

# Misconceptions about optics: an effect of misleading explanations?

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## ABSTRACT

During our activities of physics dissemination with High School students especially concerning optics, we are used to distribute a questionnaire about colors and image formation by mirrors and lenses. The answers to some questions clearly show misconceptions and naïve ideas about colors, ray tracing, image formation in reflection and refraction. These misconceptions are widespread and do not depend on the gender, the level, and the age of the students: they seem to depend on some wrong ideas and explanatory models that are not changed by the curricular studies at school. In fact, the same errors are present in groups of students before and after taking optics courses at High School. On the other hand we have also found some misleading explanations of the phenomena both in textbooks and websites. Most of the time, errors occur in the explanatory drawings accompanying the text, which are based on some hybrid description of the optical processes: sometimes the description of the path of the ray light is confused with the image reconstruction by the lenses. We think that to partially avoid some errors it is important to use a teaching path centered on the actual path of the rays and not on what eyes see (the vision). Here we present the results of data collected from more than 200 students and some considerations about figures and explanations found in textbooks.

**Keywords:** optics education, misconceptions, teaching and learning

## 1. INTRODUCTION

During the last years the researchers of the Department of Science and High Technology of the University of Insubria in Como have activated many science dissemination activities. Among these, the most challenging are those that directly reach students during their morning lessons within curricular courses at school and those performed during extra-curricular courses in the afternoon at university. Because of the short time at their disposal, researchers involved in the didactic activity mostly use frontal lessons supported by hand-on demonstrations realized with materials provided by the researchers themselves. As a part of the researchers involved in these initiatives are active in the field of nonlinear optics and quantum imaging, the subjects offered to students mainly concern optics and in particular geometrical optics and physical optics. At the beginning of the program a questionnaire is usually submitted to the students. The questionnaire is not part of a systematic investigation of High School students' understanding of physical optics but it was born with the following two purposes. First of all we note that students have their own opinions and intuitions about physical phenomena derived from prior learning, either from classroom lessons or from their interaction with the physical and social world.<sup>1</sup> Furthermore, these beliefs or opinions are sometimes different from the scientifically accepted ideas presented in the classroom. So it is important to assess how much the students know and what kind of knowledge they have about optics. Second, is to raise the interest of the students. In fact, before lessons, students have the possibility to explore some topics and to guess the right answers by using their own knowledge or to realize they are not able to answer. This might create more interest and activate the attention to catch up the correct answers from the researchers.

In the past three years the test was proposed to 300 students, some of which had already studied geometrical

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optics. The questionnaire employed a mix of open-end and multiple choice questions. The questions were formulated to see how the students are able to apply their knowledge to simple physical situations they may encounter in reality and that can be observed in the life daily. We employed some questions which were used in previous studies of light preconception (where their validity and effectiveness was proved)<sup>2,3</sup>. Our questionnaire was composed by 18 items. The results of the questionnaire are interesting and show misconceptions and naïve ideas about colors, ray tracing, image formation in reflection and refraction.

## 2. IMAGE FORMATION

We proposed some questions about image formation by mirror and lenses. We assumed that students had no deep knowledge in ray tracing. In the multi-choice question 5 we asked to predict how the image of a candle changes by covering half of the lens that performs the image.

Only 17% of students gave the correct answer, that is the entire image can be still seen, and the 16% of students

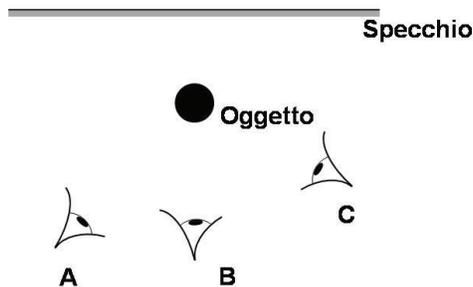


Figure 1. Image in questions 2: we ask the students to sign the position of the image of an object

thought that the image was out of focus (not bright). The interesting result is that almost half of the students (40%) believe half image would disappear. The results “not answer” (13%) and “I have no opinion” (13%) can be added together. This is a quite large percentage of “no answer” that, together with the wrong answers, show wide difficulties in understanding both lens working principle and light propagation.

In questions 2 we ask students to mark the position of the image of an object (Fig. 1) seen by three different observers in a plane mirror.

In this case the correct answer was chosen by 13% of students, but most of them did not deduce the position of the image from ray tracing. Some typical answers are sketched in the Fig. 2. In both cases the image is located right on the surface of the mirror.

In sketch “A” the image is located in the line of sight, in contrast with direct experience. In sketch “B” the image is located right ahead the observer without respecting the simple law of reflection.

In question 13 a pencil and a plane mirror are placed on a table. An observer is looking into the mirror to observe the image of the pencil Fig. 3. The lamp is the only light source in the room and the experiment is performed in a darkened room. We asked the students what will happen to the position of the image of the pencil seen by the observer when the lamp is raised a little higher. This question has three possible answers. Less than 60% (58,5%) have the right idea that the image will stay in the same place whereas the 30% think that it moves down and the 7,4% it moves up. The remaining answers are “not answered”. There is a bit difference in the percentage of correct answers if we consider only the part of students that have taken some optics course. In this case the percentage of correct answer rises to 70%. But we think it is still low considering that all of us are used to see our own images and objects’ images into a mirror under different illuminations. Following Pompea<sup>4</sup> we think that there can be many origins of such a misconception. First of all, students do not think at light as something that travels but rather only as its source (the Sun, a light bulb, etc.)<sup>4</sup> Second, students, like many other people, do not realize that their eyes receive light when they are looking at an object. The notion that

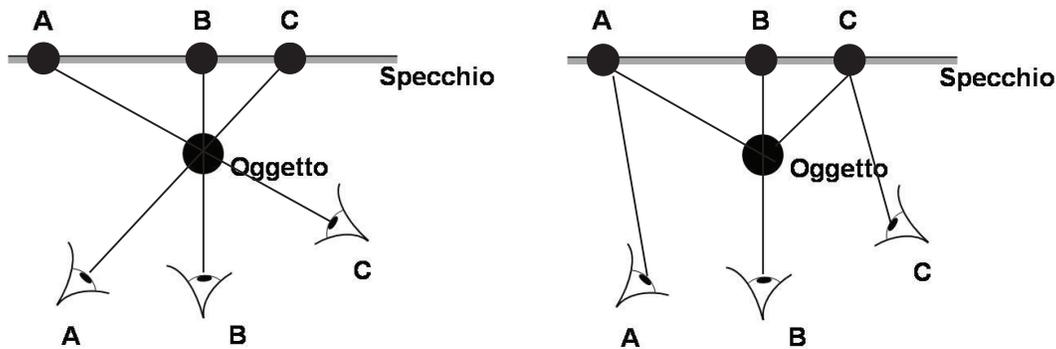


Figure 2. Two typical answers of the students in question 2.

the eyes generate light that radiates outwards is a common one.<sup>4</sup> Although they probably know the concepts of virtual and real images formed by a mirror and are but also able to calculate their position with respect to the mirror, these skills do not correspond to a real awareness in ray tracing and to an actual comprehension of the physics of image formation.

### 3. LIGHT PROPAGATION

In the questionnaire we included three questions on different aspects of light propagation: question 8 asks if light speed can change or not, question 9 asks if light always takes the shortest path and question 14 asks what happens to an image if we eliminate the air inside of a camera obscura.<sup>3</sup>

Questions 8 and 9 required a true/false answer and more than 60% of students selected the wrong one. Question 14 was a multiple choice question: 46.8% of answers are correct (nothing will change), 20.4% of students think the image will disappear and 13.9% of them believe that the image will turn into a luminous point spot. The results as a whole show that it is not clear to students to what extent light propagation can be affected by the medium in which light travels.

Some answers are actually in contradiction to each other: on the one hand, light speed is expected to be the same regardless the medium in which it travels while, on the other hand, the absence of light is expected to prevent image formation (that is the arrival of light on the screen). Once again, the main origin of these errors is that students do not think at light as something that actually propagates through space but only as light sources or images on a screen.

Moreover, students seem unable to use their direct experience to support the answers: for instance, correctly answering to question 14 would be easy by remembering that we can actually observe stars through empty space.

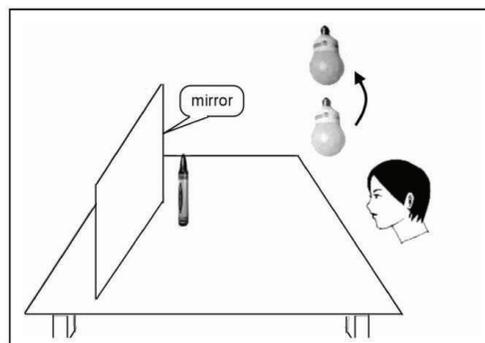


Figure 3. Where is the position of the image of the pencil when the lamp is raised?

## 4. COLORS

The problem of the nature of colors is complex as it involves very many aspects of light-matter interaction. In the questionnaire we included three questions on colors: question 1 asks if color is an intrinsic property of objects, question 18 asks what is the color of shadows and question 11 asks why the eye pupil is black. Students' answers to these questions are partially wrong. We summarize the results in Table 1. The three questions address

Table 1. Questions and answers dealing with colors.

Question	answer 1	answer 2	answer 3
1. Color is an intrinsic property of objects	True 23.8 %	False 71.8 %	
11. Why is eye pupil black ?	it's colored black 21.7 %	it's a hole 60.7 %	other 11.8 %
18. The color of shadows of an object...	depends on the light 7.1 %	depends on the diffused light 20.1 %	is always black 70.6%

different aspect of colors: color as the result of light subtraction by absorption, color as due to illumination with colored light and the meaning of appearing "black" colored. The results show a lot of confusion about the subject. In our experience we found that even after a detailed explanation of the different aspects of the phenomenon, students still fail in identify the color of an object when it is illuminated by monochromatic light.

## 5. DISCUSSION

Some consideration follows from the previous simple analysis. The first thing we have to realize that it is impossible we do not have naïve ideas ever since we were young kids<sup>5</sup> and that students do not come to instruction as blank slates.<sup>6</sup> For this reason we think that it is important to elicit by every possible means classroom discussion before introducing a new topic during lectures, so as to make some student's naïve ideas more evident to students themselves. In fact, it has been recommended that before the beginning of the instruction, students' misconceptions are discussed to build with students their awareness respect the topics they are going to learn. Moreover, teachers should take into account the existence of misconceptions during their explanations .<sup>6</sup> This preliminary analysis of students thoughts could seem a waste of time but it is actually very important to make students and teachers more aware of their own misconceptions. A second remark arises from the question about the origin and growth of students' misconceptions. This is very deep and knotty question in the teaching-learning process research. Far away to give any exhaustive answer, we suggest that it is decisive to give lectures by proposing examples as less trivial as possible. Physical reality is complex, not necessarily complicated. Many textbooks refer to situations and exercises dealing with straightforward daily life experience, with the risk of being limited to very few experiences and observations. For example, many textbooks for Primary and Secondary Schools state that light propagates in a straight line and is not able to overcome obstacles. The statement itself is not incorrect, but it only refers to one of the possible behaviors of light during its propagation (think for instance about mirage where light propagation does not occur in a straight line). As a second example, when textbooks introduce colors they always refer almost exclusively to situations in which the objects are illuminated by white light. In fact most of the events of our lives occur under white light illumination. Nevertheless, trying to make examples dealing with a monochromatic source may prove extremely useful for a better understanding of the phenomena of color, even starting from the early years of instruction.

Finally, also the monitoring exercises should show situations other than those dealt with during explanations so as not to accustom students to a mere repetition or reproduction of the lesson but to train them to a real reworking of the concepts to grasp the physical principles that underlie the phenomena.

## 6. CONCLUSION

An important outcome of studying physics should be an ability to relate general physical principles to everyday experience. Many researches showed that also older students keep misconceptions and naïve ideas still after their instruction path. We have found these during our physics dissemination activities concerning optics with High School students thanks a questionnaire we use to rise the discussion. The questionnaire has been useful to increase our awareness of students believes about optics. We guess that the origin of such misconceptions should be searched in a misleading or too simplified instruction in the Primary School and in the first level of Secondary School. The way in which optics and other topics of physics are taught often fails to bring about a functional understanding. Furthermore textbooks often use examples from everyday life, but these are too simple to allow students to get an idea of the complexity of the reality. We think there is the need for a systematic work to assess both textbooks' content and teacher knowledge from this point of view.

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