Teaching Color Optics through Playful Games with Flags: An Experience Report

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Abstract

In this article, we aim to present an account of the experience with a didactic tool used for teaching color optics in the classroom. This tool mploys low-cost and easily accessible materials for teachers in an elective class for elementary school students at a private school in Rio de Janeiro in 2023, and for high school students in 2024. Starting from the principle of the reflection of visible light and the formation of the electromagnetic spectrum, a playful game was proposed with the objective of studying the color patterns we see according to the physical principles addressed by Isaac Newton in 1672. Additionally, the game aimed to stimulate students' preconceptions (Ausubel, 1968) about the physics of colors and the flags of various nations.

Keywords: Teaching Physics, Color Optics, Playful Games.

Resumen

En este artículo, pretendemos presentar un relato de la experiencia con una herramienta didáctica utilizada para la enseñanza de la óptica del color en el aula. Esta herramienta utiliza materiales de bajo costo y de fácil acceso para los profesores de una clase optativa para estudiantes de la enseñanza primaria en una escuela privada de Río de Janeiro en 2023, y para estudiantes de la enseñanza secundaria en 2024. Partiendo del principio de la reflexión de la luz visible y de la formación del espectro electromagnético, se propuso un juego lúdico con el objetivo de estudiar los patrones de color que vemos según los principios físicos abordados por Isaac Newton en 1672. Además, el juego tenía como objetivo estimular las preconcepciones de los estudiantes (Ausubel, 1968) sobre la física de los colores y las banderas de varias naciones.

Palabras clave: Enseñanza de la Física, Óptica del Color, Juegos Lúdicos.

I. INTRODUCTION

The study of colors in various textbooks suggests that the discovery procesontributions that were relevant to the construction of this history, through the reflections of naturalist philosophers such as René Descartes [1], Robert Boyle[2], Francesco Maria Grimaldi[3], and Robert Hooke[4].

Physics involving colors and light is widely used in everyday life, for example: in shows or events, in visual arts, in scientific research, and most importantly, it explains the optical phenomenon of how we see, among many other applications. With this in mind, we can bring a didactic approach to the classroom that provides meaningful learning for the student [5]. Ausubel's theory highlights the importance of integrating new knowledge with concepts already existing in the student's cognitive structure. In this way, learning becomes more effective as there is familiarity between prior knowledge and the new content.

Seeking greater student engagement, we used the strategy of developing a playful game that encourages learning through practice, problem-solving, or even teamwork, being an excellent tool for application as an active methodology.

Active methodologies are educational approaches that place the student as the protagonist of their own learning, actively involving them in the knowledge acquisition process. The flipped classroom is an active methodology strategy that reverses the classroom role, where the teacher acts as a class mediator. With a prior introduction to the content, students use dynamics to construct possible answers and seek to understand the proposed problems, utilizing games to achieve the objectives. The combination of challenge-based learning, real problems, and games with the flipped classroom is very important for students to learn by doing, learn together, and learn at their own pace. Games and scripted classes with game language – so-called gamification – are increasingly present in the school environment and are important learning paths for generations used to playing [6].

Playful games fit into this context as they stimulate active student participation, providing a more dynamic, interactive, and collaborative environment. Highlight the use of educational games as promoters of the teaching and learning process, which can also be used in teacher training and in the teaching of Physics [7]

For these purposes, the playful game with flags aims to understand the physical phenomenon of colors through the reflection of the electromagnetic spectrum. Additionally, it aims to understand the composition of light, what the visible electromagnetic spectrum is, and also the spectrum beyond the visible.

II. THE ELECTROMAGNETIC SPECTRUM AND THE REFLECTION OF COLORS

The electromagnetic spectrum is often observed in a natural phenomenon known as a rainbow, which was explained by Newton in the 17th century when he set out to study chromatic dispersion. However, this phenomenon had already been a subject of debate among four other natural philosophers before him, in an empirical manner: René Descartes in his work "La Dioptrique" (1637), Robert Boyle in his book "Experiments and Considerations Touching Colours" (1664), Francesco Maria Grimaldi in "Physico-Mathesis de Lumine" (1665), and Robert Hooke in his work "Micrographia."

However, understanding light as an electromagnetic wave was only possible years later, in the mid-19th century, when Clerk Maxwell (1873) [8], in his book "A Treatise on Electricity and Magnetism," demonstrated through his equations that electric and magnetic fields propagated at the speed of light. This showed that electric and magnetic forces have the same nature, suggesting that light is an electromagnetic wave.

In his studies, Newton [9] considered the particle nature of light. He used various optical prisms to conduct his experiments, inspired by the accounts of Boyle and Hooke on the dispersion of colors, which, according to Schaffer [10], aimed to refute Descartes' theory about the colors of bodies.

Descartes' Cartesian theory contrasted with scholastic thought (philosophy produced by Christian intellectuals), which described two types of colors: emphatic or apparent colors (presented in the rainbow or produced with the aid of prisms) and real colors (displayed by bodies when illuminated, but without the light producing them). Descartes argued that both types of colors were produced in the same way. In contrast, Newton relied on a "Cartesian paradigm," dissecting the mammalian anatomical system and interpreting that the formation of colors occurred in stages of disconfiguring the visual image and restructuring it as physical events in the brain [11].

Darrigol [12] highlights that Newton, when interpreting how visual information is transmitted from the retina to the brain, used an acoustic analogy: light would be a pressure on the ocular system, just as sound is a pressure wave on the auditory system. In experiment 58 of the manuscript, Newton tested this analogy dramatically by inserting a thin arrowhead between his eyeball and eyelid to establish pressure on the back of the retina. He concluded through his various experiments that light was not a homogeneous beam but rather a composition of chromatic beams, each with its own refractive index, with red having the least deviation and violet the most deviation. Additionally, he determined the primary colors: Red, Yellow, Green, Blue, Purple-Violet, Orange, Indigo, and other intermediate gradations. In his article published in the Philosophical Transactions of the Royal Society he made some propositions that we consider important for concluding his ideas and justifying the phenomena of colors [9]:

-8. Therefore, Whiteness is the usual color of Light, for Light is a confused aggregate of Rays endowed with all kinds of Colors [11].

-9 Considering these things, the way colors are produced by the Prism is evident. For of the Rays that constitute incident light, as they differ proportionally in Refrangibility, they must by their different refractions be separated and dispersed in an oblong form in an ordered succession, from the lesser refracted Scarlet to the more refracted Violet [11].

-12 From there also appears the reason for an unexpected Experiment that Mr. Hook somewhere in his Micrographia reports having done with two transparent wedge-shaped containers, one filled with a red liquid and the other with blue: namely, that individually they were sufficiently transparent, but together they became opaque; for if one transmits only red and the other only blue, no ray can pass through both [11].

-13 I could add more examples of this nature but will conclude with this general one: that the Colors of natural Bodies have no other origin than this: that they are quickly qualified to reflect one kind of light in greater quantity than others [11].

We highlighted some excerpts from the history, which we consider relevant, behind the experimental development of the color spectrum carried out by Newton, to theoretically support the physical principles addressed in the playful activity proposed in this article. We strongly recommend studying this article by Newton for enriching your classes, which was translated and commented on in Portuguese by Silva and Martins in an edition of the Brazilian Journal of Physics Teaching (RBEF) in 1996.

However, the process of interpreting colors by our brain is not only due to the reflection of light on the object but also by the visual perception of the surroundings. This theory became known as the Retinex theory, developed by Edwin Land [13] He explains how the human eye and brain collaborate to perceive colors consistently under different lighting conditions.

Although this theory explains more clearly how the interpretation of light captured by the rods and interpreted by our brain works, both physical phenomena (Newton and Land) use properties of light reflection in color composition. However, this didactic experiment was designed to meet the EF09CI04 skill of the National Common Curricular Base (BNCC), as well as to promote the use of low-cost materials to justify Newton's experiments. (EF09CI04) Plan and execute experiments that show that all colors of light can be formed by the composition of the three primary colors of light and that the color of an object is also related to the color of the light that illuminates it [14].

Furthermore, we have other works like those of Henrique et al. [15] and Albuquerque et al. [16] that proposed different applications for the classroom on the study of color formation with various activities that served as a basis of inspiration for this work.

III. MATERIAL USED

The materials were chosen to be low-cost, considering the social and economic reality of the country. This way, this educational activity can be used in private and public schools nationwide and is also easily accessible.

- Colors Lamp or 3 Lamps with the RGB system (Figura 1)
- Sheet of Paper (Figura 2)
- Desk Lamp
- Black Box (Optional)

The Red, Green, Blue (RGB) light system was adopted because these are the primary colors of light. Any other intermediate or secondary colors will not work in the game. The students will only need a sheet of paper to take notes and a pen.

FIGURE 1. Colored LED Lamp.

FIGURE 2. Sheet of Paper with the flags.

IV. THE FLAGS GAME

The playful game involves studying how our eyes interpret the colors of objects. Newton described this physical phenomenon in his article published in 1672, based on the reflection of light and the composition of white light as a mixture of chromatic beams.

Based on this physical principle and the principle of the duality of light, the teacher can start the lesson with the following question for the students: How do we know the color of each object? The purpose of this question is to encourage students to reflect on the topic and put themselves in the place of the famous natural philosophers of antiquity. What would be their natural interpretation of this phenomenon?

Through the students' responses, the teacher will mediate the debate to introduce Newton's experiments and his respective propositions. It is important to emphasize the dual property of light, considering it as both a wave and a particle. Additionally, interpret that each color of the visible electromagnetic spectrum has distinct wavelengths and frequencies. It is also worth presenting the electromagnetic spectrum beyond the visible field, following the same reasoning.

After introducing the content, the 'Flags Game' is an activity where students need prior knowledge of the flags of different countries, as well as an understanding of the physical principle of color reflection addressed in the lesson.

How It Works: In an environment completely isolated from external light (if there is no isolated environment, use a black box for the activity), the teacher will select a number of flags from different nations to use in the game. Each flag will be illuminated for only 30 seconds with each light from the RGB system, causing the color of the flags to change according to the incident and reflected light. Students should take notes on each option, and at the end, compare their responses with the flags illuminated by white or natural light.

Objective: Identify the greatest number of flags from each territory.

Time: Approximately 10 to 30 minutes.

Rules of the Game: Each student or group can only submit one option per presented flag. They cannot change their answers or share them before the end of the game.

V. THE FLAGS GAME DYNAMICS

The game was implemented in an elective course for 5 small classes of a school group with a total of 53 students, aged between 14 and 16, in 2023 and 2024. This course aims to provide students with a multidisciplinary debate of knowledge outside the school curriculum, in a playful and non-traditional manner, unlike a conventional classroom lecture. In this course, students participate out of their own interest, as it is offered during their respective class breaks.

Before starting the lesson, the teacher asked the following questions: How do we see? What is light? These questions were posed to initiate a debate and assess the students' prior knowledge on the subject, playing the role of early natural philosophers interpreting natural phenomena. From this dialogue, the teacher, using visual aids, was able to start the lesson by presenting visible white light and its decomposition into colors by a prism, based on Isaac Newton's experiments.

Consequently, at the start of the game, given that there were about 10 students in each classroom in 2023, we chose to conduct the activity individually, but it could have been done in groups if the class size had been larger. In 2024, we conducted the same activity individually, and in a well-isolated environment, flags were displayed on the classroom board, and everyone did it simultaneously.

In a completely light-isolated environment, the teacher placed the sheets with flags under red light for 30 seconds for the students to interpret and take notes in their notebooks on whether they recognized the country. Subsequently, the sheets were placed under blue light and then green light, independently, for the same time interval on the same flags.

Thus, the students could perceive the different effects that each reflection of the electromagnetic spectrum had on the colors they saw. At the end of the activity, the answers were compared with the respective flags and colors under white light. The majority got the answers correct, but only one student aced the game, even though everyone recognized all the flags at the end. The following final questions were posed: Why do we see all "real" colors under white light? And what justifies the color black?

During the dialogue, they concluded that the color we see on an object is determined by the incident light on it, due to the light reflection process. They also observed that white light is composed of all colors and that a black object is a result of light absorption. Figures 3, 4, and 5 show the moments of the activity with the students under each of the three color spectrums of light: red, blue, and green in 2023. The use of the box was to minimize the effects of ambient lighting, as we did not have a fully isolated environment.

FIGURE 3. Game with the red light.

FIGURE 4. Game with the blue light.

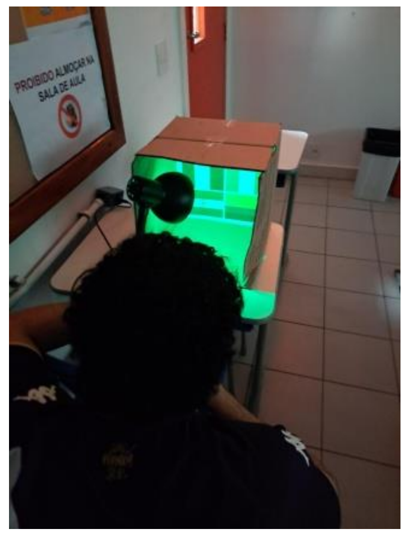

FIGURE 5. Game with the green light.

Figures 6 and 7 show the activity being conducted at one of the educational institutions in 2024. Since the classroom had good external light isolation, the game was displayed on the board for the students to play.

FIGURE 6. Game with the class with the red light.

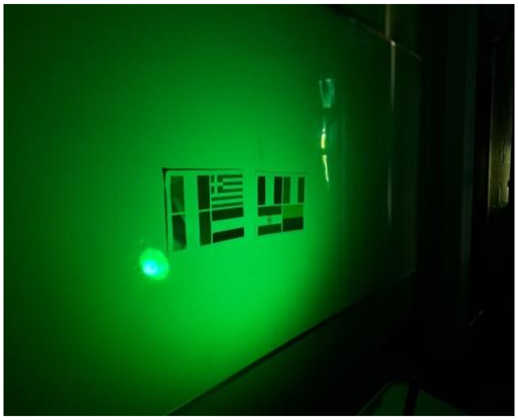

FIGURE 7. Game with the class with the green light.

V. CONCLUSIONS

The experience report provided the opportunity to explore and work on classical physics concepts. According to the traditional curriculum, these concepts are addressed only in high school. However, the activity allowed for the understanding of physical concepts both for students who had not yet studied the content in their regular education and for those who had already seen it but had not related the concepts to reality.

A pre-test was conducted with the students to determine if they could explain how we see colors with our eyes. The following question was asked: How do we see the colors of opaque objects? Yes or No? Justify.

In Graph 1 below, the data from the pre-test responses based on this question can be analyzed.

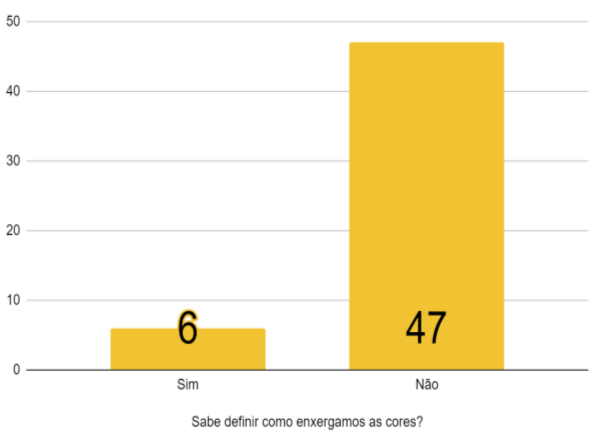

FIGURE 8. Pre-test on students' conceptions about defining how we see the colors of opaque objects.

The graphs analyze the number of students who answered yes or no. Those who said yes gave examples, such as student 1, and a few were more descriptive, like student 2.

TABLE I. Students' answers before the activity.

Student	*Answers*
Student 1	Yes, through light
Student 2	Through the reflection of light.

Those who said no, the vast majority mentioned the composition of watercolor colors but could not identify it as a property of light. After the color game with flags was applied, there was a significant change in the previous response about how to explain the physical phenomenon of how we see colors, as can be analyzed in Graph 2.

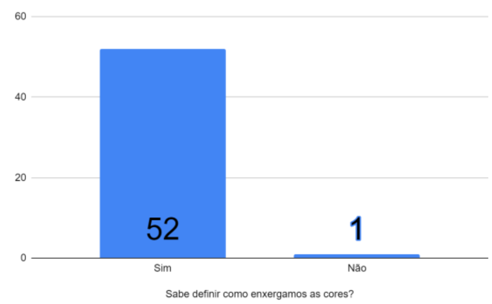

FIGURE 9. Post-test on students' conceptions about defining how we see the colors of opaque objects

And the students responded more clearly about what light is and the process of how we see it. Some of the students' responses were highlighted.

It was observed that the students were fully engaged with the proposed activity and made a direct association between the physics content and everyday life, promoting critical reflection, dynamism, and fun among the students.

It is hoped that this report will serve as an inspiration for other physics or natural science teachers, encouraging a didactic approach to understanding the colors of the electromagnetic spectrum. This activity can be applied both in elementary and high school, regardless of the students' knowledge of flags from other nations. The important thing is to promote critical thinking and an understanding of how the visible spectrum influences the perception of colors of objects.

TABLE II. Students' answers after the activity.

Students	*Answers*
Student 3	Light is an electromagnetic spectrum, and the light we see is within the visible range, meaning objects reflect this light to our eyes.
Student 4	Our eyes capture the light reflected from objects through rods.
Student 5	Light is composed of 7 colors of light, with the primary ones being the RGB system, and their composition produces the others. We see the light reflected from this composition on objects.

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