THE IDEAS OF 3rd YEAR STUDENTS OF TECHNICAL SCHOOLS IN CYPRUS ABOUT LIGHT AND ITS PROPERTIES

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ABSTRACT
This paper aims to report and investigate the ideas of 18 year-old (3rd year) students of Vocational Education in Technical Schools in Cyprus, about light and its properties. In Technical High School Education physics is a compulsory subject for all 3 years of studies for 2, 45´, periods per week. Among the wide range of topics related to the physics of light in the 3rd year curriculum, this paper focuses on reporting the student's ideas about various basic aspects of light, such as propagation, colour, the use of rays, and the mechanism of vision. The data were derived from the pupils' diagrammatic and written responses to a questionnaire. The questionnaire included actual or modified questions selected from the literature or questions especially designed to meet the needs of this paper. The participants include students of different specializations: designers, mechanics, electricians, plumbers. Common to all students in the vocational sector is the focus of their education on applications and practice. The findings are compared to other research results from the existing literature to find any similarities and, most importantly, to see whether or not there are differences that may be contributed to the different, less theoretical education provided by Technical Schools. Also the implications of the findings for the development of a curriculum in Optics for the Vocational Education in Technical Schools are being discussed.

KEYWORDS
Light, light ray, colour, propagation of light, emission of light, misconceptions.

INTRODUCTION

A great deal of information has been accumulated in how students learn science and most researches converge on the following three theses about this process: (1) science learning is difficult since even after many years of science instruction students still find it difficult to understand many scientific concepts, (2) science learning is characterized by misconceptions and (3) science learning is inert in the sense that students learn to solve science problems at school but fail to apply this knowledge to explain physical phenomena outside school (Vosniadou, 1995).

Some 15 years of research at the University of Massachusetts have shown that first year physics students come quite well trained to give the "right" answers to standard questions. However, when asked to solve a simple problem that is in some way different from the familiar ones in the textbooks, they show that they have very limited or no understanding of the conceptual relationships indicated by the symbols in the formulas they have learned by heart (Glasersfelt, 1995). Therefore, few researchers nowadays would disagree that traditional instruction, in the form of "training", is not effective. If physics instruction is to be effective, it should encourage the kind of learning that leads to conceptual understanding. Such learning occurs when knowledge is constructed by the individual (Dykstra, Boyle, and Monarch, 1992). But instructors, in their attempt to get students to construct new knowledge, are faced with some deeply entrenched beliefs about the natural world that students either have been constructing over many years of experiencing the everyday world and interacting with it, or have formed during instruction as a result of assimilation of scientific ideas into their intuitive frameworks.

This system of conceptions (*misconceptions*, *alternative conceptions*, *alternative frameworks*) differs in deeply systematic ways from those of the physicist and presents a significant obstacle to learning physics. The differences might be about the nature of scientific entities (e.g. the nature of light), or about the ontological status of scientific concepts (e.g. the ray concept), or about processes which sometimes, in student's conceptual frameworks, seem unproblematic (e.g. vision). Therefore, learning in physics requires a change of students' (mis)conceptions into the scientific ones. The process and the resulting change are both described by the term conceptual change (Chi, Slotta, de Leeuw, 1994).

Constructivism elaborates conceptual change as a strong and continuous interaction between the prior knowledge of a learner and the formal knowledge provided by the teacher (von Glasersfelt 1989; Dykstra, 1992). With conceptual change at the centre of the instructional process in physics, teachers should focus on student's beliefs about the world in two ways. The first is to identify the alternative conceptions and to address specific contents of this intuitive knowledge. The second is to include student activities that would challenge these contents, cause dissatisfaction with prior knowledge and stimulate the transformation into the new knowledge suggested by the teacher. The learner should find the new conceptions more plausible, intelligible and fruitful (Posner et al, 1982).

LITERATURE REVIEW

The ideas about light and vision that students acquire from their daily experiences and carry in the classroom have been the focus of a great part of educational research in the last few decades. In this context, numerous research programs have been carried out among pupils of all grades, among students at university level, and even candidate teachers, in order to record such ideas. All these studies have pinpointed a variety of conceptions that are not compatible with scientifically accepted ideas. The scope of the present study is to discuss the findings that concern the transmission of light, the use and interpretation of the ray model, the emission of light, and the mechanism of vision.

There seem to be two prevalent views among pupils regarding the transmission of light: First, in younger ages, the "static model" Galili (1996), namely the view that light does not travel at all, i.e., it is an entity fixed in space (Driver, Guesne & Tiberghien, 1995, p. 18, Fetherstonhaugh, Happs, & Treagust, 1987), and, second, that light travels various small distances (Andersson & Kärrqvist, 1983). These distances are believed to be greater during the night rather than during daytime (Fetherstonhaugh, Happs, & Treagust, 1987, Fetherstonhaugh, & Happs, 1988, Fetherstonhaugh & Treagust, 1992). The distance light travels appears to depend on the intensity of the light (Fetherstonhaugh, Happs & Treagust, 1987). Similar views have been expressed by candidate teachers of primary schools (Bendal, Goldberg and Galili, 1993). The use of words such "goes" or "comes" does not seem to involve the parameter of time.

The use of a line in the diagrammatic representations of light appears early on (Osborne & Black, 1993) but without any direction and may represent the "static" model of light from the sources, the distance that light can travel or the line of vision (Bendal, Goldberg and Galili, 1993). This line, perhaps through teaching, becomes a ray of light and acquires directionality.

Many researchers have recorded children's ideas about the mechanism of vision (Andersson & Kärrqvist, 1983; Bendal, Goldberg and Galili 1993; Driver, Guesne & Tiberghien, 1984; Galili, & Lavrik, 1998; Osborne & Black, 1993; Selley, 1996). These ideas can be classified into four major categories (Dedes, 2005). In the first category, which includes mostly children of younger age, there does not appear to be any systematic relationship between light, object and eye. Either vision is simply an ability that the eye possesses, or the presence of light is required to make objects visible but in a very vague fashion. In the second category, it is thought that light passes from the source to the object but the role the light plays in the process of vision is not taken into account. In the third category, lines connecting the source, the eye and the object are considered, but they lack directionality. Finally, in the fourth category, the lines mentioned in the previous group acquire direction and can be divided into six subcategories depending on the role of the eye in vision: the eye as the singular active agent for vision, the eye and external light as necessary contributors, the external light that stimulates the eye so that it "sees" by producing a secondary emission, the external light being reflected on the object and bouncing towards the eye where it produces again a secondary emission, and finally, the source illuminating the eye and the viewed object, without any connection between the object and the eye.

The idea that the eye is an active agent in the process of vision in students' models has been recently recorded by de Hosson and Kaminski (2007). In their research with 12 and 13 year olds 86% of the students explained vision with the help of an eye-object component. Diagrammatically this idea is depicted by an eye-object arrow and in written explanations is hidden in the use of the words "sight", "look", and "vision".

This first subcategory is related to two other elements that are identified in the relevant studies namely, the belief that people and animals can see in the dark, and the belief that a "look" can be perceived by the object under observation (Fetherstonhaugh, Happs, & Treagust, 1987; Fetherstonhaugh & Treagust, 1992). Such beliefs reinforce the model of "active" vision. The characteristic in all these models is that visual perception is a holistic process, i.e. the image of the object is perceived by the observer as a whole and not point by point.

This brings us to the basic characteristic of the ray model of the emission of radiation from objects, to wit, the view that radiation is emitted from every point of the self-luminous or illuminated object in all directions. Many studies show that the source or the illuminated object is regarded as a whole entity. The object radiates towards all directions but each of its points emits towards only one direction (Bendal, Goldberg and Galili, 1993). Rays also seem to have a favoured direction in relation to the observer or the illuminated body (Rice & Feher, 1987, 1988; Galili & Lavrik, 1998). Indeed in some cases it seems that the rays "prefer" a downwards path because they "fall", that is, they acquire the properties of a material body (Galili & Lavrik, 1998). In the case of images and shadows, the holistic model prevails. In the case of an extended, cross-shaped source that shines through a small aperture the prevalent model among children for image formation involves light that carries information about the source and travels as one whole entity in a preferential direction towards the object that modifies and/or transmits this information to the screen (Rice and Feher, 1987). When the aperture is replaced by a small opaque body the same holistic concept is present in all predictions of shadow shapes that blend a cross and a circle (Feher and Rice, 1988). The notion that each point of the source emits light in all directions is conspicuously absent.

As far as colour is concerned, pupils seem to be confused among the two dominant conceptual frameworks, that of the Natural Sciences and that of the Visual Arts. In the physics model, colour is the way different light frequencies are perceived in the visual process. Mixing light is called "additive" colour mixing. Additive colour mixing gives more illumination and results to a third, brighter, colour. In the case of objects, colour is not an intrinsic property of the object but the result of the selective re-emission of frequencies that are not absorbed by the illuminated object. The Visual Arts Model about colour is about mixing coloured substances. When we mix paint the newly formed colours are caused by subtracting out colours from the reflected light. That is why it is called "subtractive" colour mixing. Both models include a set of three primary but different in each set, colours which when mixed give rise to a third colour. A study carried out with students from the Fine Arts School, the department of Physics and the department of Pre-School Education Teachers, suggests that the students from all three departments have limited understanding of the concept of colour, owing either to ignorance or to the non-differentiated use of the conceptual frameworks of the Visual Arts and the Natural Sciences (Marinopoulou, 2007).

AIM OF THE STUDY

The aim of the present study is to record the ideas about light and its properties of Third year pupils of Vocational Education in Technical Schools in Cyprus. The research was carried out in a Technical School because Geometrical Optics is included in the 3rd year curriculum, so students have the opportunity to improve or reconstruct whatever knowledge or understanding they acquired about Optics in gymnasium (K8) at a more mature age. This is not the case with students in General Education, as Geometrical Optics is not included in the Physics' curriculum. Interest in this field arose due to the lack of relevant studies targeting Technical Education (but also for General Education) in Cyprus and also due to the fact that Vocational Technical Education and its curriculum in virtue of its nature presents particularities (e.g. the focus on practical skills than on abstract and theoretical knowledge or the diversity of specialties). The results will be qualitatively compared with relevant results of research in the current literature. Another aim is to highlight the ideas of pupils so that these can be taken into consideration in the development of a curriculum for Optics at Technical Schools, which will meet the needs but also the weaknesses of pupils in the Vocational Sector of Technical Education.

METHODOLOGY

The collection of data was carried out using a questionnaire containing twelve (12) questions that related to the transmission of light, the mechanism of vision and the role of light in it, colour, the use of the ray model and the model of emission of radiation. From these questions only five (5) were multiple choice type. The remaining seven (7) required diagrammatic and/or written explanation. Most questions included in the questionnaire were actual questions from the relevant literature. Other questions have been suitably modified to meet the needs of this research. Two were designed for this research and were principally aimed at the use of the ray model. The sources of the questions appear in Table 1. The questionnaire was handed out to a total of forty-nine (49) pupils in five (5) departments, of different speciality. Two of these were being taught by the researcher (Christiana Andreou) and the other three by a colleague. The questionnaires were filled during Physics class hours in the presence of the researcher and the teacher. Pupils were asked to write freely what they thought the correct answer was, and clarifications were given only with regard to the content of the question. The answers to these questions were coded according to their common characteristics so that it would be possible to divide them into groups. The number of the groups of answers to each question varied from three (3) to seven (7), depending on the demands and the complexity of the question but also on the variety of the repeated answers given by the pupils.

Table 1.Questions and source of original item

Question	Literature Source
1, 2	Andersson, B. and Karrqvist C., (1983). How Swedish pupils, aged 12-15 years, understand light and its properties.
3, 4, 5	Fetherstonhaugh A. and Treagust F. D. (1992). Student's understanding of light and its properties: Teaching to engender conceptual change
6, 7	Marinopoulou, F. (2007). Study of the conceptions of prospective teachers of the concept of "colour" within the framework of an inter-scientific approach to teaching of Visual Arts and Natural Sciences.
8, 9	---------------
10	Bendall, S. and Goldberg, F. (1993). Prospective elementary teachers' prior knowledge about light.
11	Rice, K. and Feher, E. (1987). Pinholes and images: Children's conceptions about light and vision I.
12	Rice, K. and Feher, E. (1988). Shadows and anti-images: Children's conceptions about light and vision II.

The research focuses on the qualitative analysis of the results. The choice was made for two reasons. First, the aim of the research (at this stage) is just to report the student's ideas and not the evaluation of a teaching strategy. The point we want to make here is that even after instruction (traditional in this case, although supported with a lot of experimental activities) student's conceptions remain unaffected. Second, we believe that all students' answers are equally important because the variety of ideas is indicative of the number of ways a situation can be explained by students.

QUESTIONS

The curriculum for physics in compulsory education includes the teaching of optics in the Second class of Gymnasium (14 year old students). The content focuses primarily on geometrical optics (rectilinear propagation, reflection, refraction, total internal reflection) but also on properties such as the colour of bodies. In the Third class of Technical Education the curriculum returns to the subjects of geometrical optics but also examines the nature of light, i.e. it refers to the wave description of light and its wave properties in the way these are revealed mainly through the phenomena of refraction and dispersion. The contemporary model of particle physics is examined using Bohr's model of the hydrogen atom and the emission of radiation from it. From among the wide range of subject matters in the 3rd year curriculum, the present study aims to examine the ideas that pupils hold, first, about the fundamental questions on light (its nature and its properties in the formal scientific theory, the nature of the ray concept, the way light is described to interact with objects) and, second, about the model used in physics to describe the behaviour of light, that is, the model of the ray of light. This choice was made for two reasons. The first is that teaching of optics in gymnasium comes at the end of the annual curriculum and, thus, in some schools it does not take place at all, and, in other schools, it is not covered sufficiently so as to form a solid springboard for further learning. The second, and most important, reason is that it is important for the pupils of Vocational Technical Education to ground firmly the central concepts that are necessary for interpreting optical phenomena in everyday life. Through this grounding pupils can familiarised themselves with the methods of experimental research, with diagrammatic representation and abstraction, and with the use of models that systematically describe of a group of phenomena.

The questions we attempt to answer in this paper are:

1. To what extent do pupils understand light as an entity that propagates in space?
2. How do they construe the mechanism of vision?
3. What is the role of external light in the mechanism of vision and especially in perceiving the objects of everyday life?
4. How do they apply the ray model and the model of secondary emission of light from luminous and non-luminous bodies respectively?
5. How do they use the model of the ray in describing the behaviour of light?
6. What are their ideas about the colour of bodies?

With these questions we are only searching for indications of pupils' ideas. A more thorough research could perhaps demand personal interviews, in addition to completing the questionnaire. Despite the fact that in many questions pupils were asked to give some written explanation for their answers, most of them limited themselves to the completion of the diagrams. But where explanations were given, these were telling and should be further researched.

RESULTS

Grouping of questions

The results are presented separately for each group of questions. The questions were grouped as follows:
Group A: Transmission of light. Questions 1 and 2.
Group B: Mechanism of vision. Questions 3, 4, 5, 8(B), 10.
Group C: The colour of bodies. Questions 6 and 7.
Group D: Emission and transmission of radiation, the physics model. Questions 8(A), 9, 10, 11.

Answers

Group A:
For both questions figure 1 was handed out and students were asked to describe and explain to WHICH of the areas does the light from the car's headlights reach at night (for Question 1) and during the day (for Question 2). Characteristic responses from students are seen below in italics.

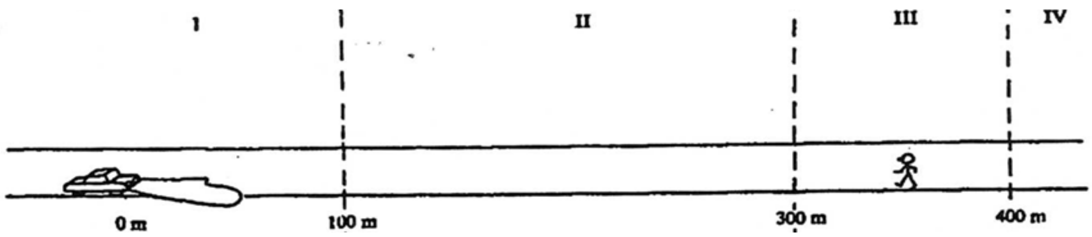


Figure 1: Questions 1 and 2

Question 1: The pupils who chose the areas I and II (47%) are either those who considered only the car, *because the headlights are dipped, the car is there, the lights reach up to here,* or those who believe that light is transmitted in short distances, *light does not reach further than 100m*. The pupils who chose area III (approximately 32%) had as main criterion the observer, *because the pedestrian is there and can see the light*. But in other instances they misinterpreted the data; *the driver had the high lights on*. Finally, some thought that the determining point was that it was night time; *at night it is easier to see the light*. Some of the pupils who chose the area IV (about 21%) also used the pedestrian as a criterion, *since the pedestrian can see it* (*light*). The absence of a *barrier* or *resistance* was another sited reason. A fair number thought it important that *it is night*, but without giving any further explanations. It is interesting to note that even those who chose the correct answer were not able to give proper explanation for it.

Question 2: A smaller dispersion appears for the second question. The great majority of pupils (75%) chose area I, but the criteria for their choice are much more different. Sometimes they refer simply to the area in which the light can be seen: you cannot see where the light reaches because it is daytime. But some are more precise: *the light from the sun will not allow the light to get through, the light from the sun masks the headlights, during the day light is not so strong, they are not so strong as to penetrate the sun, because there is light everywhere, during the day light cannot spread, it is a sunlit day and so rays of light stop*.

From among the pupils who chose area IV (answer D) only three talked about light that reaches there, whilst only two had chosen the same area in Question 1. The rest refer to daylight: *because it is a sunlit day, there is no need for lights, there is light from the sun*.

Group B:
For questions 3 and 4 the following description is given: a child and a cat are in a totally dark room (figure 2).

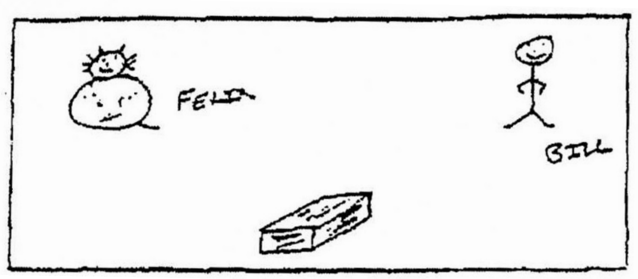


Figure 2: Questions 3 and 4

Question 3: Can the child see the box in the dark? 69,4% of the pupils replied no. *He will not see it because there is no light, because it is totally dark*. But a considerable 30% believes that he could see it. The explanations of these replies suggest that there is a widespread belief that eyes *get used to the dark after some time*. These replies reflect experiences in dark places and not in total darkness. This shows that some pupils possibly do not understand the concept of total darkness, and that they cannot think about hypothetical situations. Their thinking is totally dependent on their experiences.

Question 4: As far as the ability of a cat to see in absolute darkness is concerned, nearly 80% of the sample seems to believe that it can. *Cats can see in the dark, animals can see in the dark, a cat can see at night without light, cats can see better at night*. Only 8 pupils were consistent in their thinking and chose the negative answer, giving the correct interpretation to both cases. It appears that the folk belief that animals and especially cats can see in the dark is dominant among pupils. This might be the result of a misinterpretation of a scientifically documented view about the greater sensitivity of animal eyes to light, or due to the eerie but well known "cats eye" reflection seen in animals in the dark. Implicit in this idea is also the fact that pupils do not take light as the key component in the mechanism of vision, as can be clearly seen in the following question.

Question 5: Here, we directly examine pupils' understanding of the role of light in vision in a simple case of visual perception of an object. Pupils were asked to sketch how an observer sees a tree in the presence of the sun, which provides ample light. They are expected to diagrammatically identify the tripartite sun-tree-chid. Only 8,5% (4 students) correctly drew the arrows. All but three of the remaining answers fall into three groups, according to which part of the tripartite they believe has an active role in vision. In the first group (64% of all answers) the observer is the only active part of the process. In these answers arrows are only drawn from the child to the tree. These arrows may represent some sort of action from the eye, implying a mechanism of "active" vision, the observer's intention or in this fashion the students were simply trying depict the action of "seeing". The use of an arrow to depict vision may be result of the assimilation of the ray concept in the diagrammatic representation of the act of "seeing". The latter case may indicate that for the students the process of vision seems to be unproblematic, as they do not identify any necessary preconditions. In the second group, the sun and therefore light, have a role in vision as the tree and/or the child have to be illuminated for vision to be accomplished. A 17% of the students drew arrows from the sun to the tree and from the eye to the tree, again implying an active observer and a 4% show both the tree and the child been illuminated where again there is no mechanism of vision. What is missing from all the answers is any kind of interaction of the ambient light with the observed object. Sample responses are shown in figure 3. The variety of depictions is an indication that the pupils did not follow some systematic and consistent way in their diagrammatic representations. The sketch in the rectangle is the answer of a pupil from the specialty of Draughtsmen (his questionnaire is number 33) who, using basic knowledge of optics but also drawing from his own skills and techniques, replied correctly to all questions, including questions 11 and 12 that were the most difficult, despite the fact that he is not a pupil of high academic achievements.

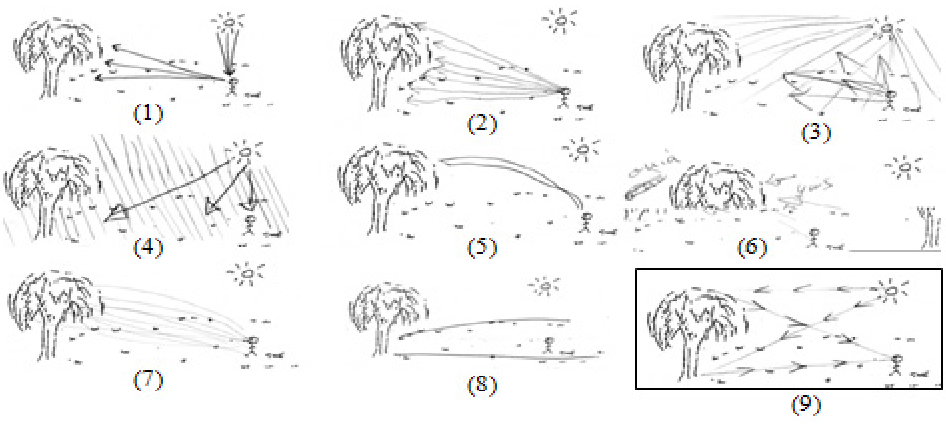


Figure 3: Indicative answers to question 5

Question 8(B): In the questionnaire pupils were given the following sketch and they were asked to draw how the light from the lamp helps the person read. The question examines the role light sources other than the sun play in vision. In this case too, about half of the pupils either drew arrows from the eye to the book only, or drew them in combination with arrows from the lamp. Only five pupils drew the correct sequence lamp-ceiling-book-eye (figure 4). Light from the lamp seems to present fewer difficulties for the pupils than the dispersed light from the sun. (The sketch in the rectangle is the reply from questionnaire 33).

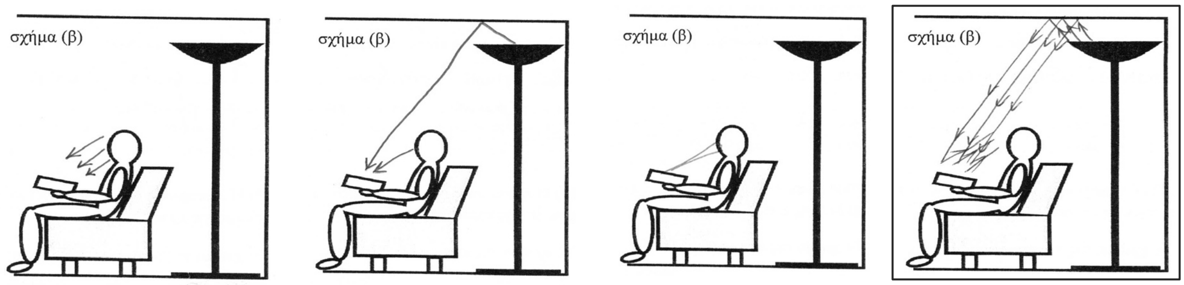


Figure 4: Indicative answers to question 8(B)

Question 10: In this question pupils were given the following situation. A pupil in the laboratory is observing a light bulb. They were asked to sketch and explain what takes place between the bulb and the eyes of the pupil when the bulb is on and when the bulb is turned off.

In the first case, Question 10(A), it is obvious for the majority of pupils that something enters the eye from the lamp, and 11 pupils drew arrows from and to the eye of the pupil. In many instances, pupils refer specifically to the light that enters into the eye from the lamp, but in their sketches have only or/and arrows from the eye. Some of them report or draw something like collision, either in the eye, *while our eye sees the lamp it can collide with a ray of light, the light hits the eye and it sees*, or in the space between the eye and the lamp. The description of the reception of the ray as a collision seems to reflect expressions in everyday speech like “the light hits my eyes”. Some of the comments in the cases of double arrows are indicative of the role played by the lines that start from the eye, as was described in question 5. In three particular cases, the arrow from the eye appears to depict schematically the verb “*to see*”, an element that also appears in question 10(B) (figure 5).

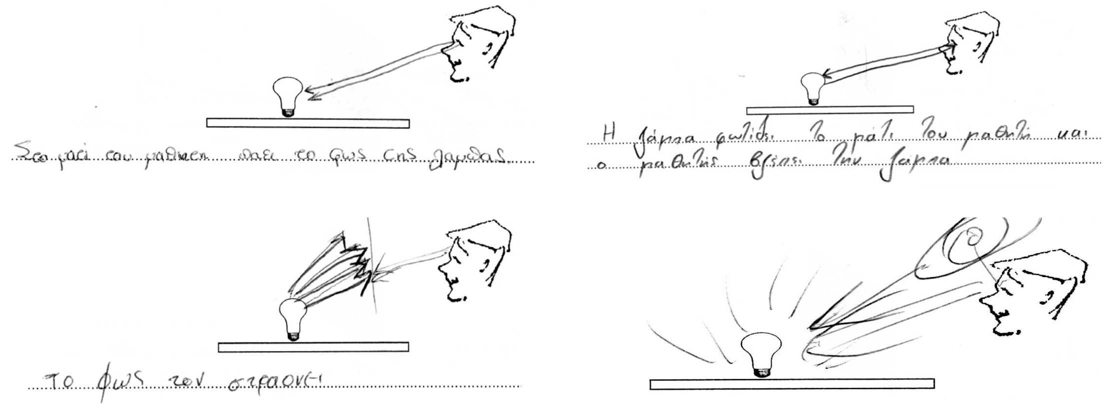


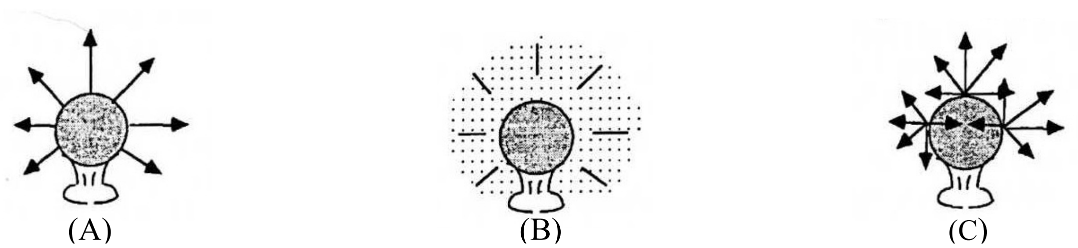
Figure 5: Indicative answers to question 10(A)

In the second situation, question 10 (B), where the lamp is turned off, 26 pupils say that nothing happens, even though some of them drew arrows from the eye to the lamp whilst in the verbal description there occurs the verb “to see”. Some make qualitative comments about the effect on the eye, *nothing will happen to the pupil’s eye, the lamp is switched off and does not cause damage to him*. The idea that the reception of light is analogous to some form of “injury” or pain appears historically in optical theories like that of Ptolemy or that of Alhazen. Only 3 pupils answered correctly. Two of these had drawn rays from the lamp to the eye without any further explanations, whilst only one said that *he sees it from the light of the sun*, without a sketch or any other additional explanation. The emphasis in the answers was in that the pupil “sees” the bulb without finding it necessary to explain how this takes place.

Group C:
Students were asked the following question about colours: there is a poppy in a completely dark room. What is the colour of the poppy? (Question 6) and what would be the colour of the poppy if it was lit with blue light? (Question 7). Students were expected to know that colour is not a property of the object but is the result of the selective reflection of frequencies that are not absorbed by the object. In this explanatory framework the poppy, when illuminated with blue light, appears to be black. 60% of the pupils stated that the colour would be black without providing any further explanation. Most likely the answers are phenomenological, i.e., the pupils do not answer the question of WHAT is the colour of the poppy but respond to what it would seem to be. Some of the written answers are as follows: *because it is dark, there is nothing indicating the colour to us, in the dark he sees everything black, at night you can’t distinguish any colour, everything looks black*. Only three refer to the absence of external light, which is responsible for the colour. From all those who replied red, some explained that the colour does not change; simply it cannot be seen in the dark. Nine pupils answer red in both questions, which is consistent with the belief that colour is an attribute of bodies. This conviction also underlies the answers of the 18 pupils who held that when the poppy is lit with blue light the visual result will be a third colour. This is what happens in combining lights of different colours or in mixing coloured substances. As students believe that colour is an intrinsic property of the poppy, probably they give their answers having the latter case in mind, i.e. by applying the Visual Arts Model. This indicates the belief that light is coloured itself and its colour is mixed with the colour of the poppy. Although the resulting colour proposed by some students is not darker, as it would be in case of mixing substances, the idea of a third colour is an implementation of the Visual Arts Model. The resulting colour, according to the most frequent answer is purple, but also the colours dark red, yellow, white, brown, pink and orange appeared as the product of the combination as well. Eight believed that the poppy acquires the colour of the light with which it is illuminated. Only one pupil gave the correct answer, i.e. black in both questions, providing the correct explanations.

Group D:
In question 8(A) we examined the use of the ray model in the transmission of light from a source through reflection. The question relates to the diagrammatic or verbal description of the transmission of light from the lamp in Image 4 to the surrounding space. More than 40% of pupils do not make use of the reflection of light from the ceiling; where as 10% drew curved lines in order to show the change in the direction of the light over the opaque surface. This shows that half of the pupils do not use correctly (or they don’t use at all) the ray model or its properties, in the description of the propagation of light. The rest of the pupils make verbal or diagrammatic use of the ray, but almost all answers are at a lower level than expected.

In Questions 9, 11 and 12 we examined the understanding and use of the model of emission of radiation from every point on the surface of a body in all directions. In Question 9, pupils were given figure 6 and were asked to choose the one that correctly represents this model.



(A) (B) (C)

Figure 6: Question 9.

There was a large dispersion of answers because a lot of students chose more than one representations. More than half of the pupils chose diagram B, which we regard as corresponding to a "static" model of light. Only five (5) chose the correct answer. Many pupils chose combinations. Ten chose various combinations and two chose the answers A and C, a finding that suggests that the two diagrams are construed by pupils as depicting the same situation.

Questions 11 and 12: In these questions, pupils are required to apply the model of the emission of radiation from every point in all directions in order to find out what appears on the screen behind a small opening or small obstacle, when this is lit from an extensive light source (figure 7).

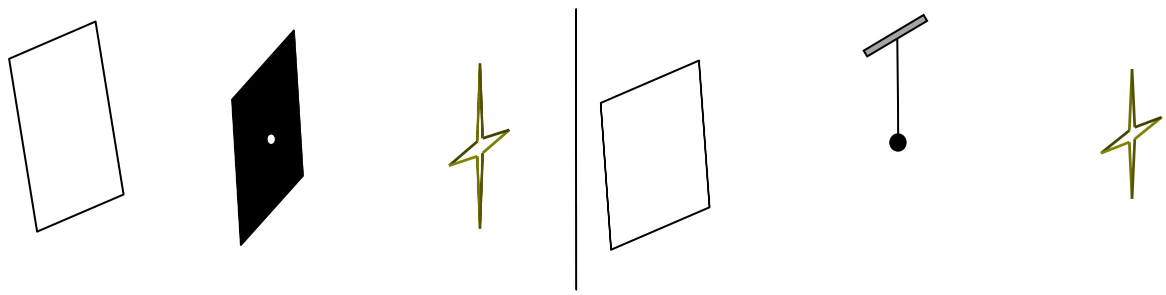


Figure 7: Questions 11 and 12

Ten and three pupils respectively gave verbally the correct answer to questions 11 and 12 without drawing any rays. In Question 11, most of the other pupils drew rays only from the centre of the cross, ignoring the fact that the source of the light was extensive. In question 12, a fair number held that the result would be a combination of the two shapes, that of the source and that of the obstacle or the opening, with the light source creating a lit image of itself and the obstacle casting its shadow in this image. Only the pupil who completed questionnaire 33 gave the correct answer to both of these questions, drawing rays from all four ends of the lit cross. Another pupil drew a cross on the screen in both cases but he drew no rays and provided any explanations. From the answers to these questions, it seems obvious that pupils do not know how to handle an extensive source of light and, of course, how to utilise the model for the emission of radiation from every point, the content of which, as has been shown in the discussion of the answers to Question 9, they do not understand.

DISCUSSION OF THE RESULTS

By coding the results, we can reach some conclusions about the ideas of pupils in Technical Education in the subject matters covered by the questions in the administered tests. In particular:

1. Most pupils seem to believe that light is transmitted to short distances in space, which become smaller during the day, since the light of the sun obstructs the transmission of light from other sources.
2. The sketches concerning the mechanism of vision suggest that the observer and not light is the dominant factor in vision. Directional lines starting from the eye of the observer appear in almost all of the questions. But we surmise that these do not reveal the belief on the part of the pupils that something is coming out of the eye of the observer, a "visual ray", as this appeared in the early optical theories of Greek antiquity up to Alhazen in the 11th century A.D. Instead, it is a way of diagrammatically sketching the act of "seeing" the object or the observer's intention. This point could only be clarified through personal interviews, and it would be good to keep this in mind in further research.
3. It appears to be easier for pupils to draw and systemise the emission of light from bright sources other than the sun. The diffused daylight, the "sea of light", appears to confuse pupils and they ignore it, perhaps because they cannot locate the sun as the source of this light, as, for example, they are able to do with a lamp. The use of a ray only emanating from the eye towards the viewed object is more common in the case of the presence of the sun.

4. Pupils are aware of the fact that self-luminous bodies emit light. However, in the case of non-luminous bodies, even when pupils verbally mention their being lit from a different source, they never draw rays leaving the object. That is, they don't seem to understand the "secondary" emission of light from such objects.
5. In sketching the emission of radiation from bodies, pupils rarely use the model of the emission of radiation from every point of the surface of the object and along every straight that can be drawn from that point. It appears that the model itself, even if it has been taught, is not well entrenched in their knowledge so that it can be useful in problem solving.
6. With regard to the colour of objects, there seem to be two misconceptions that reinforce each other. One is that colour is an intrinsic property of objects that persists in space and time. The other is the construal of the properties of colours according to the Fine Arts model, in which mixing of substances with different colours gives as a result a new colour. Accordingly, pupils hold that light is coloured itself and its colour can be mixed with that of other substances, according to the Visual Arts model.

   Children have experiences with colour at a very early age. Furthermore, very early they start using coloured pencils to draw simple drawings. The intuitive beliefs children develop as a result of their experiences are reinforced by instruction in the lesson of Art, even from Elementary Education. These beliefs are further strengthened by instruction in the Secondary Education where the colour model of the Visual Arts is at this stage taught in a more coherent and systematic way. Unlike the colour model in the Visual Arts, the scientific model of colours is expected to be taught only in K8 (to 14 year old students) but this is not always the case. It is known that optics in the Gymnasium is taught towards the end of the school year under relative time pressure and in some cases not all topics in the curriculum are covered. Therefore, it is not surprising that students are so confident about their ideas about colour and its properties.

GENERAL DISCUSSION: COMPARISON WITH OTHER RESEARCH AND IMPLICATIONS FOR TEACHING AND CURRICULUM FORMATION

Most of the findings arising from this research are similar to those documented in the relevant literature and mentioned in the review above. This indicates that students across different countries with different school systems carry the same intuitive beliefs and these beliefs are so strong that they do not change with traditional instruction. It seems that new scientific concepts, as the light ray, are being assimilated to already existing intuitive models.

Some of the students' ideas about vision, such as those related to the "visual ray", demand further research because the conclusions we were led to in this paper with respect to pupils' notion about the ray of light are different from some conclusions on the same issue in the literature. In other studies, the drawing of an arrow from the eye towards the object has been interpreted as indicating the belief that there is a ray emitted from the eye of the observer, making vision possible; a visual ray similar to that mentioned in the early theories of vision. In the present study, we assume that this arrow is a diagrammatic representation of the action of the observer, the "seeing" the object. A possible explanation of this difference is to be found in the age of the pupils. In time and with further teaching, the ray that is drawn from the eye, may have acquired a different content so that it represents the "process" of visual perception. As de Hosson and Kaminski (2007) suggest, the eye-object arrow indicates an entity of a more psychological nature than physical. If the process of vision is to be described as taking place in two spaces, the first in front of eye, which they call physical and the second from the retina to the cortex, which they call psycho-physiological (this idea is proposed as a potentially good didactic approach) then children's explanations most probably refer to the second space, and especially to the psychological part of the process of vision.

The similarity in the diagrams in the diagrammatic representations is also especially interesting. Many of the drawings of the pupils are, in some cases, nearly identical to those drawn by pupils of younger ages. This may indicate not only that teaching did not introduce any further knowledge of optics and did not result in conceptual change, but that it did not even improve the pupils' abilities in diagrammatic depiction. That is, students did not achieve through teaching the required degree of abstract thinking so that they would sketch only those elements that are necessary to answer a specific question or to solve a specific problem, ability required not only in optics but in all topics in physics.

As this research shows, it would be useful to redraw the curriculum in optics, as is taught in the Vocational Sector in Technical Schools. It is known that optics in Gymnasium is taught at the end of school year, sometimes under time pressure, and in some cases not all subject matters in the curriculum are taught. Therefore it would be more useful for pupils of the Vocational Sector if more time was allocated to teaching the basic concepts of optics, like the role of the model of the ray and the mechanism of vision, so that pupils can explain and describe, verbally and diagrammatically, in a systematic and coherent way basic phenomena of everyday life pertaining to light. This could be achieved with activities like those referred to in questions 6, 7, 11 and 12 that seem to interest pupils and which, at the same time, can aid them overcome the simplistic or alternative ideas that pupils have formed trying to make sense of their experiences. These activities aim to conceptual change.

These, and other activities, are more effective for pupils of Technical Schools, who use to base their thinking more on experience than on abstract reasoning. This information has to be passed onto instructors and one way to achieve this is to develop instructional material that includes such activities. The material can help instructors in two ways. The first to inform them, especially the novices, about student's ideas and the second, is to facilitate their work by providing ideas for activities that challenge the student's intuitive beliefs. In parallel, emphasis must be placed on the acquirement of skills for abstract diagrammatic representation. These skills are useful in whatever field a pupil might chose to follow.

Instruction of Optics occupies more than half of the curriculum in the 3rd year Physics in Vocational Technical Education. The curriculum includes all three models of light behaviour, the ray, the wave and the particle model. The ray model can be a springboard for a better understanding not only of the theories of light but also of the scientific process itself. If the ray of light, for example, is perceived as a physically existing entity that accounts for the nature of light and not as a mathematical tool, then it is impossible for them to comprehend the role of the two other models and they will end up in confusion about light and light phenomena.

Finally, with regard to colours, the model of colours in the Visual Arts should be briefly (at least) presented to pupils and discussed in class, if not taught along with that of Physics, so that pupils clearly understand that they are two different models, as regards both to content and the aim they serve. In some specialties in Technical Schools, like that of Artistic Studies, pupils are taught the theory of colours of Visual Arts and they apply it "unedited" or in combination with the theory of colour of Physics, in problems of the Natural Sciences, without differentiating between them. If instruction about colour is to become more effective, both theories must be mentioned in both topics, Art and Science early on, so that the one does not conflict with the other. Teaching must be adapted in such a way so as to reveal to pupils the different meanings that colour has in the two different conceptual frameworks This, of course, requires that teachers of both specialties should be properly informed about both theories in order to be able to carry out effectively the task of such interdisciplinary teaching.

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