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Conceptual Construction in Physics Using Inductive Teaching Methods

Construcción conceptual en física a través de métodos didácticos inductivos

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Abstract

This contribution shows the development and evaluation of an educational process with mathematics teachers in training, focused on the use of teaching strategies with inductive characteristics, in Mathematics and Physics subject of the Bachelor's Degree in Mathematics Teaching at the University of Colima, Mexico. The experience includes 19 students, who have had disciplinary training in mathematics and master the procedural knowledge and algebraic language involved in Physics at the basic levels, but they have had little access to conceptual knowledge of both classical physics and modern physics. With this principle, the course focused on reflection and problem solving. From this logic, the proposal included searching for both the procedural and conceptual domain, this second one is the central objective of this research. The inductive methods included the use of audiovisual materials and readings that go more in the order of dissemination. The results of their work show that, without omitting a more traditional training process, such as problem-solving or classic physics textbooks, the incorporation of inductive strategies focused on the concepts like "motion" or "light" allows for a deeper understanding of fundamental principles, serving as a functional complement for a more comprehensive understanding.

Keywords

Conceptualization, Inductive Method, Teaching Strategy, Scientific Dissemination, Physics, Evaluation.

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Resumen

El presente texto muestra el desarrollo y la evaluación de un proceso educativo con profesores de matemáticas en formación, centrado en el uso de estrategias didácticas con características inductivas, en el marco de la asignatura Matemáticas y Física de la Licenciatura en Enseñanza de las Matemáticas de la Universidad de Colima, México. La experiencia incluye a 19 estudiantes que han tenido formación disciplinar en matemáticas y dominan el conocimiento procedimental y el lenguaje algebraico que implica la física en los niveles básicos, pero con poco acercamiento al conocimiento conceptual, tanto de física clásica como de física moderna. Bajo este principio, el curso se centró en la reflexión y la resolución de problemas. Desde esta lógica, la propuesta incluyó buscar, tanto el dominio procedimental como conceptual, siendo este último el objetivo central de esta investigación. Los métodos inductivos incluyeron la utilización de materiales audiovisuales y lecturas que van en un sentido de divulgación. Los resultados de sus trabajos muestran que, sin omitir un proceso formativo de corte más tradicional, como la resolución de problemas o libros de texto de física clásicos, la incorporación de estrategias inductivas sobre las particularidades de conceptos como "movimiento" o "luz" permite una comprensión más profunda de principios fundamentales, siendo un complemento funcional para una formación más integral.

Palabras clave

Conceptualización, método inductivo, estrategia didáctica, divulgación científica, física, evaluación.

Introduction

The idea of rigid boundaries between the social sciences, the experimental sciences, and the humanities has been left behind. While it is clear that the objectives pursued by these areas of knowledge are different and the ways to learn their contents are also different, in recent decades there has been a debate with greater openness about the social and human implications behind the construction of scientific knowledge also in the experimental sciences, in the case of this contribution, physics. Intercultural science, ethnomathematics, scientific enculturation or mathematics and sciences for citizenship and human rights, are some examples, among many others, of emerging lines of research in this regard.

The objective of this study is to evaluate and make visible the effectiveness of using inductive didactic strategies to strengthen conceptual understanding in topics related to physics, emphasizing how this type of approach can contribute to a more comprehensive and meaningful learning. In this sense, the proposed strategies, without neglecting more conventional activities such as specialized reading or text-based problem solving, are incorporated to help overcome the limitations of processes focused solely on the procedural or technical skills of physics. The methodology of analysis was based on the approaches of Ahumada (2005) regarding the construction and evaluation of concepts.

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This research is carried out within the framework of the Bachelor's Degree in Teaching Mathematics, a degree attached to the Faculty of Educational Sciences of the University of Colima. This program aims to train professionals capable of addressing challenges in teaching and learning mathematics, promoting mathematical literacy and didactic innovation with a social responsibility approach.

The particularity of the program is the integral approach between a training in the disciplinary area of mathematics, a training in the pedagogical disciplinary area and a third axis that refers to specific didactics on arithmetic, geometry, probability and calculation. The majority of those who have graduated have joined as teachers at the basic levels and at the upper middle level, a few cases at the higher level. Those of us who participated in this program as professors have been able to realize that many of these job additions of those who graduate, are not only due to the specific need for staff trained in mathematics by the applicant institutions, but also for related subjects, particularly physics. This has then become a specific need of the program.

Although the participating group had detected a strong mastery over solving problems involving mathematics and physics with respect to the algebraic domain, this intervention focused on overcoming the common limitation of approaching conceptual understanding as simple memorization of definitions. Instead, the construction of concepts as a dynamic and evolving process was promoted. This approach seeks to equip future teachers with stronger tools to foster comprehensive scientific literacy.

The methodological proposal is inserted in a formation that transcends the domain of mathematical algorithms, integrating characteristics of the student population. While these students have a strong background in mathematics and pedagogy, their knowledge of basic sciences, particularly physics, was limited to superficial and brief previous experiences that had not been linked to mathematics in any meaningful way. In this context, where we want to promote meaningful learning and scientific literacy, using inductive methodologies favors and is in tune with educational trends that seek to integrate theoretical and practical knowledge, as reflected in various recent research and which will be mentioned later.

It is here that the proposal of work from inductive strategies for the understanding of specific concepts of physics is considered as a relevant strategy. Thus, the implementation of inductive activities was carried out with 19 students of the University of Colima, including the observation of

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audiovisual materials, informative readings and direct experimentation, organized in seven thematic blocks such as movement and light, among others. This work methodology, which includes principles of constructivist approach, encompasses an epistemological approach based on the fact that the construction of knowledge in physics—in this conceptual case—must consider basic or experimental sciences as a human activity, which cannot be disconnected from the sociohistorical conditions in which such knowledge has been, and continues to be, created (Díaz, 2013).

From here, the thematic discussion through historical readings, dissemination of science, the use of audiovisual materials and specific experimental activities that make links, both implicit and explicit to the concepts in question, promote in the student thought and conceptual construction beyond the memorization of encyclopedic definitions.

This paper first presents a position on the construction of knowledge in physics, followed by a theoretical definition of inductive didactic strategies. The methodology is described below, highlighting the use of scientific and audiovisual dissemination materials as didactic resources. Next, the implementation process of the proposal is detailed, accompanied by evidence of its application to finally present the results obtained, along with a discussion that includes possible guidelines for further research.

Building knowledge in experimental sciences

Although it is not the intention to conduct an in-depth debate on the universal or local construction of knowledge, it is considered important to mention a debate already systematized in greater depth in another contribution made by Díaz (2013), regarding the well-known discussion between Charles Taylor and Thomas Kuhn at Lasalle University. Knowing the complexity of this reference, only some of its fundamental postulates are included. According to Taylor, the construction of knowledge in natural or experimental sciences cannot have a hermeneutic basis, as it is based on the study of data independent of the historical and sociocultural context. Natural world objects of study, for Taylor, are independent of human interpretation processes.

On the other hand, Kuhn argues that the scientific work, also that performed in the experimental sciences, is an intrinsically human activity, influenced by beliefs, prejudices and specific cultural systems. In this sense, the interpretation of natural phenomena is closely linked to the previous experience of each person, so it is crucial to distinguish between

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objects of the natural or physical world and the meanings and interpretations that are assigned to them according to their use. This is clearly seen in astronomy, where stars have had specific cultural meanings throughout history, but have also served practical applications such as construction, time measurement, and orientation.

If one thinks of concepts that are now basic in physics such as temperature, light, electricity, or friction, the discussions must have been very different depending on the geographical or cultural context where they were generated. Would the same questions be asked about friction by those who had ice as a daily element over those who lived in deserts? Would they reach similar conclusions? Probably not. It can also be thought that, in the current epoch, with so much information available in real time, it is difficult for these ambiguities to happen, however, the case of Pluto can be resumed, because according to recent conclusions, it has ceased to be a planet. Interpretations and parameters continue and will continue to change.

This is not intended to deny or ignore the universal elements of knowledge in physics, but to emphasize that this knowledge is the result of multiple discussions, experiences and particular contexts that had an influence on those who contributed to the discoveries and systematization of knowledge. This process is commonly overlooked in educational processes that limit themselves to memorizing definitions presented as absolute truths in educational books, and shows that knowledge in physics is dynamic, unfinished and constantly under construction.

To mention one example, understanding a widely accepted principle such as the "law of universal gravitation" does not require each student to "rediscover" it as a condition for understanding it, but it does require understanding its formulation processes, the historical and cultural conditions that facilitated its formalization, as well as its current applications. It is in this context that the inductive approach presents as a tool that can enhance the transit of particular situations to the understanding of generalities, not only in fundamental concepts such as gravitation or movement—as will be explained later—but also in other areas of knowledge. This approach allows those who study to establish significant connections between the theoretical and the practical, favoring a conceptual construction adaptable to various topics and levels.

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Inductive didactic strategies

In a very general way, the inductive-deductive method consists of two opposite processes. Induction refers to a way of reasoning moving from situations to more general knowledge, which in turn reflects what is common in particular situations. It is based on finding the common characteristics to arrive at generalizations that have an empirical base (Rodríguez & Pérez, 2017). For authors like Dávila Newman (2006, p. 184), inductive reasoning favors accumulating knowledge from particular experiences, while deductive reasoning helps to organize this knowledge in a more general panorama.

Both deductivism and inductivism pose the same problems. In both cases, the starting point is to indicate a method or strategy that allows general statements to be justified to an undefined number of cases—or universal generalities—while justifying a cognitive value (Andrade *et al.,* 2018). Inductive reasoning is not only useful within research processes, but also allows links between observation and theory or formalization.

There are several advantages from the construction of knowledge that various authors point out for methods or inductive strategies. Repetto (2024) or Moreno and Corral (2019), refer to the fact that one of the potentialities of this type of strategies is that they not only seek the abstraction of general patterns, but also promote contextualized learning, an understanding of local reality and the development of critical dialogs. For their part, Palmett (2020) and Monroy (2004), highlight the consolidation of new knowledge from the observation and systematic recording of particular phenomena from the empirical. This collection of data within the inductive process allows generating inferences that can later be compared with existing theories.

Induction allows the transition to knowledge based on information that initially seems isolated (Álvarez & Alonso, 2018). This is related to the previous section. If we start from the idea of observation as something that is not limited to the act of sight, but as the trigger for reflection and analysis, the isolated information can serve as components of a specific mental object or in the case that interests in this contribution, a particular concept.

The position of this intervention does not consider that the starting point of the deductive is something negative or that it cannot contribute to the conceptual construction, however, an approach of this type does not refer to all the previous elements involved in the construction

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of a conjecture (Morales, 2008), or in our case, of a specific physical concept. From a teaching inspired by constructivist positions, starting from everyday and particular situations it responds with much more coherence to the process of non-universalist conceptual construction that is wanted to achieve, conceiving the multiple ideas and circumstances that lead to that knowledge. In this sense, if overcoming the idea of objectivity as the main goal in physics or any other experimental science, inductive strategies or methods are useful to minimize subjectivity or relativism in the teaching-learning process (Rivera *et al*., 2024), as they are supported by observations and concrete experiences that allow a deeper and more meaningful understanding of concepts.

In other words, teaching concepts such as a list of definitions and problems or exercises linked to these concepts, such as reconstruction processes or mechanical imitation of what the teacher previously performs or resolves, rarely constitutes a cognitive challenge for the learner. Following with Álvarez *et al*. (2018), from the application of inductive strategies, it is suggested that teachers carry out a kind of "training" towards their students, locating the existence of ideal objects (abstractions) and real objects (physical) to be able to establish the relations between both.

In this sense, it should be noted that part of the proposed methodology with the group of students does consider experimental observation, practical activities that implicitly contribute to the conceptual construction, but is not limited to this. The inductive strategies used, in addition to the experimental activities, involve a series of readings with an informative approach and the use of audiovisual materials, some explicitly designed as outreach products, but others more focused on popular culture, which is explained in greater detail in the next section.

Methodology

This section, which explains the main part of the strategy, does not attempt to go deeper into the definition of scientific dissemination, but does mention, in a general way, some key differences between this and other activities such as scientific dissemination, as well as pointing out its main characteristics. The dissemination and dissemination of science may have similar purposes and methods. But while outreach is about more peer-to-peer communication, it seeks to reach a broader audience, something that originally seemed to be reserved for a minority (Vargas, 2018).

Continuing with Vargas (2018), it is implied that in addition to the knowledge to be disseminated, the strategies and the means to do so, the-

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re is a definite recipient. This last element implies considering that the target population should be defined according to its interests, should be fully committed to that population and should select – finally and responsibly – the material and quality of the information. This last aspect highlights the elaboration of structured questions that attract attention and show the relevance of the topic.

It might seem unusual for undergraduate students with a solid background in mathematics to be considered a suitable population for developing science outreach strategies. However, it is precisely in this context that such materials and the triggering questions of discussion become relevant. As mentioned, the main problem identified in this group was their limited conceptual mastery of physics; the above derived and also corroborated by their testimonies, as well as the observations of several of their teachers. They had little contact with these topics, particularly from the constructivist approach that is sought in this work, i.e., to encourage the conceptual construction for its future teaching. It is important to note that, although this contribution focuses on the conceptual approach, the mechanized mathematical processes related to each topic were also integrated into the sessions as a complementary part.

The informative readings used were very varied, but as an example two recurring books can be mentioned and also circulate freely on the Internet: *For the love of physics* (Lewin, 2012) and *Big questions-physics* (Brooks, 2011). As for the first, whose author was known for his dynamic classes and various experiments at the Massachusetts Institute of Technology (MIT), he uses everyday natural phenomena such as rainbows or waves emitted in water when throwing a rock, in addition to simple technological contributions such as elevators or simple scales to illustrate physical concepts. In the words of its author, the objective is to be able to observe what surrounds us in a different, profound and appreciative way. As for the second—unlike Lewin's descriptive, anecdotal, and experimental style—Brooks starts with simple questions about everyday phenomena and how these kinds of questions led to some of the deepest discoveries in physics. From simple elements such as light or rain, they try to answer questions about the nature of time or the laws of physics. The text also mentions biographical parts of great thinkers of physics such as Newton or Maxwell considering the context in which their discoveries were made.

In a different way, both Lewin and Brooks use analogies as a constant resource, making comparisons in hypothetical situations that could hardly occur to us, such as falling from an elevator or a building, with situations

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that we commonly live, such as getting on a scale or tripping. In this sense, Lima and Gómez (2024, p. 108) say that analogies are extremely useful for understanding abstract concepts, in addition to low-cost materials and easily accessible resources, which are an ideal bridge to approximate theoretical conceptual construction to everyday or recognizable situations for students. Both, the use of analogies and the use of low-cost materials are transversal to this proposal, since they are incorporated, respectively, in the dissemination readings and in the experimental activities.

As for the audiovisual materials used, these were much more varied. Explicitly popular documentaries were used, for example, such as the series *Cosmos: A Space Odyssey* (Druyan & MacFarlane, 2014) and *Genius by Stephen Hawking* (Bowie, 2016). However, one of the most innovative parts was the inclusion of audiovisual that, in the first instance, can be considered as pure entertainment, but that, being part of pop culture, is an excellent trigger for the discussion of physical concepts. In this sense, films with explicitly scientific plots such as *Gravity* (Cuarón, 2013) or *Tesla* (Almereyda, 2020), as well as superhero films, action films or even cartoons come in. Why including such products?

Some years ago, based on research on social imaginaries through cinema as a didactic resource, I argued about the educational potential of films considered entertainment. In another era it was believed that television and cinema educated or rather "poorly educated", but in recent decades, this perception or prejudice has been diminishing, in part, because now that negative connotation has social networks. This perspective has continued to evolve and authors such as Casallo (2024) refer to the positive impact of audiovisual narratives—in their case from anime—as a vehicle for students to perceive and experience situations that promote personal reflections and critical thinking. In the case of inductive strategies, these products can support the construction of meaning and understanding from observing and discussing concrete experiences. These types of narratives linked to science fiction, although far from possible scientific or technological elements such as time travel, teleportation or any "superpower", are the ones that have been used most for teaching. Why? Most likely, beyond their popularity, it is because, presenting clearly implausible elements from the scientific facts, they are precisely an excellent excuse for counter-argumentation (Cuevas, 2020).

Why cannot anyone run like *The Flash* does in its latest film adaptation (Muschietti, 2023)? Why is it impossible to fight two creatures like King Kong and Godzilla as can be seen in the most recent film of these

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characters (Wingard, 2024)? Why cannot there be explosions in space as seen in *The Rise of Skywalker* (Abrahams, 2019)? Why can one travel to the future as Stephen Hawking say, but not to the past as in the *Back to the Future* (Zemeckis, 1985) or *Terminator* films (Cameron, 1984)? These ideas, so accepted while being observed on screen, but so far away when we discuss them as something really possible, are simple to compare with technology and known science, therefore, they require precisely a minimum of notions to be refuted, especially when discussing in introductory courses to scientific disciplines or with students of basic levels, level where future teachers who participate in this intervention are expected to be inserted at work.

Participating Group

Nineteen students, 7 men and 12 women, participated in the Bachelor's Degree in Teaching Mathematics at the Faculty of Education Sciences, belonging to the sixth and eighth semesters. It should be noted that the subject is optional, so in the first instance all participants were interested in the subject over other options linked to didactics.

The process took place in the period January-July 2024. The subject, as mentioned above, does not correspond to an in-depth approach to physics, since, within the same institution, especially in the Faculties of Science and Engineering, courses on these contents are given that cover several semesters. It can be considered an introductory course at the disciplinary level, but emphasizing didactic processes for future teachers of basic and upper middle levels.

Materials and phases of the intervention

The group participated in its entirety throughout the process and the themes were divided into seven blocks:

- Measurements and inaccuracies
- Newton and the movement
- Conservation of energy
- Electricity
- Magnetism
- Light and color
- Relativity

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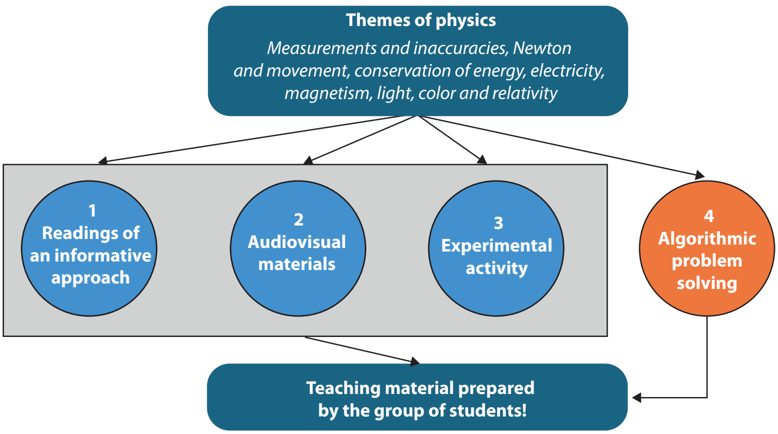
For illustrative purposes of this contribution, it is chosen, as a *corpus* of analysis, regarding the theme of movement and the theme of light and color, one of the initial themes and one of the final themes, respectively.

The methodology used for the entire course comprises four phases per block. The first has to do with the conceptual, historical and contextual understanding of each central concept of the topics; the second has to do with the observation of audiovisual materials on the same topic; and the third has to do with the axis focused on the resolution of problems of a mathematical or algorithmic nature. At the end of each of the topics, the students elaborate a mini-project with what they have learned, with the slogan that it is a replicable teaching material for teaching. The elements of the intervention are summarized in Figure 1.

Figure 1
Phases of the intervention process



Before addressing the conceptual construction and its methodology of analysis, it is important, once explained the cut of the *corpus* of analysis to two themes and the final work of the group of students, to briefly describe the readings, audiovisual materials and experimental activities that covered the theme of movement or Newton's laws, and the theme of light and color, in the order that have been mentioned.

Approach to Newton's laws from the disclosure reading

The detonating reading for the concept of movement and related to Newton's laws was "Bodies in motion" from the book *For the love of phy-*

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sics (Lewin, 2012). From an anecdotal and historical perspective, the author covers four main sections. The first refers to the law of inertia or "Newton's first law", where a situation arises that precisely favors an inductive approach. When have we seen a body in permanent motion, without it stopping?

While half of this law seems to be something common, i.e., that a body remains at rest until another force acts on it, it is the second part, i.e., that an object in motion will continue like this until something stops it, where it costs more work to think about the common, because it is difficult to remember such an example. It is here that inertia turns against intuition, according to the author. We have not seen things move in a straight line indefinitely.

This makes the reader think and reason. Concepts such as friction appear, activities such as ice skating are named. From this point the discussion of particular activities or phenomena is favored towards more general conclusions. The sections of Newton's second law (*force* = *mass* x *acceleration*), the confusion between mass and weight, and free fall follow this same logic in the material. Once the central concepts of movement from reading were already introduced, we proceeded to work with audiovisual materials where Newton's three laws could be illustrated in a more dynamic and above all visual context.

Approach to Newton's laws from audiovisual materials

Snippets from the superhero films *Antman* (Reed, 2015), *Captain America: Civil War* (Russo, 2016) and *Avengers: Endgame* (Russo, 2019) were used, the main images of which can be seen in Figure 2. The fragments were three. The first focused on the character's "shrinkage," which led, outside of the unreal possibilities of the plot, to understand the implications of size with respect to the character's movement, as well as its relationship between weight and mass. The second segment, in the same sense of the discussion, focuses on the giant version of the character. Finally, the third segment focuses on the fight between all the superheroes of the Marvel movies, where they undertake a race from the same starting point, some by flying, others by running, others by swinging and also appears the character Antman of the other segments in his giant version, however, all seem to move at the same speed, trigger element of the discussion.

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Figure 2
Movie snippets for the motion theme

Source: taken from Reed (2015) and Russo & Russo (2019).

The second audiovisual element is the film *Gravity* (Cuarón, 2013). Although it is also considered a film of great audience and multi-awarded, the interest lies in asking the group of students to freely locate elements referring to Newton's laws, and whether these are presented correctly or not, arguing in all cases. Gravity, inertia, movement, maneuvers and strategies of the characters, collisions, disintegrations, pressure, decompression and vacuum, are some of the concepts that can be identified and discussed. From the identification and discussion of these already visible concepts, we proceed to experimentation.

Approach to Newton's laws from experimentation

The experimentation in this block was a series of simple activities. The first referred to replicating the experiment attributed to Galileo and the tower of Pisa mentioned in Lewin's first reading, limiting itself to throwing objects with different shapes and densities from a rooftop and analyzing what happened in each case or comparison. A second experiment involved the use of Newton's pendulum and observing why the law of inertia seems not to be enforced, and finally, the use of a rubber rocket to discuss Newton's second and third laws. A third experiment consisted of a speed challenge, which involved walking as fast as possible (without running) for 3 seconds, trying to find the best technique to

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cover as much distance as possible. Once found, it was proceeded to argue the reason of the achievement, and the discussion focused on speed, time and distance traveled.

Approach to the concept of light and color from the dissemination reading

The detonating reading to discuss the concepts of light and color is "above, below, inside and outside the rainbow" (Lewin, 2012). Following the style of concrete and everyday experiences observable in both nature and human activity, the author starts from a personal experience about points of light on his wall, formed by sunlight through the leaves of a tree and how something so simple can generate wonder.

The rainbow is a central element of the text, where the author speaks from a historical perspective about the fascination in scientists like Newton and Haytham with phenomena related to light. The three conditions that are required for a rainbow to be generated are narrated from here: the Sun must be behind the observer, there must be rain in the sky and there must be no clouds that block the light. The diffraction phenomenon is mentioned from the understanding that the (white) light that passes through the water droplets decomposes into the visible colors that our eyes can capture. After a few simple calculations to know the distance and height of a rainbow, he finally mentions some practical tips for searching for rainbows, something that is taken up in experimentation activities.

Approach to the concept of light and color from audiovisual materials

Episode 5 of the *Cosmos* series*: A Space Time Odyssey* entitled "Hidden in Broad Daylight" was used as audiovisual material, which focuses on the exploration of the wave theory of light and how it has been studied throughout history, passing by philosophers such as Mozi or the Arab scientist Ibn Al-Haytham (mentioned in the previous reading), who was among the first to study the nature of light and laid the foundations for the later invention of the telescope.

Another important block of the documentary is the mention of the work of Isaac Newton and his demonstration that light is composed of a visible spectrum by experiments with diffraction through prisms. Von Fraunhoer's work on the spectral lines of visible light and their relationship by the absorption of light by electrons is also addressed. Fo-

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llowing this historical perspective and discoveries, it ends with the bases of astronomy and how we have been able to observe the stars and planets, see their composition, as well as understand the movement and expansion of the universe.

Approach to the concept of light and color from experimentation

The experimentation of this block, unlike the aforementioned movement block, did require very specific materials for its conduction, in addition to some basic infrastructure conditions such as dark spaces. It was divided into three, one for each phenomenon linked to light and color addressed in both the audiovisual material and the detonator reading. A series of experiments linked to reflection, others linked to refraction and others linked to diffraction of light. It is important to note that part of the inductive process refers to not starting from the concepts, but, from this series of experiments; the group of students must identify the properties and characteristics of each observed phenomenon and subsequently draw comparative conclusions. From there, one can then deduce each of the three concepts (reflection, refraction, diffraction).

As for the reflection of light, this is probably the most well-known or everyday of phenomena, since, in the words of the students, we all see ourselves reflected daily in a mirror at least once. However, the activity includes something not so everyday, such as the use of laser pointers and some curved prisms and mirrors as seen in Figure 3, an element that makes visible the changes in the direction of light. In addition to this, an activity is added with a pair of simple mirrors while increasing or decreasing the angle between them, while analyzing whether the reflections or projections of the images seen in the mirrors are increasing or decreasing in number, as shown in Figure 4. For the case of refraction, the experiments are very simple, since they only involve containers of different shapes, mainly spherical and oval, to compare how an object looks in real and apparent situation, similar to when we introduce a straw to a drink, or how an object enlarges when seeing it through a spherical fish tank, alluding to our eyes through a magnifying glass.

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Figure 3
Laser activity

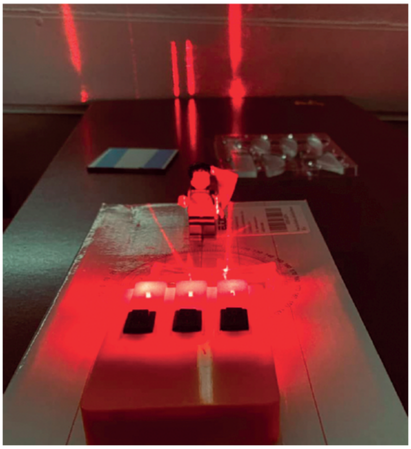

Figure 4
Activity with mirrors on reflection

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Finally, in the case of diffraction, experimentation is somewhat more extensive and sophisticated in terms of specialized material, but at the same time low cost (Figure 5), since this concept or phenomenon is linked at the same time with the central phenomenon of detonator reading and audio-visual material, i.e., the rainbow and the visible spectrum of light. Some challenges and simple questions are launched such as: "Why do we see an apple red?", to speak of how the colors of the objects we see, is the part of the white light that bounces to our eyes, while the rest of the colors of the spectrum does not bounce, but is "absorbed" by the object in question.

The group of students use green and red cellophane filters to see how we perceive the colors of objects through these, which are noticed more or less and what this has to do with the order in which light is diffracted (red, orange, yellow, green, blue and violet). If they have doubts or do not remember what the order of the spectrum is like, they use a low-cost diffraction lens, which is shown in more detail in the analysis of results. Without mentioning diffraction as such, from the "behavior" of the colors in their view to using this variety of filters, students are asked to make a drawing-like design where they can place a hidden message, which is identifiable only from the red filter (cellophane).

Figure 5
Diffraction lenses similar to those used in the class

Source: adapted from Google (2024).

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Method of analysis

The analysis is qualitative since the interest lies in the particular cases of the conceptual construction of each student and the ability to translate it into a specific didactic material. The reference on the construction of conceptual knowledge and its evaluation process starts from the postulates of Ahumada (2005), whose approach is identified with social constructivism, since conceptual knowledge goes beyond the memorization of data or facts, and implies a deeper understanding of the key concepts of an area of knowledge and how these relate. This way of learning concepts allows those who learn to transfer what they have learned to new situations and problems, instead of repeating the information in a mechanical way, something that is more related to the definitions of an encyclopedic nature.

If thinking on such a conceptual construction approach, the evaluation should go in this same direction, far from traditional exams or even standardized tests. Why doing that? This type of testing, centered on memorization, tends to focus on the reproduction of procedures or repetition of data, without requiring that the learner demonstrate a deeper conceptual understanding.

Continuing with Ahumada to evaluate this type of knowledge, an "authentic evaluation" away from traditional exams is proposed, which focuses on more complex and meaningful tasks that reflect everyday situations. These tasks require that conceptual knowledge be applied in problem solving, decision-making, and that its transferability be demonstrated.

This type of evaluation involves some characteristics such as tasks that reflect real-world situations in which the learner applies knowledge in specific products or situations, focusing on the construction process and not only on the final result, and providing information to the learner about the progress and difficulties of the learner. On the other hand, the advantages of this type of evaluation are the promotion of deeper and more meaningful learning, allowing those who learn to demonstrate their (conceptual) understanding in contexts that are recognizable to them. In addition, beyond the above advantages, it also implies some challenges and limitations. The first concerns time and resources to design and grade these types of tasks. It is not that a process of this nature cannot be carried out in large groups, but during an entire course, certain topics should be selected. In the case that corresponds to this contribution, it was possible during an entire school year because it was a group of less than 20 people.

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Another challenge is that this type of proposals can be labeled as too subjective, however, there are proposals for reliability as mentioned in the following section, but ultimately it remains based on the criterion of the professor, his own conceptual domain and the specific objective of each process, the central elements of methodological rigor. Finally, for students who are not accustomed to complex tasks of this type that involve their creativity, it is also suggested to do it gradually.

Instruments

In this type of intervention proposal, assessment tools focus on assessing skills and knowledge in real and contextualized situations, rather than relying (solely) on decontextualized standardized tests. The instruments are many and varied, ranging from rubrics to performance tests (Ahumada, 2005), but for the purposes of this contribution, emphasis will be placed on two: evidence portfolios and projects and presentations.

Portfolios are a somewhat popular tool for assessing progress and achievements. This (organized) collection of evidence can also be consulted by those who study to see their progress. Using the portfolio also promotes evaluating items that are difficult to measure in isolation or with standard tests such as critical thinking or communication. These elements are essential in this contribution because they are essential skills in teaching. Derived from this, reflection and self-evaluation can also be contemplated, since, by reviewing their own work and progress, they can identify strengths and areas for improvement, developing a greater awareness of their learning. Finally, the potential of the portfolio allows others interested in the learning process to become more actively involved, in this case, their peers. This may include reviewing with the rest of the group, and discussing their progress and achievements. They also favor a more complete and authentic image of performance due to the variety of works exhibited.

For its most effective implementation, it is suggested that the objectives be clear and specific. This includes defining the skills and knowledge being assessed. They should also be organized in a way that is relatively easy to follow up. This may include creating specific sections such as topics or time periods. If possible, feedback with the teacher should also be considered. It should be noted that, following online work during the 2019 pandemic, the standardization of educational platforms as a form of habitual work greatly facilitated the use of a portfolio, especially in the

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way it is structured and organized chronologically. In this case, the Google Classroom platform was used. That also facilitates individual feedback.

As for projects and presentations as an evaluation tool, these favor the creativity of those who learn, since there is some flexibility to incorporate, in this case, the concepts addressed with not only everyday situations, but of their particular interest. The evaluation criteria are very similar to those already mentioned in the portfolio, focused on decision-making, communication and critical thinking. For the purposes of the contribution, creativity and innovation were also essential, since we talk about the projects generated were requested with a didactic and replicable intention in the classrooms. A short project was considered for each of the seven thematic blocks; in this contribution the corresponding to the two selected blocks will be shown: movement and light.

Analysis and results

The data are presented in the same order of the analysis *corpus* mentioned in the previous section, starting with the block that refers to the movement (table 1). The selected works are an exercise in thoughtful questions about the film *Gravity* and a series of similar questions about the three video segments of the films *Antman*, *Captain America: Civil War* and *Avengers: Final Game*. Questions regarding the films were:

1. Three hits the film shows regarding Newton's laws.
2. Three errors or inconsistencies shown in the film regarding Newton's laws.

Table 1
Student responses*

Student 1
Analysis exercise, film *Gravity*
1. Three successes of Newton's laws in the film
We can see the law of inertia in every object in space, or the same protagonist who keeps moving when there is nothing to stop them, drifting.
The 3rd law of action-reaction can be seen when the protagonist uses the extinguisher to approach the station, the force that produces it drives her in the opposite direction.
The 4th law of gravitational force is seen in all objects that remain in orbit around the planet.

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2. Three errors or inconsistencies he shows regarding Newton's laws
When the protagonist is hooked from the foot to the base and holds her partner by a rope, it makes no sense that he is being pulled back and forth from nowhere.
Sudden movements outside the ship without more propulsion than the protagonist's force do not comply with Newton's 3rd law.
When there are collisions with the other ships, they only break, but many times they do not move as they should considering the force of the collisions.
Student 2
1. (Inertia) When the crew member goes astray, it is in constant motion, until the partner exerts a force to catch it. (Dynamics).
The difference between the station and the craft are different and the starting force and acceleration are exerted by the different masses. (Action reaction). The cosmic garbage when having movement collides with other objects and impacts so much that actions can be generated in the same direction or it can brake and go to opposite senses.
2. The tears that run down the scientist's face do not float.
When the escape pod was opened, the scientist inside had no reaction, though it was only in her imagination.
Upon landing, the scientist immediately exited the spacecraft without reaction in her body by the different gravitational forces.
Student 3
1. Three successes the film shows regarding Newton's laws
When the protagonist breaks off from a structure in space, she experiences a curved trajectory due to Earth's gravity. This is in line with the law of universal gravitation.
In several scenes, the characters experience the lack of resistance to movement in the vacuum of space, showing inertia in action; for example, when the doctor is in space, without moving or being subject to anything and her partner arrives for her, but she fails to stop before playing with her and that touch causes the doctor to move.
When characters use thrusters, or even in a scene, the extinguisher, they experience a reaction in the opposite direction, moving in the opposite direction; this is in accordance with the law of action-reaction.
2. Three errors or inconsistencies shown by the film regarding Newton's laws
In several scenes in the film, the main characters suddenly slow down, or completely stop their movement in space without the application of an external force; according to Newton's first law, a moving object will remain in motion unless an external force acts on it. Therefore, in the vacuum of space, where there is no significant friction, the characters should not stop so abruptly without the intervention of a force.

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The film features rapid motions and orbit changes that are unrealistic; switching from one orbit to another would require a significant amount of energy and propulsion. (not equivalent to force on both sides, action or reaction).
At times, it shows an extreme velocity of approaching objects due to gravity, as if they were suddenly falling towards Earth. This type of representation goes against the principles of the Universal Gravitation Law
Student 4
1. Three successes the film shows regarding Newton's laws
Newton's first Law (Law of Inertia) as it is observed how astronauts and objects are kept at rest until something causes them to move.
Newton's Third Law (Action and Reaction) when astronauts use thrusters to move.
Newton's Fourth Law (Law of Gravitational Force) when astronauts are shot into space, they were attracted by the gravitational force of either the moon or the earth.
2. Three errors or inconsistencies shown by the film regarding Newton's laws
When the astronaut let go he was shot fast and should be slower by the law of gravitational force.
The speed of movement and efficiency of the thrusters is exaggerated.
The sound of explosions.
* The names of each student are omitted. The responses of four students are shown. Responses respect each student's writing style, including some writing and spelling failures to keep data in the way it was received.

At the screening of the film Gravity, the students were able to identify the following **successes** about Newton's Laws: The **first student** replied that the Law of Inertia "is observed in objects that are kept moving in space, including the protagonist, who continues to move without stopping when there is no force to stop her." In the same sense, he identified that the Law of Action-Reaction is illustrated "when the protagonist uses a fire extinguisher to approach the space station; the force exerted by the extinguisher drives it in the opposite direction." As a final success, he identified the Law of Gravitational Force "in objects that remain in orbit around the planet."

The **second student**, said that the Inertia Law "is observed when a crew member strays and continues in constant movement until a partner applies a force to catch her." He also noted that the Law of Dynamics "is reflected in the observed differences in force and acceleration between the station and the spacecraft due to their different masses." Finally, he linked the Law of Action-Reaction in "the cosmic garbage in movement,

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considering that when impacting other objects it generates reactions that can direct it in the same direction or make it change its meaning".

The **third student** stated that the Law of Universal Gravitation "is evidenced when the protagonist detaches from a structure and follows a curved path due to the gravity of the Earth." Regarding the Law of Inertia, he responds that it "is shown in scenes where the characters experience the lack of resistance in the vacuum of space; for example, when the doctor is not subject to anything and her partner arrives but cannot stop before pushing her, generating her movement." Additionally, he commented that the Action-Reaction Law is seen "when characters use thrusters or a fire extinguisher, observing how the force generates an opposite reaction that drives them in the opposite direction."

The **fourth student** selected in this block replied that the Law of Inertia "is observed in astronauts and objects that remain at rest until something external moves them." He also argued that the Action-Reaction Law "is reflected when astronauts use thrusters to move around." And finally, he commented that the Law of Gravitation "is perceived in astronauts who are attracted by the gravitational force of the Earth or the Moon."

As for the **errors** detected in the scenes in the aforementioned film, the students expressed the following: The **first student** argued that "in one scene the protagonist is hooked on the foot to a base and fastened to her partner with a noose, but that it makes no sense for her partner to be pulled into space inexplicably." In addition, he identified that "the abrupt movements of the characters outside the ship, without any additional propulsion, do not comply with the Action-Reaction Law." In conclusion, he says that "in collisions between spacecraft they only break, but they do not move as they should if the laws of the forces involved were correctly applied."

Meanwhile, the **second student**, said that "the tears that run through the face of the scientist do not float in space as they should." Plus. He identifies that "when opening the escape capsule, the scientist does not experience any reaction, which seems more an imaginary than a physical representation." He also criticized that "the protagonist lands and leaves the ship without showing physical effects on her body, contradicting the influence of different gravitational forces."

The **third student** argued that "in some scenes the characters slow down or suddenly stop in space without an external force applied, which contradicts the Law of Inertia." He also questioned the rapid orbit changes presented in the film, replying that "such maneuvers would require a great deal of energy and propulsion." In conclusion, he argued that "the extremely fast approximations of some objects towards the Earth do not respect the principles of the Law of Universal Gravitation."

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Finally, the **fourth student** said that "in a scene an astronaut is released and launched quickly, when in fact it should move more slowly due to the Law of Gravitational Force." He also stated that the film "exaggerates the speed of movements and the efficiency of the thrusters used." In the last error identified, he noted that "sounds of explosions are heard in space," which is inconsistent with vacuum physics.

The analysis of these responses, as mentioned, focuses on the understanding of concepts seen or analyzed at another time, the relationship between these, the transfer to other situations and critical thinking. From the induction on specific situations that the film shows, each student can vary their responses towards generalization or deduce how close each situation is to Newton's laws previously seen, since there is no specific one to reach, but the ability to identify concepts within scenes; in this sense, it is notorious how various situations are identified and all can have valid arguments.

Some answers give concrete concepts of movement or Newton's laws, such as the first one making explicit allusions to inertia, action-reaction or gravitational force, all correctly. While some responses are more in relation to small objects, such as extinguishers or the protagonists themselves, other responses are more in the sense of large objects, such as ships, space stations or planet Earth. Regarding the errors detected, the responses are even more varied.

They comment on exaggerations in parameters of speed, distances or the detail of objects such as hair and tears that seem not to respond to the three laws. There is also the failure to comply with other phenomena not necessarily linked to Newton's laws, such as sound in space, the skills that a person would have to navigate with a fire extinguisher in a vacuum or the immediate decompression problems shown in the protagonist when returning to Earth.

The responses with the superhero fragments followed this same pattern, although it was easier to find the faults, as they are very evident in terms of strength, speed and endurance of the characters. At least, in the case of the character Antman, elements such as the speed required to travel distances such as a simple bath in its reduced size as an ant, or the advantage that it would have over other characters also when traveling large distances in its giant size, were noticeable. To a lesser extent there were discussions about what would happen to the density of someone who does not change mass, but does change size.

As for the final project of this block, the group was asked to develop their corresponding teaching material to illustrate something concerning the laws of Newton's movement. For illustrative analysis purposes, four examples are also presented in Figure 6.

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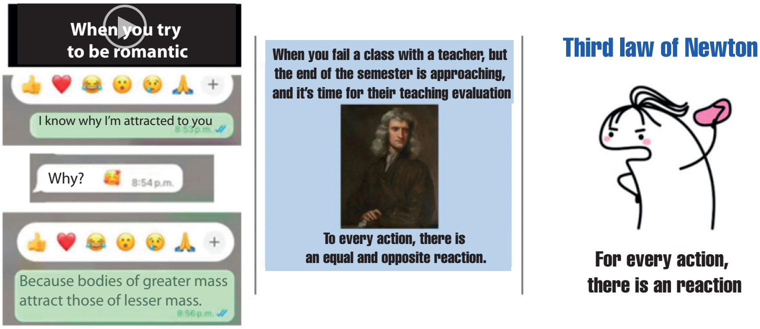
Figure 6
Extracts from the final projects of the block on movement



Regarding the second block (Table 2), some excerpts from the questions for discussion after Lewin's reading on the rainbow and how from this well-known phenomenon can be explained concepts that have to do with light, such as diffraction. This part of the portfolio was carried out after the disclosure reading and the refractive lens experiment mentioned in the previous section. The questions of this exercise were as follows:

1. How is the formation of the primary and secondary rainbow explained by the theory of refraction and reflection of light in water droplets? What are the differences between the two arches?
2. What is the relationship between rainbow formation and the lens diffraction experiment we did in class?
3. How could mathematics teachers integrate the teaching of concepts of optics and refraction, such as those shown in reading and in classroom experiments to enrich students' educational experience?

Table 2
Transcribed answers to portfolio light questions

Student 1
1. How is the formation of primary and secondary rainbows explained by the theory of refraction and reflection of light in water droplets? ¿What are the differences between the two arches?
Both rainbows are formed because the sunlight, when passing through the water droplets is refracted, and the white light is "separated" in the colors that compose it at different angles.

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The difference between the two is that in the secondary rainbow the light passes through two reflections inside the water droplets and is therefore dimmer.
2. How did Young's double-slit experiment show that light is composed of waves rather than particles? How does this relate to the formation of supernumerary arcs in small raindrops?
Because if it always behaves as composed of particles at the time of having two slits some of the particles would pass through one and another for another, but to be waves patterns of interference are formed that pass when two waves interact; it relates to supernumerary arcs because in very small raindrops the waves of the different colors interfere more with those of the other colors, forming these dark or white areas that characterize this type of arcs.
3. What is the relationship between rainbow formation and the diffraction experiment with the lenses we did in class?
I consider that the mica of the lenses acts like a drop of water, making the light when entering them reflect and refract before reaching our gaze, and that is why we can observe that field of colors when using the lenses.
Student 2
1. How is the formation of primary and secondary rainbows explained by the theory of refraction and reflection of light in water droplets? ¿What are the differences between the two arches?
The primary and secondary rainbow formation are differentiated by the amount of bounce that light has within the water drop, since for the primary arc the light beam is reflected only once, and for the secondary arc, they are reflected 2 times before going out and refracting.
2. How did Young's double-slit experiment show that light is composed of waves rather than particles? ¿How does this relate to the formation of supernumerary arcs in small raindrops?
He proved this because he split a fine beam of sunlight into 2 and observed a pattern that could only be explained if the light was made up of waves, if it was made up of particles, each particle would pass through one or the other of the holes (not both) and look like 2 bright points instead of the pattern. This is related to the formation of supernumerary arcs in small droplets by the effects of interference (diffraction), since the interference of light waves is what produces the dark and bright fringes.
3. What is the relationship between rainbow formation and the lens diffraction experiment we did in class?
The relationship that exists between the formation of the rainbow and the experiment is that the light that we placed when passing through the lenses causes white light to divide between its different components of colors producing a pattern of colors with similar lengths

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At the end of a rainbow while the formation of the rainbow acts in the same way when sunlight passes through a drop of water, this is refracted thus causing white light to decompose into the already known colors.
Student 3
1. How is the formation of primary and secondary rainbows explained by the theory of refraction and reflection of light in water droplets? What are the differences between the two arches?
The primary and secondary rainbow formation are differentiated by the amount of bounce that light has within the water drop, since for the primary arc the light beam is reflected only once, and for the secondary arc, they are reflected 2 times before going out and refracting.
2. How did Young's double-slit experiment show that light is composed of waves rather than particles? How does this relate to the formation of supernumerary arcs in small raindrops?
He proved this because he split a fine beam of sunlight into 2 and observed a pattern that could only be explained if the light was made up of waves, if it was made up of particles, each particle would pass through one or the other of the holes (not both) and look like 2 bright points instead of the pattern. This is related to the formation of supernumerary arcs in small droplets by the effects of interference (diffraction), since the interference of light waves is what produces the dark and bright fringes.
3. What is the relationship between rainbow formation and the lens diffraction experiment we did in class?
In that both the drop and the lenses have no flat shape, but have curvatures that cause the light to change its direction many times and being so small and on several occasions is what allows the phenomenon of diffraction.
The answers, for the most part, allude to the implicit analogy between the concrete experiment—seeing white light from a common focus through diffraction lenses—and the phenomenon of rain described as an anecdote by Lewin. The vast majority identify the emission of white light from the Sun and white LED as a comparable phenomenon, as well as the function of raindrops with the diffraction grids that the lenses have. In some cases they go as far as to mention that the "non-flat" shape of both is the main cause for light to be decomposed into the visible spectrum.

As for the **first block of questions:** How do you explain the formation of the primary and secondary rainbow according to the theory of refraction and reflection of light in water droplets? What are the differences between the two arches?: The **first student** commented that the formation of the primary and secondary rainbows "is due to the refraction of sunlight as it crosses water droplets, separating into the colors that

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compose it." He commented that the difference between the two arches lies in the fact that "in the secondary rainbow the light experiences two reflections inside the drops, which makes it dimmer". The **second student** said that the formation of the primary and secondary rainbows "is explained by the number of reflections that light makes within a drop of water: in the primary arc, light is reflected only once, while in the secondary it is reflected twice before refracting and leaving." Finally, the **third student** explained that the primary and secondary rainbows are formed due "to the refraction of light in water droplets, differing in number: one for the primary and two for the secondary."

Regarding the **second block of questions:** How did Young's double-slit experiment prove that light is composed of waves rather than particles? How does this relate to the formation of supernumerary arcs in small raindrops? The **first student** pointed out that it was "shown that light is formed by waves and not by particles, since waves produce interference patterns when interacting", and related this phenomenon with supernumerary arcs, recalling that "in small raindrops light waves of different colors interfere more, generating dark or white areas characteristic of such arcs." The **second student** noted that the experiment demonstrated the wave-like nature of light by splitting a beam of light in two and observing interference patterns that would not occur if it were composed of particles. The relationship he made with supernumerary arcs was by arguing that the interference of light waves in small raindrops generates dark and bright stripes. The **third student** stated that the experiment proved that light behaves like a wave, in a very similar argument to the second student. Regarding the relationship with supernumerary arcs, he alluded to the fact that wave interference "in very small droplets produces those characteristic fringes".

In relation to the **third block of questions: What is the relationship between the formation of the rainbow and the diffraction experiment with lenses that we did in class? The first student** said that "the diffraction **experiment included "a mica that acts like a drop of water, refracting and reflecting light to produce a visible field of colors."** The **second student** pointed out that the relationship between rainbow formation and the lens experiment lies in the fact that "both phenomena involve the decomposition of white light into its colored components, either through water droplets or when passing through curved lenses," while the **third student** explained that "both water droplets and lenses have curvatures that cause light to change direction repeatedly, allowing to observe rainbow-like patterns of color."

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Moreover, the project of this block also referred to the visible luminous spectrum. After identifying that by diffraction the color pattern is always the same in order, it was corroborated that some colors called cold (green, blue and violet), are darkened when filtered by some color on the other side of the spectrum (red, orange or yellow). From detecting these patterns, it was generally asked that they use these features to design a hidden message, which was only discovered using a filter (red cellophane paper). This aspect requires the understanding of the filter with respect to the visible spectrum, but at the same time it gives enormous flexibility for creative thinking to develop. For example, two examples are presented in Figure 7, where it can be seen what an unfiltered and filtered message looks like; while Figure 8 shows some designs made by the group of students. The patterns are identifiable, however, if the reader has a red cellophane paper on hand, they can use it and the messages will be clearer.

Figure 7
Filter-free and filter design

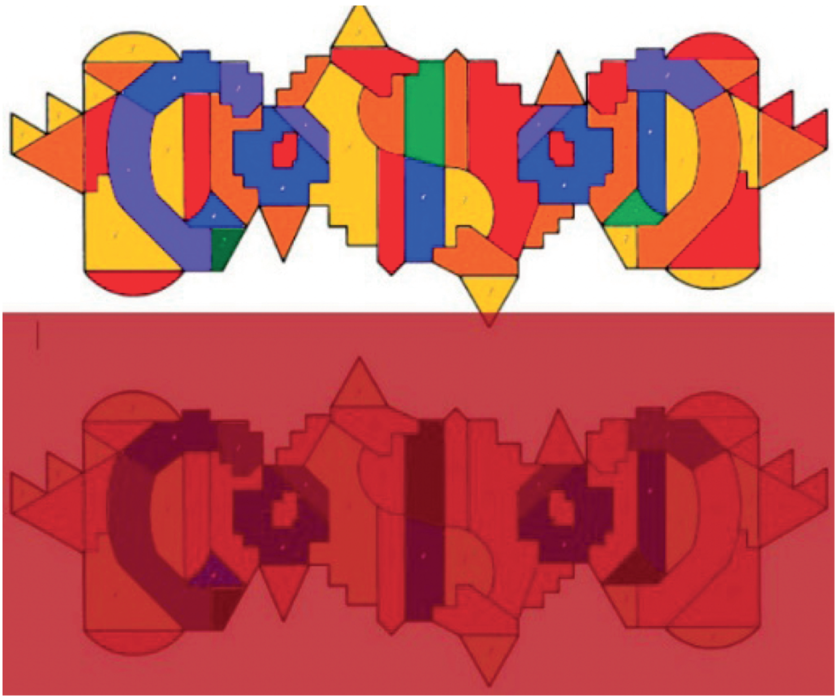

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Figure 8
Some group of designs

Results of the use of strategies

Taking up what was raised by Andrade *et al*. (2018), the student has historically had a receptive and passive role in learning scientific definitions and guaranteed formulas. More active participation of learning experiences places them in a meaningful learning process. The claim that science is a combination of imagination and logic may not be as common, but the assumptions and theories for imagining how the world works is something that requires as much creativity as the arts.

In this sense, the inductive strategies used in this research show that induction, sometimes in the form of experimentation or through the dissemination readings, is effective to promote the conceptual construction of physics topics among future teachers of the Bachelor of Science in Mathematics. Unlike more traditional approaches, focused on problem solving and memoristic learning of definitions, inductive strategies show that students can, in effect, start from particularities to come to the understanding of more general concepts.

The use of audiovisual materials and popular scientific readings as triggers for this induction, instead of more conventional textbooks, managed to encourage the group of students to reflect on the applications and context of physical concepts, instead of focusing solely on mathematical formalism. This allowed them to develop a more comprehensive un-

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derstanding of topics such as movement and light, transcending simple procedural mastery.

Several students made conclusions from linking the three aspects and not in linear order, but some gave meaning to the readings from a direct observation of the audiovisual material, or from experimentation. It also occurred in reverse, i.e., using the popularization readings to name the visual or experimental elements. Under this logic, it is possible to speak of an integration into a broader and even cumulative scheme, as mentioned by Dávila Newman (2006), from deductive reasoning, the above without having a specific chronological order for the use of the various materials.

Discussion

An important finding of this research was that the inductive approach favored students, who had a solid mathematical training but little prior exposure to physics, to build a deeper conceptual understanding of the topics addressed, especially in some evident processes of transfer to other situations. From their own observations and everyday experiences, they were able to establish significant links between physical concepts and their application or at least their presence in the real world.

This contrasts with the memoristic and decontextualized learning that often characterizes traditional teaching of experimental sciences, where students tend to master equations and procedures without coming to a full understanding of the underlying phenomena. The inductive approach implemented in this study allowed participants to develop a more integrated and meaningful view as far as physical concepts are concerned. Only two thematic blocks were shown in this article, but in the rest of the blocks it was similar.

The results of the evaluation carried out at the end of the course show that the students achieved an outstanding performance in the conceptual understanding of the topics addressed. Not only did they demonstrate mastery of definitions and formulas, but they were able to explain concepts, relate them to everyday situations and apply them in solving problems, some not necessarily numerical, but related to creativity. In addition, the final works of the students showed a capacity for reflection and analysis that goes beyond the mere reproduction of information. This suggests that the inductive approach allowed them to develop critical thinking and knowledge-building skills, rather than being limited to memorization (Ahumada, 2005).

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Regarding the contribution to the educational field, by integrating the use of scientific dissemination materials and experimental activities (Cuevas, 2020), this approach manages to transcend the traditional emphasis on the resolution of repetitive exercises and the memorization of formulas. Furthermore, the fact that this experience has been carried out in the context of the training of mathematics teachers opens the door to the implementation of these strategies at various educational levels, from basic to higher education. This has the potential to improve the teaching and learning of physics, while contributing to the scientific literacy of students.

The findings, up to this point, open a further possibility that the implementation of inductive didactic strategies, combined and supported by dissemination and experimental resources, can be a valuable tool to promote a deeper and more meaningful conceptual understanding of the experimental sciences. This approach, with potential for replicability, represents a relevant contribution to the field of science and mathematics education, with positive implications for the training of future teachers and the learning of students.

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