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Primary School Preservice Teachers' Alternative Conceptions about Light Interaction with Matter (Reflection, Refraction, and Absorption) and Shadow Size Changes on Earth and Sun

Abdeljalil Métioui

Department of Didactics, Faculty of Science Education, Université du Québec à Montréal, Montréal, QC H3C 3P8, Canada; metioui.abdeljalil@uqam.ca

Abstract: The present qualitative study investigates the conceptual representations of 132 preservice Quebec elementary teachers regarding matter–light interaction (reflection, refraction, and absorption) and the size of the shadow of an object on the Earth's surface illuminated by sunlight. A paper-and-pencil questionnaire composed of six questions was constructed and managed. The data analyses demonstrate that most encounter several conceptual difficulties in explaining phenomena related to light, which are omnipresent in their immediate environment and with which they interact daily. The conceptual difficulties identified in analyzing the students' explanations were as follows: (1) a black-colored body absorbs all light rays; (2) light travels rectilinearly and stops when it hits a white paper; (3) a mirror reflects light; it does not absorb it; (4) the glass surface of a mirror reflects light; (5) specular reflection and diffuse reflection are confused; and (6) the shadow varies during the day because the Sun moves around the Earth. These findings have implications for creating teaching strategies that confront preservice elementary teachers' alternative conceptions and their corresponding scientifically accepted counterparts.

Keywords: prospective teachers; misunderstanding; matter–light interaction; absorption; diffusion

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1. Introduction

Since the 1980s, many studies have extensively investigated alternative conceptions (ACs), i.e., conceptions about light that contradict accepted scientific theories held by students from preschool to the university [1–15]. Fewer studies focused on identifying ACs among preservice and in-service teachers [16–23]. On this subject, Krall et al. [19] (p. 2) underlined that these studies among students as well as elementary teachers "indicate that individuals over a broad range of ages and with diverse educational experiences have many conceptual difficulties with light concepts."

The most common ACs identified in those works are that white light cannot be a mixture of light colors; black color consists of all wavelengths of light; color is an intrinsic property of the object; yellow light is less dark than red; the eyes see an object's color rather than the reflexive light's color; confusion between light and pigment colors; light moves to different distances, depending on whether it is daylight or dark; only shiny materials (e.g., mirrors, lakes, polished metal) reflect light, rough surfaces do not reflect light; light needs air to travel; light does not take time to travel somewhere—it is instantaneous; a shadow is a reflection because it is the same shape as the object; the shadow's size depends on the light source's intensity; a luminous source does not emit light rays in all directions; confusion between light and its effects (e.g., intense illumination or glare); and light does not need to reach the eye to see an object. Notably, these ACs are made-up assumptions derived from linguistic constructions (e.g., daily used phrases such as "come out of your shadow"). On this subject, Galili and Hazan [24] (p. 59) point out that many daily used phrases reinforce ACs about light and its properties and constitute an obstacle to acquiring scientific language:

> *"Thus, many linguistic constructions do not conform to present-day scientific knowledge. Phrases such as 'her eyes shine', 'his face radiates light', 'she casts a glance', 'light fills the room', 'the mirror reflects images', and 'the tree casts its shadow' are at odds with contemporary optics."*

Moreover, they note conceptual difficulties related to the limitations of the senses in interpreting a light property such as color addition (i.e., the production of various colors of light by mixing the three primary colors of light: red, green, and blue) and the light propagation phenomenon. For example, the eye cannot distinguish the addition of two wavelengths as when we combine light green with light blue color, and the brain assimilates them to a single wavelength, yellow. Another example is related to the model of the rectilinear propagation of light in space [24] (p. 59):

> *"[In optics], the observed phenomenon presumes an inclusion of the observer's eye as a part of the optical system. Nothing indicates his/her true physical role to the observer since vision and light delivery to the eyes are not accompanied by perceptible muscular effort. Like breathing, the progress of seeing (i.e., interpretation of visual images) operates subconsciously."*

These common misconceptions also derive from other types of influence, such as intuitional or spontaneous learning; popular science, based on the daily use of language and media images; and school science, based on a symbolic universe and idealized science class [25].

It should be noted that only some of the above research focused on the ACs of both students and teachers concerning light and matter interaction to explain notions such as reflection, refraction, and absorption. The purpose of the present study was to investigate the following questions:

a. Do elementary preservice teachers know that reflection, refraction, and absorption occur when light falls on the material's surface?
b. Do elementary preservice teachers know that light is a form of energy and travels as a particle and a wave?
c. Do elementary preservice teachers know that energy light absorbed by a given object is converted to heat energy?
d. Do elementary preservice teachers know that when we illuminate an object, electrons in the object's atoms vibrate more firmly in response to the oscillating electric field of the illuminating light?
e. Do elementary preservice teachers know that the shadow of a given object on the surface of the Earth changes size because of the rotation of the Earth on itself and around the Sun?

2. Population and Methods

2.1. Population

The present study concerns the preservice ACs of absorption and light diffusion. To this end, 132 preservice teachers from Quebec, enrolled in the third academic year of the four-year final exam program in elementary education, participated in this study in the setting of a structural course on the didactics of the sciences. They were aged 19 to 25 years, the majority were female, and they came from the sector of the liberal arts and were not taking any science courses at the university. Their only science education went back to their secondary studies, where they had taken two courses in physics and biology.

2.2. Methods

To investigate trainee teachers' ACs, we constructed a paper and pencil questionnaire with open-ended and multiple-choice questions. As illustrated in the Appendix A, five questions were formulated as a multiple-choice questionnaire with 2 or 3 answer choices and one open-ended question. They explained their choices of multiple-choice answers to characterize their conceptual explanations.

They were given sixty minutes to complete the paper-and-pencil questionnaire. It is pertinent to note that the questions were formulated based on works on student and teacher ACs about the light properties summarized above. Moreover, the questions formulated require students to refer to their conceptual knowledge. Thus, we do not ask students to recite a law (e.g., the Snell–Descartes laws of reflection or refraction) but rather to explain the physical phenomena when light interacts with a given object. On this subject, Timmermann and Kautz [26] (Page 26.1179.4) point out that such an approach has two positive features:

> *"[. . .] On the one hand, we do not expect students to recite the law in question but rather to be able to apply it. Thus, it is only logical to also test for this. On the other hand, this makes it easy to generate many different questions about the same topic without the possibility for students to memorize the correct answer. One can exchange the situation the students have to predict."*

We analyzed the data collected from the "paper-pencil" questionnaire with the approaches that require the definition of scientific response (nomothetic) and the classification of students' justifications in specific categories (ideographic) [27–29].

We have referred to two approaches to identify the categories of the students' conceptual representations:

1. The data collected from the answers provided by the students.
2. The conceptual framework underlining the questions formulated. Fraenkel, Wallen, and Hyun [28] underline that at the methodological level, this step of analysis is relevant in the qualitative study because it allows the researcher to know what he is looking for in the experimental data:
    - 2.1 Scientifically correct and complete explanations.
    - 2.2 Responses involving correct but incomplete explanations.
    - 2.3 Ideas that include partially correct and incorrect statement sentences (i.e., the coexistence of several contradictory representations).
    - 2.4 Explanations that are challenging to understand or that have no relationship with the question.
    - 2.5 Students who did not provide any explanation related to the question and used the same expression given in the question.

We regrouped students' answers into distinct categories of representations for each question. The number of categories is variable from one question to the other. Second, we interpreted the set of categories identified to prove their representations.

The paper-and-pencil questionnaire was designed to take sixty minutes to identify trainee teachers' ACs about the interaction between light and matter, particularly the absorption and diffusion phenomenon, and was composed of six questions. The questions were constructed based on works on the conceptual understanding of basic optics topics by pupils and trainee teachers, as summarized above. Moreover, we considered the notions prescribed in the Québec Education Program [30]. In the document, the scientific concepts and instruments about light phenomena that pupils must acquire (explicitly or implicitly) in each of the three elementary school cycles (two years duration each) related to the following categories: I. Material World; II. Earth and Space; and III. Living Things (see Table 1). For more details about the structural concept of each category, see Métioui [31].

Table 1. Scientific notions prescribed in the Quebec Education Program.

I. MATERIAL WORLD
I.1 Matter
I. 1.1 Properties and characteristics of matter * Classifies objects according to their properties (e.g., color, shape, size, and texture). Cycle One * Distinguishes between translucent substances (transparent or colored) and opaque substances. Cycle One * Describes the shape, color, and texture of an object or a substance. Cycle Two * Recognizes the materials of which an object is made. Cycle Three
I.2 Energy
I.2.1 Forms of energy * Describes different forms of energy (e.g., electrical, light, heat, and sound). Cycle Two * Identifies energy sources in his/her environment (e.g., a chemical reaction in a battery, sunlight). Cycles Two/Three
I.2.2 Transmission of energy * Identifies the characteristics of a sound wave (e.g., volume, timbre, and echo). Cycle Two * Describes the functions of the components of a simple electric circuit (conductor, insulator, energy source, light bulb, and switch). Cycle Three * Describes the behavior of light rays (reflection and refraction). Cycle Three
I.2.3 Transformation of energy * Describes the transformations of energy from one form to another. Cycle Two * Recognizes energy transformations from one form to another in various devices (e.g., flashlight: chemical to light; electric kettle: electrical to heat). Cycle Three
I.3 Forces and motion
I.3.1 Magnetism and electromagnetism * Identifies objects that use the principles of electromagnetism (e.g., electromagnetic crane, fire door, and solar panel). Cycle Three
II. EARTH AND SPACE
II.1 Energy
II.1.1 Sources of energy * Explains that the sun is the primary source of energy on Earth. Cycle Two * Identifies natural sources of energy (e.g., sun, moving water, and wind). Cycle Two
II.1.2 Transmission of energy * Describes methods for transmitting thermal energy (e.g., radiation, convection, and conduction). Cycle Three
II.1.3 Transformation of energy * Explains that sunlight, moving water, and wind are renewable energy sources. Cycle Two * Describes the methods invented by humans to transform renewable sources of energy into electricity (hydroelectric dam, wind turbine, and solar panels). Cycle Two
II.2 Forces and motion
II.2.1 Rotation of the Earth * Associates the day and night cycle with the Earth's rotation. Cycle Two
II.2.2 The tides * Describes the ebb and flow of the tides (rise and fall of sea levels). Cycle Three
II.3 Systems and interaction
II.3.1 Light and shadow * Describe the influence of the apparent position of the Sun on the length of shadows. Cycle One
II.3.2 System involving the Sun, the Earth, and the Moon * Illustrates the formation of eclipses (lunar and solar). Cycle Two
II.3.3 Meteorological systems and climates * Makes connections between weather conditions and the types of clouds in the sky. Cycle Two
II.3.4 Technologies related to the Earth, the atmosphere, and outer space * Recognizes the influence and the impact of technologies related to the Earth, the atmosphere, and outer space on people's way of life and surroundings (e.g., prospecting equipment, meteorological instruments, seismographs, telescopes, satellites, and space stations). Cycles Two/Three
II.4 Techniques and instrumentation
II.4.1 Use of simple observational instruments * Appropriately uses simple observational instruments (e.g., magnifying glasses and binoculars). Cycles Two/Three
III. LIVING THINGS
III.1 Matter
III.1.1 Organization of living things * Explains the sensory functions of certain parts of the anatomy (skin, eyes, mouth, ears, and nose). Cycle Two
III.1.2 Transformations of living things * Names the basic needs for plant growth (water, air, light, and mineral salts). Cycle One
III.2 Energy
III.2.1 Sources of energy for living things * Describes how photosynthesis works. Cycle Three * Explains how water, light, mineral salts, and carbon dioxide are essential to plants. Cycle Three
III.3 Forces and motion
III.3.1 Motion in plants * Distinguishes among the three types of motion in plants (geotropism, hydrotropism, and phototropism). Cycle Three * Explain how plants' motion types enable them to meet their basic needs. Cycle Three

2.3. Diversification and Saturation Sample

In order to ensure the variability of the conceptual representations and the validity of the conclusions, we considered the two criteria generally accepted in qualitative research, namely the diversification of the sample and the saturation of the responses [29]. Concerning the diversification criterion, the question does not arise since all the students registered in the teacher training program hold a college diploma in human sciences. During their secondary studies, they had all taken two courses in science. The second criterion used to ensure the variability of the representations is that of saturation, that is to say, the phenomenon by which the researcher has the impression of not learning anything new from the students' responses. Of course, if one changes the context in which we question the students, such as interviews instead of the paper-and-pencil questionnaire, or interview students in an informal setting, we will learn more because of the dynamic and complex nature of the notion of representation.

Below, we will present the goal of each question and its analyses, followed by some students' answers as illustrations. To keep the anonymity of the respondents, we identified students (S) by the Si letter ("i" represents the number designating the student).

3. Results

3.1. Objective and Data Analyses: Question #1

The first question aimed to find out how students explain what happens when light strikes the solid surface of a mirror. When light hits the mirror surface, the light rays reflect off. To make a mirror, we need a perfectly polished surface on a microscopic scale. In practice, it is a metal layer (good conductor of electricity) placed on a shiny glass plate. This layer of metal reflects most of the light rays, while the glass in front serves as a support. Indeed, when the light rays (electromagnetic waves) reach their surface, the free electrons compensate for the electric and magnetic fields of the incident wave and return a wide range of visible frequencies. Formerly, we interpreted the reflection by referring to Newton's corpuscular nature of light or Huyghens's wave aspect of light. The reflection phenomenon for Newton was due to the corpuscles' reflection, and for Huyghens, the wavefront's reflection when light clashed with the mirror.

Thus, Newton proposed that small particles compose light that travels through space. As for Huyghens, light propagates perpendicular to the direction of its movement. It was Maxwell who proposed that light is a wave phenomenon made up of electromagnetic waves (e.g., the human eye can detect wavelengths from 380 to 700 nanometers) propagating in space at the speed of light. Finally, thanks to the work carried out by Einstein on the nature of light, we know that light is composed of photons (e.g., a "particle of light"), and these photons travel in waves.

We divide the student responses into two response categories. The first category represents students according to whom light emitted by the flashlight surrenders on the mirror and stops on its surface. The second category represents students for whom light emitted by the flashlight stops on the mirror and is sent back by the mirror elsewhere in the piece. The data put forward to explain their answers allowed us to identify three subcategories in the first category and four subcategories in the second category, as illustrated in Table 2.

In Table 3, we synthesize students' responses and percentages for these categories and subcategories, followed by students' responses for illustrative purposes.

The categorization of the answers was based on the observation that many students (76%) affirm that the mirror will reflect light. However, the advanced justifications are incomplete, absent, or are simply a matter of the evidence, for example, the fact that a mirror reflects light and absorbs some (e.g., significantly less than the reflected light). Students should have referred to the principle of constructing a mirror to explain its reflective property as synthesized above.

Table 2. Categories and their subcategories for Question #1.

Categories	
Category 1	Category 2
Light emitted by the flashlight surrenders on the mirror and stops on its surface.	Light emitted by the flashlight surrenders on the mirror and is sent back by the mirror elsewhere in the piece.
Subcategories	
1.1 Light emitted by the flashlight surrenders on the mirror and stops there because the mirror does not reflect light.	2.1 The mirror has a property that reflects light, returns brightness, throws light, and reflects rays of light.
1.2 The mirror absorbs light emitted by the flashlight.	2.2 Light directed at the surface of a mirror is reflected because the mirror does not absorb light.
1.3 The light stays on the mirror; it cannot bounce because its trajectory is rectilinear.	2.3 Sunlight is directed with a mirror, so it is the same with a flashlight.
	2.4 The mirror reflects the light since it reflects the image.

Table 3. Students' responses to Question #1: categories and subcategories and their percentages.

Category 1 (32/132—24%): light emitted by the flashlight surrenders on the mirror and stops on its surface
Subcategory 1.1 (8/132—6%): light emitted by the flashlight surrenders on the mirror and stops there because the mirror does not reflect light.
"I know that with the Sun, the light would reflect through the mirror, but I don't think artificial light can do the same thing." S_6 "The flashlight emits the light; it travels to the mirror and its surroundings but is not reflected elsewhere in the room." S_{39}
Subcategory 1.2 (10/132—8%): the mirror absorbs light emitted by the flashlight.
"The mirror absorbs the light; it does not redirect it." S_2 "Because the light is absorbed by the mirror." S_{19}
Subcategory 1.3 (14/132—11%): the light stays on the mirror; it cannot bounce because its trajectory is rectilinear.
"The light does not bounce. It stops where we light up. It travels in a straight line." S_5 "Because light propagation is rectilinear and does not deviate nor bounce. So, it stops there." S_8
Category 2 (100/132—76%): light emitted by the flashlight surrenders on the mirror and is sent back by the mirror elsewhere in the piece.
Subcategory 2.1 (24/132—18%): the mirror has a property that reflects light, returns brightness, throws light, and reflects rays of light.
"The light that beats on a mirror is always reflexive on an object." S_{98} "If the light goes into the mirror, it does not stop there since the room will be lit, and it will not be dark. The mirror reflects the light." S_{108}
Subcategory 2.2 (30/132—23%): light directed at the surface of a mirror is reflected because the mirror does not absorb light.
"The mirror reflects light; it does not absorb it. It acts as an object on which light bounces." S_{88} "The mirror reflects 100% light. Where the light is reflecting depends on the angle of the mirror." S_{115} "Since the light is reflected thanks to the mirror's surface (characteristics specific to the mirror) entirely." S_{129}
Subcategory 2.3 (26/132—19%): sunlight can be directed with a mirror so it is the same with a flashlight.
"I take the example of a mirror and the Sun. We can redirect the Sun's rays to a specific point as if to emit signals." S_{39} "Take the example of a ray of light that bounces off the glass of a watch and that we have fun directing its rebound in people's faces." S_{104} "I remember an experience where the Sun hits a magnifying glass, and the light reflects off the grass to burn it (thus, the light reflects off a magnifying glass)." S_{110}
Subcategory 2.4 (20/132—15%): the mirror reflects the light since it reflects the image.
"In my opinion, the mirror makes the ray of light jump as it reflects my image." S_{22} "The mirror reflects the images, so the light also." S_{72} "The reflection of light reflects in (rebound) because the mirror reflects the picture." S_{96}

3.2. Objective and Data Analyses: Question #2

As for the mirror, the present question aimed to know the students' conceptions about the phenomenon happening when light reaches the surface of the sheet of white paper. In both cases, we observe the phenomenon of reflection. However, in the case of the piece of paper, the rays of light are reflected irregularly with different angles, which gives the paper a translucent appearance.

In the case of the paper, we want to know if, for the students, the paper will act as a mirror when the light reaches its surface. The paper must be smooth relative to the wavelength of light striking the surface. It is not the case; even though the paper's surface appears smooth, a photograph taken under a microscope reveals its irregular surface. Thus, the light rays will be reflected irregularly with different angles, making the paper translucent.

We divide the students' responses into two conceptual categories. The first category represents students according to whom light emitted by the flashlight surrenders on the paper; it stops there. It is relevant to note that in Guesne, Sere, and Tiberghien's [32] research with 10–14-year-old French students about the nature and behavior of light, most of them thought that after light strikes a blank sheet of paper, the light remained on this surface.

The second category grouped together students for whom light emitted by the flashlight surrenders on the paper and is sent back by the paper elsewhere in the room. The data put forward to explain their answers allowed us to identify three subcategories in the first category and three subcategories in the second category, as illustrated in Table 4.

Table 4. Categories and their subcategories for Question #2.

Categories	
Category 1	Category 2
Light emitted by the flashlight surrenders on the paper; it stops there.	Light emitted by the flashlight surrenders on the paper and is sent back by the paper elsewhere in the room.
Subcategories	
1.1 The light stops on the paper because the latter absorbs it and does not have the property of reflecting light.	2.1 The white sheets of paper reflected light; otherwise, we could not see it. The light scattered by the paper must enter our eyes to see it.
1.2 Light travels rectilinearly and stops when it hits a white paper.	2.2 The sheet of paper is white, and white reflects light.
1.3 The white paper does not have the properties to reflect light like a mirror.	2.3 The white color reflects light.

In Table 5, we synthesize students' responses and percentages for these categories and subcategories, followed by students' responses for illustrative purposes.

Table 5. Students' responses to Question #2: categories and subcategories and their percentages.

Category 1 (72/132—55%): light emitted by the flashlight surrenders on the paper and stops there
Subcategory 1.1 (25/132—19%): the light stops on the paper because the latter absorbs it and does not have the property of reflecting light.
"Because the light does not reflect on the paper, it is an opaque body that keeps the light." S_{71} "Because paper does not have the property of reflecting images in rays. The paper absorbs rays of light." S_{80} "The light stops on the paper because it absorbs it." S_{111}
Subcategory 1.2 (30/132—23%): light travels rectilinearly and stops when it hits a white paper.
"Light travels in a straight line. So, it stops there." S_{12} "The light travels in a uniform rectilinear motion and does not bounce off objects." S_{18} "Light is an entity that moves in a straight line. Moreover, the paper does not reflect light in all directions like the mirror." S_{100} "The light is rectilinear and illuminates until it is not blocked by a mast object (no glass)." S_{106}

Table 5. *Cont.*

Subcategory 1.3 (17/132—13%): white paper does not have the properties to reflect light like a mirror.
"The light emitted by the lamp stops on the paper. It does not reflect; it is not like the mirror." S_{66} "Because the sheet of paper cannot send light, its surface is not shimmering." S_{79} "The light cannot go from the white sheets to another place. We cannot see our faces by looking at ourselves on a white sheet." S_{90} "Unlike a mirror, the paper does not have the reflecting light property (unless it is painting with a special paint)." S_{97}
Category 2 (59/132—45%): light emitted by the flashlight surrenders on the paper and is sent back by the paper elsewhere in the room.
Subcategory 2.1 (20/132—15%): the white sheets of paper reflected light; otherwise, we could not see it. The light scattered by the paper must enter our eyes to see it.
"The white becomes more vivid. When it makes the sun, and we try to read, we will not be capable because the white reflected too much." S_3 "The light reflects in our eyes; otherwise, we would not be able to see it." S_{46} "The light that hits the paper is reflected since some rays come to our eyes, which is why we can see it." S_{47} "Because paper reflects light. For example, white snow dazzles us when it is sunny, and paper is also when we read, and the light is strong." S_{48}
Subcategory 2.2 (22/132—17%): the sheet of paper is white, and white reflects light.
"White reflects light; for example, in some hot countries, everyone wears white clothes." S_{38} "White reflects light. In the cinema, we use a reflector to increase the effect of the light (intensity)." S_{83} "Because the sheet of white paper reflects the full spectrum of light. For example, white curtains in a room will illuminate the room more by reflecting light than black curtains, which do not reflect anything." S_{88}
Subcategory 2.3 (17/132—13%): the white color reflects light.
"The sheet of white paper reflects the light because of the color." S_{58} "Light is reflected elsewhere because white is the mixture of all colors and therefore reflects all these colors." S_{64}

3.3. Objective and Data Analyses: Question #3

This question aims to know if, for the students, the black cardboard cannot absorb all the visible light it receives; otherwise, we will not see it. It is noteworthy that black is the absence of color, which means that almost all the incident light is absorbed. Following the principle of conservation of energy, this light energy is transformed into thermal energy.

We divide the students' responses into two response categories. The first category represents students according to whom black cardboard will absorb all visible light it receives, and the second category, students for whom black cardboard will absorb almost all the visible light it receives and diffuse the rest. The data put forward to explain their answers allowed us to identify six subcategories in the first category and two subcategories in the second category, as synthesized in Table 6.

Table 6. Categories and their subcategories for Question #3.

Categories	
1. Black cardboard will absorb all visible light it receives.	2. Black cardboard will absorb almost all the visible light it receives and diffuse the rest.
Subcategories	
1.1 We are warmer when we wear black clothes because black absorbs all light rays. 1.2 A black body attracts light. 1.3 A black body absorbs all light rays. 1.4 Black cardboard absorbs all light because black is not a color. 1.5 A black body absorbs all light because it is opaque; no light can pass through it. 1.6 A black-colored body absorbs all light rays.	2.1 Some of the light rays are reflected; otherwise, no brightness can be seen. 2.2 The black color does not absorb all the light, and some is reflected.

In Table 7, we synthesize students' responses and percentages for these categories and subcategories, followed by students' responses for illustrative purposes.

Table 7. Students' responses to Question #3: categories and subcategories and their percentages.

Category 1 (105/132—80%): black cardboard will absorb all visible light it receives
Subcategory 1.1 (20/132—15%): we are warmer when we wear black clothes because black absorbs all light rays.
"Black will absorb light and will not reflect light rays; it is why the black color heats up quickly in the sun." S_1 "The color black absorbs light. When we walk outside with a black sweater, when it is sunny, we will be warmer than if we wear a white sweater." S_{71}
Subcategory 1.2 (16/132—12%): a black body attracts light.
"This is true because we all know that black attracts light. For example, black cardboard will have much more heat than white cardboard. We can explain this because the light rays in contact with the black cardboard have been absorbed." S_{10} "In my opinion, this statement is true. I have always heard that black attracts more light than other colors." S_{12}
Subcategory 1.3 (18/132—14%): a black body absorbs all light rays.
"True, black absorbs light rays since black is not a color, and it will absorb the rays, which are colored." S_{20} "It will make sense if we think that white snow hit by the sun dazzles us, whereas a black object in the same context would not dazzle us." S_{43} "Indeed, all the light that illuminates a black object is absorbed since black does not reflect light." S_{62} "All light rays that strike the cardboard are absorbed." S_{78}
Subcategory 1.4 (14/132—11%): black cardboard absorbs all light because black is not a color.
"True, black absorbs light rays since black is not a color, and it will absorb the rays, which are colored." S_{20} "It is for this reason that black "is not a color." Instead of being a mixture of pigments, it results from the absorption of all the light rays surrounding it." S_{35}
Subcategory 1.5 (19/132—14%): a black body absorbs all light because it is opaque; no light can pass through it.
"If the cardboard is opaque, then the light is absorbed, no matter what color, whether red, black, or white, the cardboard will block the passage of light rays." S_{23} "Black cardboard is like an opaque body. Then, all the light rays that "hit" it will be absorbed." S_{57}
Subcategory 1.6 (18/132—14%): a black-colored body absorbs all light rays.
"All the light rays (all the colors in the rainbow) are absorbed when we see black. Thus, as no color reaches the eye, it perceives the black card." E_6 "Black is the composition of all colors together. As a result, objects have the characteristic of absorbing all light rays except that of the color that composes them, which is why we can see the color of this object. Black, composed of all the colors, absorbs all the light rays that "strike" it." E_{58}
Category 2 (27/132—20%): black cardboard will absorb almost all the visible light it receives and diffuse the rest.
Sub-category 2.1 (12/132—9%): some of the light rays are reflected; otherwise, no brightness can be seen.
"When a black card is illuminated, most of the light rays that hit it are absorbed, but not entirely. For example, if they were all absorbed, it would not be possible to say that this one is enlightened." S_{24} "Black indeed absorbs light, but I do not think it absorbs all of it. For example, if there are black walls in a room and the light is on, the room will not be lit as when there are white walls, but it will still be." S_{66} "I could not say that the black cardboard absorbs all the rays. The color black makes us think this, but this is not the case. I believe there is a small ray of light on the black cardboard." S_{74}
Subcategory 2.2 (15/132—11%): the black color does not absorb all the light; some is reflected.
"The color black indeed absorbs much light; however, it will not absorb all the light. It will still let through a faint ray of light." S_9 "It is true that the color black absorbs light instead of reflecting it but does not absorb all the rays that strike it." S_{30}

3.4. Objective and Data Analyses: Question #4

This question asks whether students referred to the light waves' properties and their propagation in different materials to explain why the submerged part of the pencil appears bent. In this experiment, the pencil appears to bend, but this is only an illusion created by the wave nature of light. In modern optics, we know that any transparent substance has an index of refraction, which measures the slowing down of light passing through matter and is ultimately related to its chemical composition. It is important to note that

when light waves pass through glass and water, their propagation speed changes while the frequency remains unchanged. The submerged pencil does not change color or appearance; its relative position and shape appear altered when viewed through a substance with a different refractive index than air. So, when light transmits from air to water, it changes direction slightly based on its properties (liquid water is denser than air). In the following passage, Walmsley [33] (p. 23) synthesizes the refraction of a ray at the interface between air and water to explain the 'kink' observed in a pencil partially immersed in a cup of water by drawing an analogy with walking through water:

"The refractive index can be thought of as being a measure of the optical 'sluggishness' of the medium as experienced by a light ray. So light travels more slowly in a medium with a larger refractive index because the molecules of the medium are slightly more resistant to having their atoms and electrons moved by the light. It is like running in a pool of water. If the depth is very small, your legs can move easily and you can run fast. If the water is up to your knees, it's harder, because you have to work against the resistance of the water."

In addition, we wanted to know in the case of students who refer to the change in the speed of light from air to water if this speed variation causes the brain to interpret the ray's light inclination as a pencil twist.

We divide the students' responses into five response categories: (1) the pencil appears bent because the speeds of light in air and water differ, (2) the light rays that enter the water are deflected because the water is denser than the air, hence the illusion of seeing the deformed pencil, (3) the pencil seemed bent because the water acted like a magnifying glass, (4) the pencil looks bent due to the angle of our vision, and (5) the pencil appears bent because the light path is bent as it passes from air to water.

In Table 8, we synthesize the percentage of students in each category and their responses for illustrative purposes.

Table 8. Students' responses to Question #4: categories and their percentages.

Category 1 (20/132—15%): the pencil appears bent because the speeds of light in the air and water differ
"Light does not travel at the same speed in water as in the air. This phenomenon gives us the impression that the pencil in the water seems deformed." S_2 "Light, when it travels through water, has to travel through it at a different speed and cause this visual distortion." S_{77}
Category 2 (28/132—21%): the light rays that enter the water are deflected because the water is denser than the air, hence the illusion of seeing the deformed pencil.
"When a ray of light comes into contact with water, it slightly deviates from its trajectory because it encounters a liquid denser than air. What we see through the water may seem distorted to us." S_{49} "Water is denser than air; the light rays reflected in it are different, which is why the pencil looks different." S_{69} "It is an optical illusion, the density of water being different from that of air." S_{80} "Light rays that pass through a liquid like water are blurrier because they have a harder time penetrating it than through air. This effect also makes the pencil in the liquid appear deformed." S_{89}
Category 3 (40/132—30%): the pencil seemed bent because the water acted like a magnifying glass.
"Water acts like a magnifying glass when you look through it. The pencil in a glass of water seems deformed because of an optical effect." S_9 "It looks distorted because the water makes the pencil look deformed. Water has a small amount of the function of a magnifying glass." S_{10} "It is an illusion. The effect of water deforms the object. A bit like a magnifying glass but with a smaller effect." S_{15} "Water acts like a magnifying glass; it magnifies the appearance of things. This phenomenon is because the reflection reaching us from the object is not regular; the water deforms light rays." S_{30}
Category 4 (21/132—16%): the pencil looks bent due to the angle of our vision.
"There must be something to do with the light and the angle of our vision." S_{52} "It seems deformed because of the position in which we are. The orientation causes this is changed." S_{67} "It is about the phenomenon of refraction. When the light rays pass from one transparent material to another, there is a material deformation, according to the angle under which one perceives the pencil. One could say that there is a fracture. That is why it looks like the pencil is broken." S_{107}
Category 5 (23/132—18%): the pencil appears bent because the light path is bent as it passes from air to water.
"I believe we can speak of deflection of light rays, in this case. A ray of light generally travels in a straight line. When it "hits" the water, it will modify its trajectory. The returned image will then be different." S_8 "It is harder for light to pass through glass water, so everything gets magnified through a glass of water." S_{37} "Because light goes through water differently than the air." S_{85}

3.5. Objective and Data Analyses: Question #5

The size of the shadow changes during the day. How to explain this phenomenon? The Earth makes two important movements; one around the Sun (translational movement) that lasts one year, and one around its north–south axis (rotational movement) that takes one day. The Earth rotates counterclockwise. This counterclockwise rotational movement gives us the false perception that the Sun "rises in the east" and "sets in the west." The size of a person's shadow changes during the day because the angle of the Sun's ray intercepted by a point on the Earth's surface changes throughout the day. The angle is the lowest in the horizon, very early in the morning, so the shadow is the most elongated. At midday, the angle is highest (most perpendicular) to the Earth's surface, so the shadow size is the smallest. After that time, the shadow begins to enlarge, but in a different direction.

We divide the students' responses into five response categories: (1) the size of the shadow changes because sunlight is at a different intensity during the day; (2) the size of the shadow changes because the Sun changes places; (3) the shadow's size changes because the Sun's position changes: depending on the time of day, it is either up or down; and (4) the shadow's size changes because the Earth goes around the Sun.

In Table 9, we synthesize the percentage of students in each category and their responses for illustrative purposes.

Table 9. Students' responses to Question #5: categories and their percentages.

Category 1 (36/132—27%): the size of the shadow changes because sunlight is at a different intensity during the day
"Because your shade will be average in the morning because the Sun is average. It will be great in the afternoon because it is the time when it has more Sun. In the evening, it will be almost gone because the Sun is all gone, or almost all gone." S_1
"Because the sunlight is sometimes at different intensities during the day." S_{22}
"Because of the intensity of the light, the shadow changes." S_{88}
"The Sun changes intensity during the day." S_{101}
"Because the light must be strong for our shadow to be like us, the less light, the fewer shadows." S_{111}
Category 2 (34/132—26%): the size of the shadow changes because the Sun changes places.
"Because the Sun changes place during the day." S_7
"That if he advances, the shadow will advance, but if he stays, the shadow will remain. If we move forward, the shadow will move but change sides and places." S_{55}
"That it is because the Sun rises and sets. It changes places, and that is why our shadow grows and shrinks." S_{83}
"Because the Sun moves during the day." S_{118}
Category 3 (29/132—22%): the shadow's size changes because the Sun's position changes: depending on the time of day, it is either up or down.
"Because the Sun is higher or lower, depending on the time." S_{22}
"The higher the Sun, the bigger your shadow." S_{37}
"The Sun changes position (e.g., it goes up and down)." S_{87}
"When the Sun is high, the shadow is smaller; when the Sun is low, the shadow gets longer." S_{99}
"Because when the Sun is low, its shadow is bigger, and when it is higher, it is smaller." S_{131}
Category 4 (33/132—25%): the shadow's size changes because the Earth goes around the Sun.
"Because the earth revolves around the Sun, the Sun ends up at different angles during the day." S_{17}
"Because the earth turns and the Sun, first it lights up on another side and then the shadow changes." S_{69}
"The Earth rotates and makes the Sun change places, so the angle of illumination changes." S_{99}
"Because the earth rotates, and when the earth rotates, the Sun changes places." S_{106}
"In the morning, the Sun is far from the earth, but when it is afternoon, the Sun is closer [closer] to the earth, and in the evening, it is the same for the morning." S_{130}

3.6. Objective and Data Analyses: Question #6

When we walk, our shadow makes the same movements as us. Which of the moves is the fastest? This question aims to test students' knowledge of the speed of light propagation and the relationship between light and shadow. Mathematically, body movements occur before 'shadow movements'. As the speed of light propagation is about 300,000 km/s,

perception of the shift, with the naked eye, between the movements of the body and those of the shadow is impossible.

We divide the students' responses into four categories: (1) the body and the shadow movements will be the same; (2) the body and the shadow move at the same speed; (3) the movement of the shadow is faster than that of the body; and (4) the body's movement is faster than the shadow's.

In Table 10, we synthesize the percentage of students in each category and their responses for illustrative purposes.

Table 10. Students' responses to Question #6: categories and their percentages.

Category 1 (30/132—23%): the movements of the body and the shadow will be the same
"Both movements are just as fast because we are doing the same thing." S_1
"The movements will be the same because it is your reflection; it will be the same." S_{30}
"The shadow is like a mirror. She makes the same gestures as us at the same time." S_{80}
"The shadow is as fast as the movement because the light we block forms the shadow of our movement." S_{92}
"At the same time, because the shadow is only a surface with no light." S_{120}
Category 2 (48/132—36%): the body and the shadow move at the same speed.
"Neither, because the shadow is double me and does everything I do at the same speed." S_5
"Both go at the same speed. Of course, the shadow cannot go faster than us because we are in control of our bodies and cannot go faster than the speed of light." S_{22}
"My shadow and I are the same sizes because the shadow goes at the same speed." S_{76}
"It is the same speed." S_{94}
Category 3 (22/132—17%): the movement of the shadow is faster than that of the body.
"My shadow because it is faster than me." S_2
"The one in my shadow. Walking on the street (at night), I often noticed that my shadow led me by a step. I try to catch him, but I cannot." S_{12}
"The shadow, because of the strength of the sun." S_{93}
"The one in the shadows, because it will lengthen us and enlarge our movements." S_{106}
"The movement of the shadow is faster than ours because the light travels faster than us." S_{132}
Category 4 (32/132—24%): The body's movement is faster than the shadow's.
"My movements are faster since the shadow makes the same movements as me, so he must copy me." S_3
"Mine, because I believe that if I put my hand near a wall, the shadow will come after my hand." S_7
"The fastest movements are mine because we can move faster because it is not the shadow that decides our movements, but we are the ones who make the shadow move." S_{43}
"Mine because the shade takes longer." S_{20}
"My movement is faster but so little that you do not notice it because it takes a few moments for the light to come to me." S_{79}

4. Discussion and Conclusions

In the case of Question 1, the objective was not to ask students about plane mirror image formation as analyzed in many studies but to know their ACs about the interaction between the particles composing the mirror (Question 1), the white sheet of paper (Question 2), or the black card (Question 3) and those composing light, as synthesized above.

In the same perspective, Question 4 aimed to know their ACs about the interaction between light and water on the surface and the water inside the glass. The analyses presented above show that most students need help elaborating on absorption and light diffusion. However, in the case of the bent pencil in water, some students referred to the density of water compared to that of air to explain the variation in the speed of light in these two environments. On the other hand, for 18% of the students, the pencil seems bent because of the change of medium (air $\rightarrow$ water).

Regarding question 5, for 23% of preservice teachers, the size of the shadow depends on the light intensity. This false conception has been investigated by many researchers with children 10–12 years old [11]. However, let us note in this regard that for several students when one suspends above an object posed on a table and illuminates it with lights of various intensities at the same distance, the size of the shadow does not vary. It was

established that when we asked them about the same phenomenon but in a more complex case, such as the Earth–Sun system, they explained the variation in the size of the shadow by referring to the intensity of the light. Thus, the misconceptions that students abandon as a result of teaching resurface in the case of more complex situations [34].

Regarding preservice teachers' conceptual difficulties revealed in the present study and those published in international scientific reviews as outlined in the Introduction [16–23], many researchers have used various conceptual change strategies to help students and preservice teachers' ACs to incorporate different light phenomena such as image formation in plane mirrors, the shape of shadows, rectilinear propagation of light, and matter and light color properties [35–47]. They have used different teaching approaches such as hands-on laboratory experiments [45], analogies [46], phenomenological approaches [38,39], historical approaches [41], and other critical didactic strategies.

With regard to the historical approach, researchers Dedes and Ravanis [42] and Djebbar, de Hosson, and Jasmin [43] experimented with pupils from elementary school, using experiments related to the formation of shadows, and the rectilinear propagation of light and vision, placed in their historical context. To do this, among other things, they offered the pupils the opportunity to analyze historical texts that they adapted to their level. Paulo, Bianor, and Isabel [44] (p. 527) highlighted teaching geometrical optics by creating a teaching sequence requiring a dialogical process between preservice students' previous knowledge and the history of geometrical optics development. Such an approach will make it possible to value preservice teachers' misconceptions by studying false theories developed during history by renowned scientists. Bhakthavatsalam [48] (p. 5) highlighted the relevance of false theory in teaching and learning science:

> *"Teaching false theories goes against the general pedagogical and philosophical belief that we must only teach and learn what is true. In general, the goal of pedagogy is taken to be epistemic: to gain knowledge and avoid ignorance. [. . .] There are several good reasons for teaching false theories in school science. These are (a) false theories can bring about genuine (non-factive) understanding of the world; (b) teaching some false theories from the history of science that line up with children's ideas can provide students "intellectual empathy" and also aid in better grasp of concepts; (c) teaching false theories from the history of science can sharpen students' understanding of the nature of science; (d) scientists routinely use false theories and models in their practice and it is good sense for science education to mirror scientific practice; and (e) learning about patently non-scientific and antiscientific ideas will prepare students to face and respond to them."*

Thus, the pupils and the future primary teachers could compare their ideas on the phenomena above with those developed by the Greek, Arab, and European researchers who marked the development of optics.

It is important to note that the classic approach to teaching the reflection and absorption of light does not allow us to understand the interaction between the molecules and electrons that make up matter and the photons when they reach this object. Most textbooks limit themselves to presenting a quantitative analysis of reflection and refraction based on the Snell–Descartes laws.

These researchers affirm that more is needed to construct a teaching strategy that considers students' alternative conceptions, which many teachers are unaware of, for the reasons raised in the theoretical framework presented in the Introduction.

Thus, we must develop situations consider their ACs and the relevant scientific concepts synthesized in Table 11. The activities must be embedded in standard teaching and fit into a theoretical framework. We propose investigating conceptual conflict problems and their practical effectiveness in future studies. It is not enough to suggest an experiment that contradicts the student's conception so that he would abandon it. According to many researchers, these false conceptions persist in teaching. Moreover, we are considering constructing a two-tier diagnostic instrument to detect elementary preservice teachers' ACs in the area of light.

Table 11. Summary of preservice teachers' alternative conceptions and their corresponding scientifically accepted counterparts.

Student's ACs	Scientific Concepts
The glass surface of a mirror reflects light.	The glass surface of a mirror does not reflect light; the layer of metal placed under the glass reflects light. The light rays reflected by the metal layer pass through the glass.
A mirror reflects all the light received.	The metal under the glass absorbs some of the light rays (about 10%) and reflects the rest.
It is reflected when light strikes objects.	When light interacts with an object, the molecules that compose it interact with light waves (or photons). Some of them are reflected according to the properties of the object.
A black object absorbs all the light that reaches it.	A black object reflects little light to the eye. By contrast, an ideal black object absorbs all the visible light it receives.
A black body stores the light it receives, so we do not wear black T-shirts during the summer.	During the summer, we do not wear black T-shirts because black absorbs most of the light that hits it; it converts that energy to heat energy.
When the Sun is at its most vigorous, the person looking at the water will be blinded, and the opposite is true if the Sun is at its lowest intensity.	The greater the angle of incidence (i.e., the angle between the incident light ray and the perpendicular to the surface), the more intense the light reflected on the water.
If one places a long, narrow object in a clear glass filled with water so that one half is underwater and the other half protrudes from the glass, the straight object appears tilted due to the water.	The pencil appears to bend, but this is only an illusion created by the wave nature of light, not water. When the medium in which the light propagates (e.g., air or water) changes direction, the brain interprets this speed change as the object's tilt in the water. It is an optical illusion.
The size of our shadow changes during the day as the Sun moves.	The size of our shadow varies during the day depending on the Sun's height.
The size of our shadow changes during the day as the Sun moves during the day.	The motion of the Sun is the apparent illusory position of the Sun, which is responsible for changing the magnitude of the shadow.
The position of the Sun defines the size of the shadow.	The Sun's apparent position at different times of the day explains the change in the size of the shadow.
The size of the shadow during the day varies due to the rotation of the Sun around the Earth.	The rotation of the Earth on its axis makes us believe that it is the Sun that revolves around it. Thus, the shadow size varies during the day because the Earth turned around its axis and not because the Sun turned around the Earth.
The size of a shadow is related to the sunlight intensity; a more vigorous intensity corresponds to a giant shadow.	The size of the shadow is related to the position of the light source relative to the position of the object casting the shadow, not the intensity. The object blocks "more or less" light when changing this position. During a day, the Earth rotates on its axis, causing the relative angle between a person and the Earth to change and, therefore, the length of their shadow.
The body moves faster than the shadow since it is the body that controls the shadow.	The shadow is unlike a "material" that moves under the body's order (e.g., the body's shadow at rest changes if the position of the light source changes without any intervention from the body.
Shadow formation and that of an image with a mirror are similar. So, the body moves at the same speed as its shadow.	The principle of shadow formation is not like that of an image on a mirror because image formation, contrary to the shadow, does not depend on the position of the source.
A shadow is an area with no light intensity, so it does not reflect any light to the eye.	A shadow is an area of less light intensity, reflecting little light to the eye.

A brief review of the literature on students' and preservice teachers' ACs of light phenomena presented in the Introduction shows their inconsistency with the scientific notions. It has been established using à paper-and-pencil questionnaire that student teachers in Québec experience considerable difficulties in explaining the interaction between light and matter, as summarized in Table 11. The data analyses revealed accurate knowledge and erroneous reasoning in the student teachers' explanations.

The poor performance of the preservice teachers in the test is not surprising since the conceptual understanding of the nature of the light aroused intense quarrels among renowned scientists such as Newton and Huygens [49–51]. The epistemological rupture between everyday and scientific language also explains the students' conceptual difficulties [52].

Concerning the study's limitations, the paper-and-pencil questionnaire represents a shortcoming. On the one hand, the preservice teachers' answers required more information that could be collected using semi-structured interviews. In addition, the questions formulated do not refer to the phenomenon of the interaction between light and matter in fields of knowledge such as biology, chemistry, and the environmental sciences and are limited to the area of physics. Another limitation relates to categorizing the answers given by all participants for each question. Thus, it would have been relevant to categorize each student's answers with each question to obtain his epistemological profile, as the French philosopher Bachelard recounted in his book *The Philosophy of No* [53]. Such an analysis consists of carrying out an interpretation for each subject and for all the questionnaire questions, which makes it possible to bring to light the variability of representations of the same subject.

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Appendix A

Table A1. Paper-and-Pencil Questionnaire.

Question #1
One illuminates a mirror with a flashlight. Which of the two following affirmations best represents the trajectory followed by Light? ❒ Light emitted by the flashlight surrenders on the mirror and stops there. ❒ Light emitted by the flashlight surrenders on the mirror and is sent back by the mirror elsewhere in the piece. Explain as best you can your choice of the answer:
Question #2
A white sheet of paper deposing on a table, and one illuminates it with a flashlight. Which of the following affirmations best represents the journey followed by light? ❒ Light is emitted by the bulbs' pocket-size lamp, surrenders on the paper, and stops there. ❒ Light emitted by the bulbs' pocket-size lamp surrenders on the paper and is sent back elsewhere by the paper in the piece. Explain as best you can your choice of the answer:
Question #3
Consider a black cardboard on a table, and one illuminates it with a flashlight. Which of the following statements best represents the interaction between light emitted by the flashlight and the surface of the black cardboard? ❒ Black cardboard will absorb all visible light it receives. ❒ Black cardboard will absorb almost all the visible light it receives and diffuse the rest. Explain as best you can your choice of the answer:
Question #4
If one places a long, narrow object like a pencil in a transparent glass filled with water so that one half is under the water and the other protrudes out of the glass, it appears to bend as soon as it enters the water. How do you explain this phenomenon?
Question #5
The size of our shadow changes during the day. How to explain this phenomenon?
Question #6
When we walk, our shadow makes the same movements as us. Which of the moves is the fastest: ❒ That of our body ❒ That of our shadow ❒ None Explain answer choice:

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