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Light and Color: Art and Science Using an Interdisciplinary Approach in Primary Education Teacher Training

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Abstract: Light and color present complex interactions whose understanding is not always intuitive. Over the past forty years, numerous studies have aimed to identify preconceived notions and the various models employed in schools. Numerous teaching and learning strategies, along with didactic analyses, often fail to consider the multidimensional and interdisciplinary nature of these phenomena. This article presents a teaching experience aimed at training future primary education teachers. The theoretical context of this proposal, designed within the domains of physical and chemical didactics and plastic and visual expression, will be discussed. Instruments consistent with qualitative action research were used. Some results from the analysis of students' narratives, both in laboratory notebooks and in sessions recorded audiovisually, will be presented.

Keywords: art and science; light and color; scientific and visual learning; STEAM

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1. Introduction

The multiple conceptual, ontological, and epistemological dimensions and their importance in the construction of reality have made light and color recurrent topics of reflection in didactics despite their limited curricular presence. One of the most significant school environments, which employs various strategies and analyses, is primary education. Primary teachers, who must adopt multiple roles (including science teachers), face the complexity of managing different models. As noted by Arnantonaki, Boilevin & Ravanis [1], from the precursor models of light comprehension used by young children to the various methods of addressing light and color interactions at all educational levels, including at university, the approaches are extensive. However, a bibliographic review reveals that the topic of complexity is often addressed mono-disciplinarily despite its systemic nature. The numerous relationships and connections required in physical, chemical, biological, psychological, and artistic aspects are often absent when designing more integrative proposals. As Wagensberg [2] pointed out, reality is not to blame for curricular designs and the rigidity of disciplinary boundaries. From the reflection on this complex nature and the need to cross boundaries, as well as from the analysis conducted by Department of Specific Didactics at the University of Zaragoza regarding our students' difficulties, arises the idea of designing proposals such as those presented in this article. Specifically, one was designed in the areas of physical and chemical didactics and plastic and visual expression, a field where light and color are particularly relevant but also introduce discrepancies compared with the scientific model. Thus, a general objective is established between the two areas involved in the process: to analyze the learning, motivations, and knowledge construction regarding light by future primary school teachers when approached from two seemingly distant fields. Both the intervention and analysis take place within a common framework of light–color/object–material interactions mediated by vision. This provides an opportunity to analyze the types of learning that occur, students' perceptions in an interdisciplinary work environment closer to their future professional context, and the explanatory models they employ.

2. Theoretical Framework

Different models describe the behavior of light, and as discussed by Muñoz, Medina-Rivilla & Guillén-Lúgigo [3], students need to use appropriate explanatory models. This work is based on systemic approaches where the act of seeing is understood through models that consider light/object or illuminated material interactions and the visual system in use. The authors note that the history of optics has developed by asking questions about how and why we see and analyzing potential answers and parallel questions.

It is important to note that many of the answers provided by scientific models may not align with the ideas of future teachers or students at various educational levels. Bravo, Pesa & Pozo [4,5] have indicated that pre-conceptual schemes, predating Kepler's theories on light and color, are often still in use regardless of the educational level. When designing didactic proposals, it is crucial to consider the points made by authors such as Wizman [6] regarding the understanding of the nature of light and the act of seeing as prerequisites for understanding interaction phenomena, such as shadows. As Barrow [7] pointed out, practical knowledge about light does not necessarily translate to understanding the phenomena, highlighting the need to align factual knowledge (what they know or believe) with conceptual knowledge. The goal is to connect ideas to build meanings. Haagen-Schützenhöfer [8] have noted that the properties attributed to light by students do not necessarily activate specific domains regarding its characteristics. When focusing on the nature of light (trajectory, rectilinear propagation, and constant speed in a given medium) or ontological aspects (light as energy or an electromagnetic wave), the knowledge provided by trained and untrained students is not significantly different. The studies by Bravo, Pesa & Pozo [4,5] show a considerable gap between scientific models and students' intuitive models, which are also far from school science models.

Many authors have analyzed the difficulties students face beyond their intuitive ideas, which seem related to classroom learning models in dealing with light [9]. On the one hand, the scientific model's systemic nature is not always present in classrooms, and on the other hand, teaching and learning strategies are not always adapted to students' experiential and phenomenological intuitive models, strongly involving the senses. For instance, color is still attributed to objects as an intrinsic property, consistent with artistic practice using coloring materials. As noted by Bravo, Pesa & Pozo [5], there is a special connection between color and aesthetic experiences, particularly those related to coloring materials, which students have experimented with since early childhood. Despite color's special characteristics, as noted by Chauvet, Viennot & de Hosson [10,11], students' difficulties in understanding color can provide insights into their difficulties with light. Some first-year art students still explain color phenomena based on pigment luminosity without considering absorption, reflection, or transmission, a finding also seen in other university students.

To address these limitations, authors like Tregidgo & Ratcliffe [12] emphasize the need to expand the range of models used in classrooms to establish and highlight differences rather than confuse students. Schools and resources already present simplified theoretical models, such as using rays from a geometric perspective or the wavefront model.

Métioui, & Trudel [13], again, emphasize that proposals should start from the prior ideas and preconceptions teachers use to develop their intuitive models based on personal and intuitive experiences, consistent with forty years of research [14,15].

Based on the insights of multiple authors, this proposal aims to expand the systemic nature of phenomena associated with light and color, integrating motivational, emotional, and sensory aspects highlighted by Gardner, Eisner and Dewey [16–18]. Additionally, it introduces light and color models related to material work, which have a strong experiential basis for students, expanding the multifocal analysis of phenomena through a coordinated sequence designed by two didactic areas involved in teaching and learning.

3. Materials and Methods

3.1. Fundamental Aspects of This Project

One of the fundamental aspects of this project considers the importance of a common framework for practical work. In the area of the didactics of physics and chemistry (DP&C) and experimental sciences in general, although there is no consensus on improving learning outcomes [19], there is a general agreement on the positive aspects introduced when linking professional science with the science of teachers and school science [20,21]. In this regard, and in line with this project's objectives, Tamayo & Sanmartí [22] have pointed out that experimental activity plays a fundamental role when there is an intentional design that considers students' prior ideas and their evolution toward more elaborate concepts and models. López & Tamayo [23] have noted that among the positive aspects is designing appropriate strategies for teachers to relate theory and practice and, above all, address the lack of knowledge this group presents when working in these contexts.

In the case of visual and plastic expression (VP&E), there is also a long tradition and voices recognizing and advocating for the meeting between techniques, workshops, and reflection in the construction of knowledge promoted by art [17,24–26].

3.2. Context and Description of the Project

The "Light and Color Workshop" encompasses all actions aimed at achieving the objectives outlined previously. Reflecting on conceptual issues related to the curriculum in the DP&C, such as the confusion students often have when light and sound are taught together, led to a reflection on how students approach and understand light and color and what models they use. In this regard, and as previously mentioned, in the area of VP&E, light and color are not only present but are central to many artistic movements, from Impressionism to Video Art. Therefore, a joint, integrative proposal was developed, focusing on the artistic object as a didactic reflection product combining artistic and scientific perspectives for our teacher-training students.

The participants were second-year students in the Primary Education degree program. The involved subjects were taught during the first semester (from September to January), facilitating coordination. Each academic year, the sample consisted of an average of 250 students organized into four groups. Twelve faculty teachers from both areas were involved in the design, implementation, and monitoring of this project, as well as in gathering information and recording activities for subsequent analysis.

The didactic sequence is organized into the following phases and sessions:

A three-hour laboratory session focused on various experiments related to light and color.

Three classroom sessions in VP&E to analyze a contemporary artwork and create a personal piece based on this analysis and the laboratory session learnings.

Tutoring sessions throughout the process to monitor the development of the artistic/scientific object/product.

A session for the presentation and defense of the work and product.

Each session within the proposal addresses the general and specific objectives detailed in the previous section, explained as follows:

First, considering the theoretical framework and project objectives, the importance of practical work in the DP&C field has been highlighted [20,24]. Thus, this case is structured to help teachers explore complex concepts such as light and color, linking theory and practice and working with scientific explanatory models. The laboratory session is designed to enable students to analyze observed behaviors and phenomena, reflect on those that are most interesting for their learning, and integrate these experiences into the design of their artistic/scientific product. From the start, it has been intended that these experiences contribute to the teachers' development through deep reflection on didactic practices and the transposition to the primary classroom.

The session itself is divided into different parts: a brief theoretical introduction to contextualize students in the historical evolution and controversies about light and color, including artistic perspectives, followed by a series of experiments demonstrating various aspects of the nature of light and interaction phenomena. The worksheet provided does not follow a classic lab guide format but allows students in each group to incorporate observations and possible explanations supported by visual representations. It also includes argumentation on their explanations, decision-making processes, and additional experiences conducted to test their scientific model. Students are also encouraged to incorporate didactic reflections on their learning, difficulties, and other aspects that will be used for individual entries in their lab notebooks.

As a bridge connecting the DP&C session to the next, students are given a list of over 60 works by contemporary artists to choose from. These works were selected for their historical relevance, either of the work itself or the author, and for the significance of light and color as present, explicit, or implicit aspects. The aim was to cover major movements from the late 19th century, the 20th century, and the early 21st century. During the selection process, students conduct a preliminary analysis of the work and reflect on its potential as a resource for integrating selected physical phenomena into designing their own product/object.

The second stage, corresponding to the VP&E area, traditionally develops technical skills and aesthetic language analysis from a practical dimension. The inclusion in the "Light and Color Workshop" broadens its objectives by incorporating the integration of art and science knowledge. Pre-service teachers are encouraged to connect, as in the sciences part, technique and theory through the analysis of an integral didactic resource based on light and color as the conceptual foundation. Simultaneously, they build, elaborate, or design their own artwork. During this second stage and in parallel, various tutoring sessions are conducted with each group. These sessions are designed to confront the narratives among group members and teachers, reflecting on the integration of scientific phenomena in the context of the aesthetic–artistic discourse analysis of the selected work. The goal is to guide the development and creation of their own artistic/scientific object. This involves finding common meanings related to light and color models, interaction phenomena, their use in contemporary art, the science models of the teachers, and school science. Additionally, there is a didactic reflection on the potential usefulness of the developed product for further exploration of the concepts, nature, and representations of light and color.

The final phase involves preparing for the presentation and defense of the group proposals. Students are required to justify the phenomena they have integrated, analyze the selected artwork, and explain how these aspects were incorporated into their didactic validity as art and science objects. It is crucial that students can analyze, evaluate, and detail what they have learned and the gaps in their scientific model, their integrated model, and their role as art and science teachers.

3.3. Evaluation Instruments

As previously mentioned, within an interdisciplinary teaching and learning approach in teacher training and practical work, qualitative analysis follows the principles of action research. Therefore, the evaluation and data collection instruments must be consistent with this context.

In recent years, the DP&C area has promoted the design of laboratory notebooks by students. The laboratory notebook, also known as a practical work journal or field notebook, captures various narratives that, from the perspective of promoting critical and reflective teachers, detail what the work involves and how teachers relate to it. This is always within a broader context related to their individual progress and the activities themselves [27]. In this sense, the laboratory notebook is highly valuable. As Novak, Hofstein and Lunetta have noted [28,29], in a context where laboratory practice should go beyond mere knowledge transmission, the narratives should not solely reflect the completion of instructions to find a correct answer but should primarily be a process of reflection by teachers, focusing on the didactic aspects of the processes rather than just the manipulative ones.

As Nobel laureate Richard Feynman pointed out, science transcends a body of transmitted theories that should allow observation, comparison, experimentation, inference, deduction, doubt, and verification. This perspective supports views on practical work and the utility of instruments to reflect the interactions in collaborative student work, providing a space to gather opinions, arguments, alternative explanations, and reasoning in scientific formation within small groups.

Thus, the value of the notebook extends beyond its role as an assessment tool. In the context of educational action and research, it becomes a primary tool for analyzing students' ideas in many aspects of practice. Ruiz-Primo et al. [30] highlight how students' writings can present significant value and richness regarding their thinking while working as scientists. Klentschy [31] further notes that the laboratory notebook is not just a list of observations or collected data but serves as information for drawing conclusions. It is a record of their prior knowledge and ideas, plans, predictions, problems to solve, procedures, and ideas they will work on, as well as the meaning of the experience and inquiry for them.

In this case, the notebook was designed and elaborated individually by the teachers based on their reflections and analyses from group work. The analysis focused on entries corresponding to the light and color laboratory experience and what was detailed regarding the "Light and Color Workshop" in its integrative proposal.

Due to the large number of records evaluated, a sample of these notebooks was taken, considering the variables of gender and the evaluation of the project and the notebook itself. It should be noted that although the projects were group-based, the notebook entries were individual, and there may have been discrepancies in observations and narratives within the same group.

For the notebook entry corresponding to the laboratory session, responses were considered regarding the following questions posed during the session. In many cases, students structured their notebooks accordingly. Additionally, the drawings or graphic materials provided by the students, within the didactic value of such resources, were crucial. The questions posed were as follows:

- What and how have you observed?
- How would you explain it?
- What types of experiences would you design to work on these phenomena in the primary classroom?
- What did you know and what have you learned from these experiences?
- What is its didactic value from the perspective of a Primary School Teacher's training?

4. Results

4.1. Experimental Lab Stage

The objective of the first part of this project was that the students, starting from their prior ideas, could evolve toward more elaborate concepts. Several fragments of the answers to the questions posed, offered by some students in their notebooks (and picked up from the laboratory stage), are transcribed below.

In the first stage, the students experimented with light and solid objects, such as plastic (black and transparent) or cardboard. Some of their reflections were as follows:

"When light hits an object, it behaves differently depending on the material that makes it up" (light–material interaction and the importance of the object or materials); "Transparent, light passes through"; "Understand the characteristics of materials and perceive and explain the differences"; "The shadow is black but it is not the color of the light"; "The shadow is where the light does not reach"; "The size of the shadow varies depending on the distance from the light source to the object, smaller further away, larger closer" (the nature of light, interaction with objects, and phenomena); and "The shadow is the image that an object projects on a surface, that projection is a space that light does not reach" (see Figure 1).

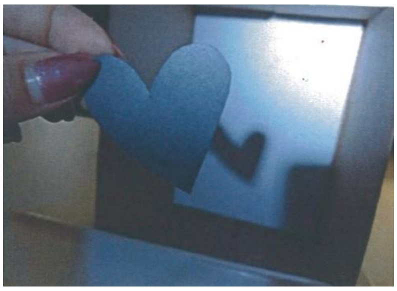

Figure 1. Students generating shadows.

The drawing they made shows precisely the variation in the size of the shadow in relation to the distance.

The objectives of the experience indicated by the student are relevant because of the following:

- They note the variation in size and position depending on the distance to the light source.
- They identify black light as the absence of light.
- They discover the origin of shadows.
- They differentiate light from darkness.

In the theoretical framework, it has already been mentioned how many authors point out that to understand the phenomenon of shadows, one must first understand a conceptual aspect of the nature of light, such as the rectilinear journey of light, in this case, of the light of a red laser. Therefore, there was a second stage where the students experimented with the interaction between light and liquids.

The student's degree of understanding can be observed in the images where the student was checking different experiments (see Figure 2) and in her explanations.

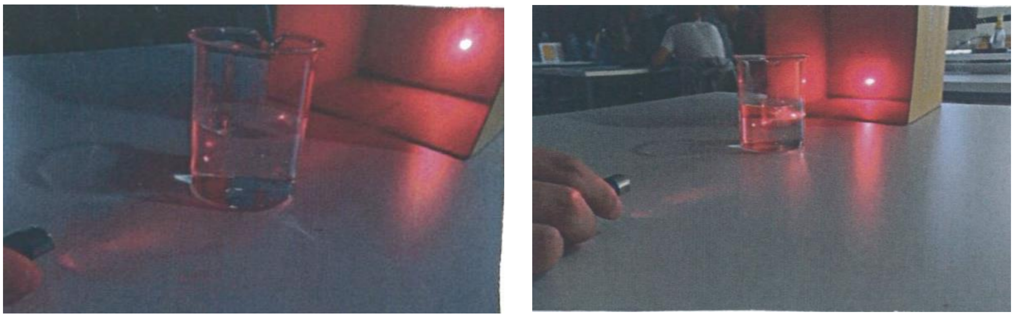

Figure 2. Student developing experiences.

"In the first image, the laser pointer passes through the beaker of water, but since the water is transparent, the path is not visible. However, it allows us to see where the light enters and exits in the projection onto the blank sheet, appearing to follow a straight line". "In the second image, 4–5 drops of milk have been added to the water. At this point, the suspension of these drops in the water causes the laser to interact with them, allowing us to see the path and confirm that light indeed travels in a straight line". "Finally, if we continue adding milk, there comes a moment when the milk again prevents us from observing the laser's path". "We are seeing how different materials affect or prevent the perception of light properties".

"The objectives are to observe the path of light and understand how it behaves with other media such as water or milk, as well as to introduce phenomena like reflection and refraction".

Lastly, we detail what a student noted about an experience with unfamiliar materials, such as hydrogel beads and Johnson's oil.

"In the case of the hydrogel beads, since they are made of a material very similar to water, light behaves the same way in both the water and the beads, making it impossible to distinguish the beads due to their identical refractive index". "In the case of the oil with the glass cup, they have a similar behavior due to the refractive index, and when the cup is filled with oil, it is not visible in the water; light passes through without us being able to distinguish it". "Refraction allows us to see or not see objects, and sometimes our eyes cannot distinguish these similar materials".

In summary, it can be said that in supplementary experiences related to the concept of a light path and the phenomena of reflection and refraction in light interactions with different materials, the students demonstrate their explanatory model based on observations. The explanations provided are consistent with the different experiences. The path of light is straight unless phenomena such as reflection or refraction occur in a different material medium. When materials are similar, light behaves the same way, and if opaque objects obstruct the light's path, shadows are produced due to the absence of light, as it does not pass through opaque objects.

For the notebook entry related to the "Light and Color Workshop", students were also asked questions that delve into reflections on the interdisciplinary work model, the importance of practical sessions, the value of the object as a teaching resource, and their learning in relation to their role as science teachers:

- What have you learned about light and color in relation to their physical behavior?
- How would you plan to bring your art and science project into the primary classroom?
- What importance has the laboratory session had?
- What advantages do you find in working interdisciplinary?
- Which are your final reflections?

4.2. Didactic Art–Science Product

In this section, the analysis focuses on the object/product created based on the analysis of the selected artist's work following the laboratory session. The answers of some students were as follows:

"Our object allows us to explore the theme of light and color from both a scientific and artistic perspective". "The work of artist Donald Judd, an American sculptor associated with the minimalist movement, was chosen for its special emphasis on how light influences the perception of artworks". "In designing our product, it was crucial to select materials based on their interaction with light and their effect on visual perception". "Through the creation process, we have learned that light is electromagnetic radiation. White light is a mixture of radiations with different wavelengths, and color is not an intrinsic property of objects but rather related to the nature of the light they receive." "We say that an object has color when it reflects or transmits certain radiations corresponding to that color". "The human eye can perceive color from different physical stimuli. The theoretical white is formed by mixing primary colors (blue, green, and red)." "The product is the result of a reflective process". "The interdisciplinary project offers numerous advantages". "It allows us to address the reality around us, breaking down the barriers between disciplines and contributing to weakening the compartmentalization of students' knowledge". "It illustrates the complexity of natural and social phenomena as they appear in reality". "It increases student motivation by applying knowledge received from different subjects". "It fosters teamwork, cooperation, and creativity among both teachers and students". "One disadvantage is the coherence or consistency in the meanings assigned from different areas".

In the following figure (Figure 3), two images from the students' products are shown. In the left figure, the students built a mobile, taking as reference the mobile created by the OPN studio. In the right figure, the installation made by the students can be observed, with a circus theme, for which they took mechanical lettering as a reference (Large Feather Wheel by Rebecca Horn).

Figure 3. Student's production (extracted from [24]).

The positive value attributed to an interdisciplinary approach is evident, as it aligns more closely with reality and work in primary school classrooms. However, we also need to analyze which aspects of learning about light and color are highlighted. The relationship between theory and practice is evident in aspects that have not been explicitly mentioned, such as the electromagnetic nature of light.

Above all, the interdisciplinary approach reveals an integral and systemic understanding, as it addresses the visual system and the interaction of light with materials. For example, the concept of color as a non-intrinsic property of objects is mentioned. This aspect is highlighted in various studies [8–10] and is sometimes still a challenge, even for university students [20,24]. This project demonstrates that interdisciplinary work helps address and clarify these complex concepts, integrating theoretical knowledge with practical application.

5. Conclusions

In this study, we presented and described a training intervention proposal for future teachers in training. We believe the originality of this proposal lies in its interdisciplinary approach to teaching and learning about the nature of light and color and their conceptual aspects, as well as the didactic value it provides. In this regard, the analysis of the discourse that students engage in within their laboratory notebooks provides us with valuable insights in several ways, all of which align with the objectives and purpose of the proposal.

Firstly, within the framework of practical work, students highly valued the laboratory session dedicated to experimentation with various aspects of light interaction with materials and the phenomena that occur. Many of the students' comments highlighted the opportunities this session offers for experimenting, observing what happens, seeking explanations for these observations, and thus establishing their own explanatory models. The freedom to confront this session in a group setting, which, as previously mentioned, goes beyond following a typical lab script, allows them to design their own experiences and reflect on the didactic value of this process for them as they take on the role of "science teachers". Asking them to reflect on what they knew, what they have learned, and what they need to know to intervene in a primary school classroom provides us with an approximate understanding of their prior ideas and starting conceptual models and how they learn while exploring [24].

Given that this is a qualitative ethnographic analysis from an action–research perspective, it is important to detail what the results indicate about the learning processes involved when applying this knowledge toward the integration of knowledge based on a didactic object.

In this sense, the analysis of what the various scientific and artistic analyses meant for them pointed to an increase in motivation. Art has the capacity to introduce emotional elements, and this framework is evident in their comments [25,26]. Once they engaged with the conceptual framework of science regarding light and color phenomena, they were able, through an aesthetic–artistic analysis, to detail the importance of these elements in the creation of meanings in the works of many artists [8,13]. Thus, we could speak of a multidimensional analysis: the analytical dimension of the phenomena concerning scientific models, the analytical dimension of the artistic work, and the dimension where the focus is on how the artistic and scientific discourse are present in the work itself and how this informs their understanding. As a result, they were able to value the product as the outcome of conceptual and didactic reflection.

Despite multiple studies over the last forty years analyzing the difficulties our students face in understanding the nature of light and color [9], the phenomena of their interaction with materials, and the proposals made to improve comprehension and the use of teaching models more aligned with scientific models [4], we find that there are no evident improvements. Throughout this text, it has been mentioned how the inclusion of proposals and actions that allow exploring multiple models, especially if these models, whether correct or not, come from the different disciplines involved in the act of seeing and understanding phenomena, seems to improve learning by understanding all processes within integrative frameworks. In this sense, it appears that the proposal corroborates what some research has indicated as a possibility without making concrete proposals. At the same time, it is noted that incorporating art and visual expression seems to have a motivating effect related to those sensory aspects, especially when there is development and reflection around the constructed object. An artistic–scientific object or product provides a resource as an element of didactic reflection closer to the new working methodologies in primary classrooms and STEAM (science, technology, engineering, art, and mathematics) approaches. Although the proposal lacks all the elements that are part of the STEAM working principles in some cases, and due to the value it provided them with, the students themselves pointed out how this experience could be extended to work in the fields of mathematics, biology, and, of course, technology.

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