What does Newton's second law say? A comparison between Principia and university and school physics texts in Chile.

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ABSTRACT

Traditional teaching focuses on memorizing formulas and problem solving, especially in mechanics, crucial in secondary education and teacher training. The difficulty of understanding Newton's second law is discussed, attributing it to erroneous preconceptions about force and acceleration. It is suggested to teach the law from Newton's original formulation for a deeper and more contextualized understanding. The present work addresses the perception of physics students, especially in Chile, about the discipline, where it is considered boring, difficult and disconnected from everyday life. A comparative analysis is carried out on how Newton's second law is taught in university and schoolbooks in Chile, observing differences in the mathematical formulation and conceptual approach. The importance of promoting a reflective and contextualized approach in teaching physics is highlighted to develop problem-solving skills and connect concepts with reality. In summary, a change in physics teaching focused on a deep understanding of concepts and the contextualized application of fundamental laws, such as Newton's second law, is advocated to promote meaningful and lasting learning.
Keywords: Newton 2nd Law, physics education, Mechanics.

INTRODUCTION

When [1] claim that physics students see it as a boring and very difficult science, that is far from their daily context, and also has a large amount of mathematics this idea connects with what [2] point out when they propose that high school students in Chile believe that physics classes should always have a mathematical exercise.

Thus, it has been found that school physics teaching has a traditional approach, which focuses on teaching content and formulas to solve common problems [3] which, as has been said, reaffirms the position of needing to solve exercises by school physics students.

These ideas have to do with the topics that must be addressed in the teaching of school physics, in which, according to [4] mechanics plays a predominant role in high school courses, since it is expected that with these contents high-school students can work on scientific skills at this educational level. Considering this relevance of mechanics courses, in teacher training processes one or two courses should be assigned only to these contents so that teaching strategies can be proposed to improve the learning of Physics.

This idea is reinforced when one thinks that, in the training of physics teachers, they must learn mechanics. According to [6] mechanics is considered fundamental for the learning of physics and therefore should be part of teacher training programs [6]. These same authors point out that learning mechanics is so relevant that it should be understood as the space that will determine the “rules of the game”, since it is in the mechanics course where the main tools of physics are defined, and the most universal laws of nature are present [5; 6].

Within the subject of mechanics, there are different conceptual elements, such as the laws of conservation of energy or momentum, kinematics or dynamics. It is in the latter that Newton's second law of motion is found.

Newton's second law is relevant to the learning of physics because it establishes relationships between elements that can be observed in daily life: why objects move or why when pushing an object, it has increasingly more speed or less. But this law is extremely challenging for physics students, since, when solving life problems, students tend to generate alternative ideas around the concept of force, such as, for example, that a force is associated with idea of speed and not acceleration [7].

This has generated difficulties in the understanding of Newton's second law in school classes. The analysis of the information provided and the way in which problems are solved in different contexts call into question the students' conceptual understanding of said law [5].

Thus, [7] points out that Newton's second law is extremely difficult because it is associated with preconceptions that forces generate velocities and not accelerations. Based on the above, it is noted that contextual reasoning is opposed to students understanding physics as a unified and coherent explanatory framework [7]. This means that when students are proposed a different context for solving problems, it could present many difficulties in its resolution.

RESEARCH QUESTION AND OBJECTIVE

The question guiding this study is the following: What is the difference between the definition of Newton's second law of motion and the way it is taught in teacher training and/or school physics in Chile?

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This is associated with the objective of this article, which is to compare the way in which Newton's second law is proposed in his original work with the way in which this law is presented in the basic texts for teacher training and school physics teaching in Chile.

THEORETICAL FRAMEWORK

In 1687, Isaac Newton proposed in his work Principia, or mathematical principles of natural philosophy, the three laws that described motion. In this work, these laws are proposed axiomatically, so in the edition of the book to which we had access, these laws were not demonstrated. In this research, ff the three laws proposed there, we will pay main attention to the second law, which is stated as follows in the Principia [8].

> "The quantity of movement is the measure of it, arising from the speed and the amount of matter together"

When interpreting this statement in mathematical terms, it is found that Newton's statement seems to correspond to $F\Delta t = \Delta(mv)$, and not to $F = m * a$, that is, what Newton proposed is more related to the ideas of quantity of movement or momentum than to the idea of force, which was adopted by Euler in 1752 in his book Discovery of a new principle of Mechanics [8].
In this sense, it is possible to ask why Newton's second law is taught as $F = m * a$, in university or school physics? Why do we still call the formulation $F = m * a$, Newton's second law and not Euler's or Newton-Euler's law?
Although it is true that by carrying out algebraic work it is possible to relate the two expressions that have been proposed, the question remains as to why a law should be worked in one way and not another. Today, this difference proposes a teaching possibility for physics as a science that is built throughout history. Since, according to [8] both formulations of the law, Newton's and Euler's, have 60 years apart approximately, why not take advantage of this to work on the idea that science is not ahistorical and that it is built from what someone did before?
Continuing with the idea of the opportunities that would arise when working on the law as originally formulated by Newton, it is possible to propose the following learning sequence around the idea of momentum. From the original formulation $F\Delta t = \Delta(mv)$ it is possible to work on the quantity of movement and from it its conservation law, this is a didactic change in the way this law is approached, since it again allows a historical transition, even to Einstein's postulates, when he points out that the laws of conservation of energy and momentum must be fulfilled in any system.

METHODOLOGY

For the analysis, four so-called "classic books" in the teaching of university physics and three books that are used in the teaching of physics at the school level in Chile have been selected. Then, we look for the way in which each of these texts defines Newton's second law.
In each of the selected texts an attempt has been made to answer the following questions: How is Newton's second law defined for teaching physics at both the university and school levels?
To what extent are these definitions of Newton's second law close to what the same author proposes in his work Principia?
After stating Newton's second law, in what way do each of these texts, used for university or school training propose, their mathematical work?

Once the texts have been selected, their definition of Newton's second law was copied and said definition was added to Table 1. After having the information organized in Table 1, the elements in common that Newton's definition has with the definitions found in these texts were analyzed, and finally a search was carried out in each book on the way in which each of these texts was used in the training propose working on Newton's second law.

RESULTS

After selecting the texts, the definitions of Newton's second law and its mathematical statements have been copied. This is seen in Table 1.
In the first row of Table 1 you can see what is found in Newton's book Principia, written in 1687, and the mathematical statement that can be interpreted from the definition, since said mathematical expression is not found in the book itself.

Table 1. Definitions of Newton's second law

	Source	Definition of Newton's second law	Mathematical formulation
	Principia	"The quantity of movement is the measure of it, arising from the speed and the amount of matter together"	$F\Delta t = \Delta(mv)$
University level Physics	Tippens	[The change in velocity per unit of time is defined as acceleration a. Newton showed that there is a direct relationship between the applied force and the resulting acceleration. This principle is postulated in Newton's second law.]	$F_N = ma$
	Serway	[Newton's second law answers the question of what happens to an object that has one or more forces acting on it.	$F_N = ma$
	Giancoli	The mathematical relationship, as stated by Newton, establishes that the acceleration of an object is inversely proportional to its mass.	$F_N = ma$
	Sears Zemanzky	Newton's second law of motion: If a net external force acts on a body, it accelerates. The direction of acceleration is the same as the direction of the net force. The net force vector is equal to the mass of the body multiplied by its acceleration]	$F_N = ma$
High-school level	2nd year	. He then stated Newton's second law, also known as the principle of masses,	$F_N = ma$

Physics	SM, 2018	which states the following: If a net force acts on a body, it will acquire an acceleration directly proportional to the applied force, where the mass of the body is the constant. of proportionality.]	
	2nd year CPE 2020	[the principle of masses or Newton's second principle, which is stated as: The acceleration that a body acquires is directly proportional to the net force acting on it and inversely proportional to its mass]	$F_N = ma$
	Conceptual Physics Hewitt, 2008	[the principle of masses or Newton's second principle, which is stated as: The acceleration that a body acquires is directly proportional to the net force acting on it and inversely proportional to its mass]	$F_N = ma$

After the definitions were found, the way in which university or school texts propose to work on Newton's second law was sought. For this analysis it is necessary to point out the difference between a problem and an exercise for science teaching. Thus, [9] propose that the exercises can be resolved without too much work, while the problems involve more work on the part of the student, especially if the problems are contextualized to the real world. This is complemented by what [10], propose when they discuss that physics students have more problems solving the qualitative part than the quantitative part when faced with problem solving.

Thus, the following examples are found in university texts.

In Tippens' text there is an example of an exercise on Newton's law that is proposed to work on this law mathematically.

Una fuerza resultante de 29 N actúa sobre una masa de 7.5 kg en dirección Este. ¿Cuál es la aceleración resultante?

Plan: La fuerza resultante se da por la ecuación $F = ma$, y la aceleración está en la misma dirección que la fuerza resultante.

Solución: Al resolver para a, obtenemos

$$a = \frac{F}{m} = \frac{29\text{ N}}{7.5\text{ kg}}; \qquad a = 3.87\text{ m/s}^2$$

Por tanto, la aceleración resultante es 3.87 m/s^2 dirigida hacia el Este.

Example 1: example of exercise resolution in Tippens

A resultant force of 29 N acts on a mass of 7.5 kg. in the east direction. What is the resultant acceleration? Plan: the resultant force is given by the equation F=m*a, and the acceleration is in the same direction as the resultant force. Solution: solving for "a", we get a=F/m=29N/7.5 kg; a=3.87 m/s^2. Therefore, the resultant acceleration is 3.87 m/s^2 directed eastward.

In the Serway, an exercise is proposed that has differences from the previous one, since in this example more elements are seen than just the resolution of the exercise, such as, for example, there are more steps than a plan and its resolution. Here, an initial conceptualization is proposed, that conceptualization is reanalyzed and then the exercise is completed. On many occasions one might think that this is a problem, but for this it is necessary that the students who intend to solve this situation do not know what tool they should use to reach their solution.

EJEMPLO 5.1 **Un disco de hockey que acelera**

Un disco de hockey que tiene una masa de 0.30 kg se desliza sobre la superficie horizontal sin fricción de una pista de patinaje. Dos bastones de hockey golpean el disco simultáneamente, y ejercen las fuerzas sobre el disco que se muestran en la figura 5.4. La fuerza $\vec{F}_1$ tiene una magnitud de 0.5 N y la fuerza $\vec{F}_2$ tiene una magnitud de 8.0 N. Determine tanto la magnitud como la dirección de la aceleración del disco.

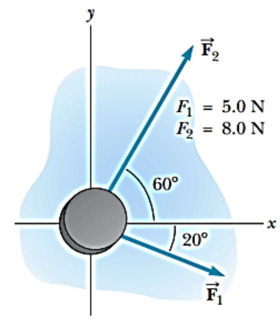


Figura 5.4 (Ejemplo 5.1) Un disco de hockey que se mueve sobre una superficie sin fricción está sujeto a dos fuerzas, $\vec{F}_1$ y $\vec{F}_2$.

SOLUCIÓN

Conceptualizar Estudie la figura 5.4. Use su experiencia en suma vectorial del capítulo 3 y prediga la dirección aproximada del vector de fuerza neta sobre el disco. La aceleración del disco estará en la misma dirección.

Categorizar Puesto que es posible determinar una fuerza neta y se quiere una aceleración, este problema se clasifica como uno que se puede resolver aplicando la segunda ley de Newton.

[2] El *slug* es la unidad de masa en el sistema usual estadounidense y es la contraparte de la unidad del SI de *kilogramo* en dicho sistema. Puesto que la mayoría de los cálculos en el estudio de la mecánica clásica están en unidades del SI, el slug se usa rara vez en este texto.

Analizar Encuentre la componente de la fuerza neta que actúa sobre el disco en la dirección *x*:

$$\sum F_x = F_{1x} + F_{2x} = F_1 \cos(-20°) + F_2 \cos 60°$$
$$= (5.0 \text{ N})(0.940) + (8.0 \text{ N})(0.500) = 8.7 \text{ N}$$

Encuentre la componente de la fuerza neta que actúa sobre el disco en la dirección *y*:

$$\sum F_y = F_{1y} + F_{2y} = F_1 \text{ sen}(-20°) + F_2 \text{ sen } 60°$$
$$= (5.0 \text{ N})(-0.342) + (8.0 \text{ N})(0.866) = 5.2 \text{ N}$$

Aplique la segunda ley de Newton en forma de componentes (ecuación 5.3) para encontrar las componentes *x* y *y* de la aceleración del disco:

$$a_x = \frac{\sum F_x}{m} = \frac{8.7 \text{ N}}{0.30 \text{ kg}} = 29 \text{ m/s}^2$$

$$a_y = \frac{\sum F_y}{m} = \frac{5.2 \text{ N}}{0.30 \text{ kg}} = 17 \text{ m/s}^2$$

Encuentre la magnitud de la aceleración:

$$a = \sqrt{(29 \text{ m/s}^2)^2 + (17 \text{ m/s}^2)^2} = 34 \text{ m/s}^2$$

Localice la dirección de la aceleración en relación con el eje positivo *x*:

$$\theta = \tan^{-1}\left(\frac{a_y}{a_x}\right) = \tan^{-1}\left(\frac{17}{29}\right) = 30°$$

Finalizar Los vectores de la figura 5.4 se pueden sumar gráficamente para verificar lo razonable de la respuesta. Puesto que el vector aceleración es a lo largo de la dirección de la fuerza resultante, un dibujo que muestra el vector fuerza resultante ayuda a comprobar la validez de la respuesta. (¡Inténtelo!)

Example 2: example of exercise resolution in Serway

A hockey puck having a mass of 0.30 kg slides on the frictionless horizontal surface of a skating rink. Two hockey sticks hit the puck simultaneously, and exert the forces on the puck shown in figure 5.4. Force FS1 has a magnitude of 0.5 N and force FS2 has a magnitude of 8.0 N. Determine both the magnitude and direction of the acceleration of the disc.

SOLUTION

Conceptualize Study Figure 5.4. Use your experience in vector addition from Chapter 3 and predict the approximate direction of the net force vector on the disc. The acceleration of the disc will be in the same direction.

Categorise. Since it is possible to determine a net force and you want an acceleration, this problem is classified as one that can be solved by applying Newton's second law.

Analyse. Find the component of the net force acting on the disc in the x-direction:

Find the component of the net force acting on the disc in the y-direction:

Apply Newton's second law in component form (equation 5.3) to find the x and y components of the acceleration of the disc:

Find the magnitude of the acceleration:

Locate the direction of the acceleration relative to the positive x-axis:

Finish The vectors in figure 5.4 can be added graphically to verify the reasonableness of the answer. Since the acceleration vector is along the direction of the resultant force, a drawing showing the resultant force vector helps to check the validity of the answer (Try it!).

In Giancoli, an exercise is proposed that, similar to what happened in Tippens, starts with a statement and ends simply with the way in which the exercise should be solved.

EJEMPLO 4–2 ESTIMACIÓN Fuerza para acelerar un automóvil rápido. Estime la fuerza neta necesaria para acelerar *a*) un automóvil de 1,000 kg a $\frac{1}{2}g$; *b*) una manzana de 200 g a la misma rapidez.

PLANTEAMIENTO Utilizamos la segunda ley de Newton para encontrar la fuerza neta necesaria para cada objeto. Esto es una estimación (no se indica que $\frac{1}{2}$ sea preciso), así que se redondea a una cifra significativa.

SOLUCIÓN *a*) La aceleración del automóvil es $a = \frac{1}{2}g = \frac{1}{2}(9.8\,\mathrm{m/s^2}) \approx 5\,\mathrm{m/s^2}$. Usamos la segunda ley de Newton para obtener la fuerza neta necesaria para lograr esta aceleración:

$$\Sigma F = ma \approx (1000\,\mathrm{kg})(5\,\mathrm{m/s^2}) = 5000\,\mathrm{N}.$$

(Si usted está acostumbrado a las unidades inglesas, para tener una idea de cuánto es una fuerza de 5000 N, divida ésta entre 4.45 N/lb y obtendrá una fuerza de aproximadamente 1000 lb).

b) Para la manzana, $m = 200\,\mathrm{g} = 0.2\,\mathrm{kg}$, por lo que

$$\Sigma F = ma \approx (0.2\,\mathrm{kg})(5\,\mathrm{m/s^2}) = 1\,\mathrm{N}.$$

Example 3: example of exercise resolution in Giancoli

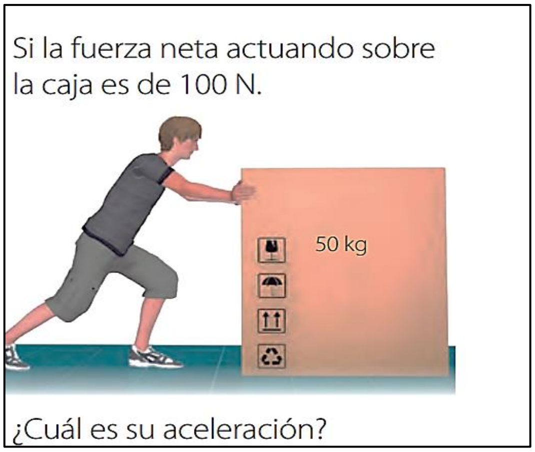
Force to accelerate a fast car. Estimate the net force needed to accelerate a) a 1,000 kg car to b) a 200 g apple at the same speed. We use Newton's second law to find the force required for each object. This is an estimate (it is not stated to be precise), so it is rounded to a significant figure.

SOLUTION a) The acceleration of the car is
We use Newton's second law to get the net force needed to achieve this acceleration: a) The acceleration of the car is
this acceleration:
(If you are used to English units, to get an idea of how much a force of 5000 N is, divide it by the number of Newton's second law.
a force of 5000 N, divide this by 4.45 N/lb and you get a force of about 1000 lb).
(b) For the apple, m 200 g 0.2 kg, so
∑F = ma L (0.2 kg) A5 mys2B = 1 N.

RUN: From Figure 4.18, only the force of 20 N has a non-zero x-component. Therefore, the first relation of equations (4.8) tells us that

EVALUATE: The acceleration points in the 1x direction, as does the net force. The net force is constant, so the acceleration is constant. If we know the initial position and velocity of the box, we can calculate its position and velocity at any subsequent instant using the equations of motion with constant acceleration in chapter 2.
It should be noted that, to obtain ax, we did not have to use the y-component of Newton's second law, equation (4.8). Using this equation, can the reader show that the magnitude n of the normal force in this situation is equal to the weight of the box?]

In school physics in Chile, it is found that:
An exercise is proposed in which, rather than carrying out a deep analysis of the situation in which the person is observed, students are asked to solve an equation, since they have been given a mathematical expression and then asks them to replace it in a function, since you assign values to a variable and then get a result.



Example 5. Example of exercise resolution in a school physics textbook in Chile

If the net force were 100N. What is its acceleration?

On the other hand, in the second school physics text consulted, a greater development of the process that must be done to solve the exercise is observed, but the idea is maintained that values are given to the students and after analyzing the situation they must put these values into an equation to get the requested answer.

In what is defined as the penultimate step, it is proposed to write the answer, this statement leaves space free so that when writing, the students can associate what they have done with elements of their daily life. However, the book only indicates that what you should do in that step is give a numerical answer.

With the examples that have been found in the various texts that have been analysed, it is relevant to note how there is a relationship between what happens with the teaching of Newton's second law in the training of physics teachers in Chile and the way it is proposed in the texts used in school teaching, even existing a relationship in the type of activity following the statements, since traditionally there was an example and then exercises to solve equations related to the second law. However, this can also be associated with the learning problems associated with this law, since it is associated with elements that are not very commonplace, that motion is associated with velocity rather than acceleration [7].

CONCLUSIONS

There is a difference between what Newton proposes to address as his second law of motion and the way it is worked on in the teaching of physics in Chile. From here we can propose the possibility of working on the second law in the way its author formulated it and from there make a development with the quantity of movement, its variation and the relationship with the idea of force, the conservation of the quantity of movement and its importance for the historical development of physics and how Einstein proposes that this law must be preserved, even if objects move at the speed of light.

Four texts popularly used in the training of physics teachers in Chile have been reviewed and in all of them it has been found that the approach to Newton's second law of motion differs from what the author had proposed in his original work. From this analysis, the question arises as to why this law is taught in this way and not as it was originally proposed?

Since there is a difference in the way Newton's second law is taught at university, it was to be expected that this would be the case in the texts used for the teaching of physics at school. In the three texts to which we had access, the second law is taught according to what happened in teacher training, generating this distance between the original work and its teaching.

Furthermore, it is worth noting that, in the texts reviewed, whether for university or school physics, the teaching of Newton's second law is associated with the resolution of exercises, more similar to solving equations than to working with problems that imply a relationship with the reality that one is trying to explain from the sciences, and in this particular case, physics.

The elements found in the texts that were reviewed point out differences in the enunciation of the law and in its mathematical formulation. Without further background it is difficult to indicate the reasons that lead the authors of said texts to propose the differences that have been discussed. One could only speculate about a possible continuity in the teaching of the law, that is, the authors of the texts were taught that the law was one way and they have continued to repeat it in the writings that they have developed. This can be ventured, because there are no major differences in the mathematical handling required to work with free body diagrams or the superposition of forces on an object and what happens with the momentum and its conservation.

What has been found after this review proposes a challenge for the teaching of physics, particularly mechanics and more specifically Newton's laws, since, if the teaching of these laws continues in a transmissive methodology, in which the lesson is oriented towards learning to solve quantitative problems such as those that appear in physics study books -which are solved by teachers without giving space for future teachers to look for their own ways of solving physics problems [11]. This, according to the same authors, causes students to be unable to explain the meaning of their own numerical solutions, which generates little development in skills and procedures associated with problem solving and, above all, a disconnection with reality [11].

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