly without stopping to evaluate the results.

This seems to occur because in the experimental group when asked if they agreed that the force at the highest point of the ball's trajectory was zero since this was deduced from their belief, they said yes, but when asked to stop and analyze their answer, and to think about if the force there is zero, then why does the object begin to accelerate again, by themselves, they ended up concluding that their premises were wrong.

Similarly, when asked the question about a box being pushed on the floor with constant velocity, all students considered that the box would come to a complete stop when they stopped pushing it. Again, the preconceptions were similar in both groups. However, on the second day of class, the experimental group students visualized how their ideas failed, and all seemed to be aware of their mistakes, so they were enthusiastic about continuing to investigate the topic.

In quantitative terms, the students in the experimental group had a 25% better average performance than the control group, and this was ratified by the qualitative analysis, where it is seen that the ideas of force associated with the movement have been overcome, as well as force as a property of objects, while in some members of the control group, these ideas persisted after the subject was developed.

Conclusions

According to the results of the three applications of the didactic sequence, there is a certain uniformity in the students' prior ideas, and these coincide to some extent with Aristotle's physics; force is associated with motion and is considered an internal property of objects.

Philosophical reflection has awaken a critical and self-critical attitude in the students, which will contribute to the questioning of their conceptions in other subjects and other classes, and also encourages the willingness to change these alternative concepts. Likewise, it is observed that philosophical discussion allows students to develop more clarity in their exposition of ideas, thus strengthening the learning process.

From the synthesis of our qualitative and quantitative results, it can be inferred that philosophical reflection contributes to a better understanding of the concept of force in Newton's second law and awakens a genuine interest in learning because such reflection arouses positive emotions in students.

Although introducing philosophical reflection in teaching requires more time and effort from both the teacher and the student, it represents a great opportunity to overcome previous ideas. On the other hand, time could be optimized if the three laws of motion were included in the same didactic sequence instead of dealing only with the second law.

The results obtained in this research favor the hypothesis that "philosophical reflection contributes to an appropriate conceptual evolution that culminates in a better understanding of the concept of force in Newton's second law."

The didactic sequence, guided by philosophical reflection and based on the theory of conceptual change, can be developed not only for the concept of force, but for many other topics within physics whose conceptual structure has philosophical implications.

Thus, apart from the results of the control group, the sequence showed a great incidence in improving the students' construction of arguments. Students also interpreted the proposed problems with greater agility by introducing philosophical reflection in the class. This has to do with the fact that reflecting philosophically on something broadens the vision of the object of reflection.

As for the student's attitude towards the development of the topic, with the philosophical reflection, a greater involvement of the students was achieved, and this can be seen in the standard deviation of the *Cpost* results, which is considerably small and reflects a certain homogeneity in the learning process.

Acknowledgment

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