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DESIGN AND DEVELOPMENT OF CONSTRUCTIVIST EDUCATIONAL SOFTWARE TO DEAL WITH STUDENTS' EMPIRICAL IDEAS ABOUT OPTICS

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ABSTRACT

The paper introduces the design and development of quality interactive multimedia educational software based on students' empirical ideas and conceptual difficulties, identified in Greek students 7–12 years old. The software promotes interdisciplinary study of geometrical optics concepts. We present a survey, which investigated 40 students' initial ideas about light phenomena using personal interviews. Then we describe the design of the educational software "Light-Life", which was designed based on constructivist views of learning and students' initial ideas about optics phenomena, such as linear propagation of light, shadows formation, light reflection, diffusion and refraction, synthesis of colour light beams, and vision. Appropriate printed worksheets were also developed for the students. The proposed approach intends to improve the quality of educational approach and tools to better respond to students' needs of learning with understanding and help them reformulate their empirical ideas to better explain everyday life situations related to basic optics phenomena.

KEYWORDS

Multimedia educational software, constructivist interdisciplinary teaching, conceptual change, primary school students, optics phenomena

1. INTRODUCTION

Science education research has revealed that the majority of students enter school with pre-instructional knowledge or beliefs about natural phenomena and concepts based on their everyday experience. Their personal views about science phenomena integrate into students' cognitive structures and contradict science concepts universally accepted by the scientific community. They develop only a limited understanding of science concepts following instruction (Driver and Oldham, 1986; Driver et al., 2000). Furthermore, it is possible that students may apply scientific ideas in solving traditional text-book problems in science in school examinations, but not in explaining natural phenomena in everyday life (Driver 1989; Driver et al., 2000). So, it is essential for teachers to become aware of their students' conceptions and misunderstandings in order to organize their teaching more effectively.

The emergence of constructivism as a learning theory promises to improve teaching and learning in school. Constructivism is viewed as a theoretical perspective about knowledge construction, which may be useful to the design of constructivist learning environments (Jonassen, 1999).

Educational software has great potential as a cognitive tool (Jonassen, 1993). Although, this offers a powerful environment for manipulating the formal representations, its actual contribution depends on how effectively each task is designed in order to enhance student achievement (Bransford et al., 2000; Tekos and Solomonidou, 2009). Conceptual difficulties are a prerequisite for designing and developing effective instructional approaches utilizing the potential of the information and communication technology (ICT) tools. It is necessary to investigate and take into account students' empirical ideas before designing educational activities and the ICT tools to be used in them (Solomon, 1994; Osborne, 1996; Jonassen, 1999).

This study is based on the D.E.S.T.E. model (Solomonidou, 2006), which describes the steps that should be followed to create, implement and evaluate constructivist learning environments with the use of ICT tools. The name comes from the initials of the Greek words for Investigation, Conception, Design, Development, and Implementation. To elaborate on this, the words are understood in the following ways:

1. Investigation of students' initial empirical conceptions.
2. Conception of the teaching and learning content based on both the scientific knowledge and the students' initial conceptions and conceptual needs.
3. Design of constructivist learning environments which are student-centred, collaborative, problem solving and authentic task-based, and supported by teacher scaffolding.
4. Development and formative evaluation of the educational environment.
5. Implementation of the digital environment in the classroom and final evaluation of it based, among other things, on students' final conceptions and learning outcomes.

2. INVESTIGATION OF STUDENTS' IDEAS

2.1 Previous Studies

For almost four decades there has been intensive research directed to students' alternative conceptions regarding light phenomena across all ages (Andersson and Karrqvist, 1983; Guesne, 1985; Galili and Hazan, 2000; Osborne et al., 1993; Selley, 1996; Watts, 1985).

Concerning the nature of light, students do not conceive light as a distinct entity; they equate light with its source and others with its effect and therefore have difficulty in interpreting a range of light-related phenomena (Guesne, 1985). For seeing in the darkness, students do not recognize the necessity of light and think that it is possible to see things even if it is dark. They do not consider the presence of light as the essential factor in order for them to see things even faintly, expressing that eyes can get used to seeing in total darkness (Fetherstonhaugh and Treagust, 1992). They claim we can see things just 'because our eyes have the ability to see' or 'because objects are bright' (Tiberghien et al., 1980; Andersson and Karrqvist, 1983; Osborne et al., 1993; Ravanis et al., 2002).

Concerning light propagation students think that the distance travelled by light varied from a few millimetres to an infinite distance. Most children decided that the distance travelled by light depended upon whether it was day or night (Fetherstonhaugh and Treagust, 1992), and only one direction from each source, like flash light beams (Bendall et al., 1993).

Moreover, the majority of 10 - 12 year old students think that shadow belongs only to the nonluminous object and it always looks like the object (Feher and Rice, 1988). Students tend to believe that shadow is the presence of something tangible to which they give material characteristics, rather than absence of the light (Bendall et al., 1993). According to Galili and Hazan (2000) children perceive shadows in much the same way as optical images. Shadows can be manipulated in the same way as independent objects.

Most of the students think that in the region of geometrical overlap there would be either lightness (full illumination) or darkness (shadow). They do not consider semi darkness. Also, many children aged 11-12 believe that light stays inside a mirror or on a piece of paper when it falls on it (Guesne, 1985).

Regarding vision primary students do not believe that their eyes receive light when they look at an object. A great number of students, generally younger ones, attribute no relationship between object, light and eye (Osborne et al., 1993; Ravanis, 1999), in spite of the well known fact that we can see objects because of the presence of ambient light. Other students think that we can see due to a 'light bath' that fills space and they draw simple connecting lines without showing direction between the vertexes of the classical triangle: source-object-eye (Hosson and Kaminski, 2002). Some believe that we can see an object because the observer directs sight lines toward the object, with light possibly emitted from the eyes (Langley et al., 1997; Tekos et al., 2008). Moreover, a difference between seeing luminous and non luminous objects has been indicated (Guesne, 1985). Students might adopt an 'active role' of the eye emitting light and receiving light in the case of luminous objects. Regarding colour, the majority of children think it is a property of objects, e.g. a book is red because has the ability to be red and has no relation to light (Fetherstonhaugh et al., 1987).

In this paper we describe the step-by-step design and development process of the educational software "Light-Life". The design was based on students' (aged 8–12 years) alternative conceptions identified by previous research. The aim of the software is to remedy students' alternative ideas and misconceptions about Optic's concepts and phenomena, and to provide educators with a proper educational tool for effective teaching.

2.2 Our Study

During the year 2008–2009 we conducted the initial research with 40 Greek primary school students aged 7–12 years aiming at (a) investigating their initial ideas about light propagation, shadows formation, light reflection, diffusion and refraction, synthesis of colour light beams, and vision and (b) informing the design and development of appropriate educational software and other digital material, to promote a better conceptual grasp of the subject.

First, an open-ended questionnaire, with free response, was administered to 140 primary school students (6-12 years old) in order to identify students' misconceptions, which could serve as guide for interviews. After studying the first findings we developed four semi-structured interview protocols, each one for 2nd, 4th, 5th and 6th grade students based on the misconceptions found in the initial search and we conducted individual interviews with 40 students (ten of each grade). The analysis of the students' answers allowed us to identify the following fundamental alternative conceptions, some of which were revealed in previous studies (Andersson and Karrqvist, 1983; Osborne et al., 1993; Ravanis et al., 2002):

1st category: A great number of students, generally from 2nd grade, think that light equals both to its source and effect, and that light is not conceived as a spatial entity propagating through space.

2nd category: Students, even in 6th grade, think that light reflection and light diffusion are phenomena, which happen independently of the kind of the surface light falls on. They do not know about the trajectory of a light beam falling on a smooth surface such as a plane mirror. Moreover, a number of students pointed out that the light beam returns to the light source independently of the angle of incidence, and others stated that light stays on a plane surface. Light diffusion does not happen in the atmosphere and they give special attributes to light rays, such as their inability to travel in space. Students also think that earth daylight is due to the existence of the sea, ozone, etc., and not to light scattering on particles, dust, etc.

3rd category: Primary students, up to 4th grade, conceive shadows in the same way as independent objects. Light was associated with shadow formation, mainly in the sense that a light source was mentioned verbally. Also, regarding the size of a shadow, they associate it with the brightness of the light source: the brighter the light source is, the bigger the shadow is formed. Moreover, when students of the same age were asked to draw an object's shadow with the light falling on it slantwise, many of them did not put in the same line source, object and shadow.

4th category: Students in 6th grade attribute the denaturation of the objects' shape (e.g. when a pencil is half sunk in water) to the shape of the object or they give material characteristics to objects, rather than different speed of light propagation into different material. Other students used refraction to mean reflection.

5th category: Regarding vision, the 'emission model' (the eye emits rays) is the dominating model among 4th and 5th grade students explaining how we can see non-luminous objects. Moreover, there seems to be no awareness of the directionality of light in sight processes in younger students, who were not representing light at all but rather illustrating the geometrical connection between the viewed object and the eye.

In order to cope with these students' learning difficulties we developed the software 'Light-Life' on the basis of this research outcomes. The software comprises visualisations, simulations, and learning activities having an interdisciplinary character. As a matter of fact, Optics is essentially an interdisciplinary subject. Physics, biology, physiology, chemistry and psychology are all needed for comprehensive discussions of optical phenomena (Feynman et al., 1964; Ronchi, 1970; Gregory, 1979). Moreover, *'Optics instruction using only physics is limited and cannot confront spontaneous knowledge about light. Such instruction cannot explain those natural phenomena which intrigue the novice learner'* (Galili and Hazan, 2000, pp. 60). The instruction used in this study utilized a scaffolding process to guide the learner from what is presently known to what is to be known. Therefore, the student engages in cognitive processes, appropriate for the learner's zone of proximal development (Vygotsky, 1978).

2.3 The Digital Learning Material Used

We have designed and developed interactive multimedia educational software entitled 'Light-Life', using Microsoft Visual Basic 6 as an authoring tool and also Macromedia Authorware, CorelDraw, Adobe Photoshop, and Windows Movie Maker. The students become involved in a technologically rich multimedia learning environment posing educational tasks and providing help and feedback while they undertake a variety of investigations. They come across concepts such as sound, energy, heat and related concepts such as space, time and change. In the activities there is also an attempt to see light in other frameworks such as those of biology, medicine, linguistics, history, ethnography and art. At the same time, students are encouraged to work together on a range of problems concerning light.

'Light-Life' is multimedia software in the sense that it presents the user with various combinations of texts, static and moving pictures, sound, video, simulations, applets, etc. The way that the learning experience unfolds depends on the choices made by the users as they navigate their way through the multimedia environment. The structure of that environment is in some parts linear and in others tree-like. Along the linear sections the user progresses along a predetermined series of stages (from A to B to C, etc.). In the sections with a tree-like structure the user has access to related sections to find the information he or she seeks. There is a main menu with seven sections, each of which takes the user to an initial page providing access to many other pages by clicking hyperlinks, the choice of which depends on the interests of the user. More particularly, "Light-Life" consists of 95 shot screens aiming to help students construct knowledge according to the scientific accepted one, through various experiments in this thematic field.

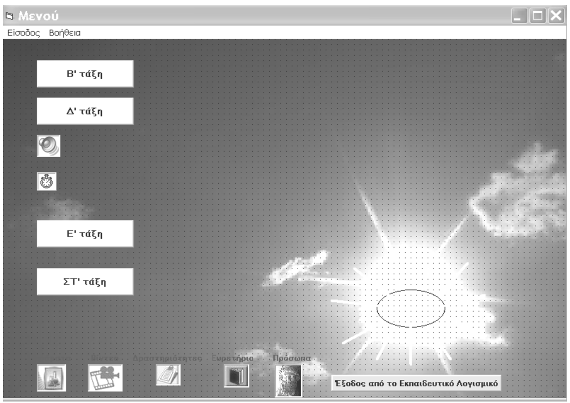


Figure 1. First screen shot of the educational software 'Light-Life'

The software has a uniform design throughout the forms with simple and convenient navigation panels providing an easy manipulation of it. Specific questions are posed to students, having the following order: a) Eliciting their own interpretations or hypotheses about the phenomena they observe, b) use of metaphors relating to common everyday situations in order for students to construct a suitable analogy c) engaging in activities to confirm or not their initial hypothesis and d) extract deductions about the phenomena. The software provides immediate feedback to confront students' alternative ideas and help them redefine their hypotheses about the phenomena under study. Moreover, it is accompanied with supplementary 'instructional' type activities ('drill and practice'). Useful tool tips pop up which help students to choose the right answer. When the student chooses a wrong answer a warning appears, pointing out that she/he has not taken into account something that had already been elaborated in a previous section.

Regarding the software's structure, in the first screen shot students can choose their level and whether to go directly to one of five different sections: experiments, video, glossary and important people-scientists (Figure 1). The four levels correspond to four different school grades. The material presented to the user draws on the following academic disciplines of Physics, Biology, Astronomy, Technology, Art, Medicine and Literature.

2.4 Specific Features of the Software Items

The software 'Light-Life' aims to cope with students' alternative conceptions, found in the previous research, and grouped in five categories by using a series of features which are the following (for each category of students' alternative conceptions):

First category: Equating light with its source and effects was identified as the most prevalent students' initial idea among 7-8 years old students. This property of light is taken for granted in Greek school textbooks and yet is a prerequisite for understanding light in a more advanced level (Watts, 1985), as students do not distinguish between light as a physical entity and light as a sense perception stimulus. The software 'Light-Life' includes the following features to cope with these students' difficulties: A real life video about a ball bouncing on a plane surface and animations with tennis balls bouncing on a table used to help students construct a suitable analogy with light reflection. Students are asked to predict the 'correct' reflected course and then to confirm their prediction by activating the animation or the video (Figure 2).

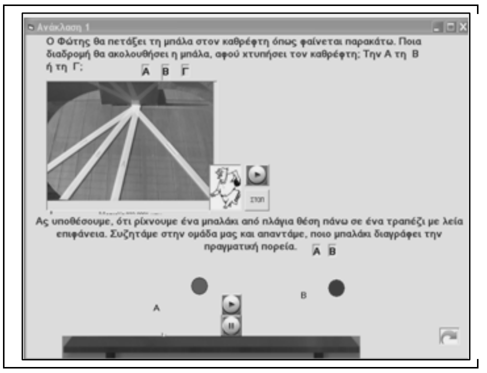
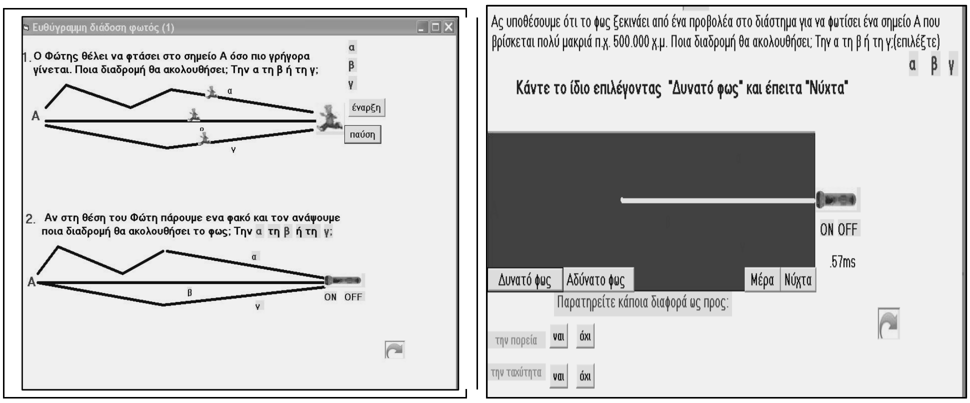


Figure 2. "Light-Life": real life video and animations of a ball bouncing on a plane surface

Gradually, a torch substitutes the child who throws the ball and a light beam substitutes the ball. Also, a number of drag-and-drop activities refer to various sources (sound, heat, energy or light sources) aiming to help students understand that a radio speaker differs from the sound it emits, an electric burner differs from heat, and light differs from a torch or the sun or any other light source.

Moreover, in another screen shot about the study of linear propagation of light the student is asked to choose the shortest route a child must take to reach his/her destination, i.e. a straight line. Then the child is replaced by a torch and a light beam falls on the spot that was previously the child's destination. They can also choose day or night, faint or strong light and compare the distance light covers and speed in the different conditions. Thus students confront their previous ideas about speed light depending either on daylight or the intensity of light (Figure 3, 4).



Figures 3, 4. 'Light-Life': linear propagation of light

Second category: The initial students' answers showed that they do not distinguish between the kinds of surface on which they can observe light reflection and diffusion phenomena (i.e. plane mirror, cloth, shiny marble, ground, dust, etc.). Also they do not know about the trajectory of a light beam falling on a smooth surface such as a plane mirror. Moreover, a number of students pointed out that the light beam returns to the light source independently of the angle of incidence, and other ones stated that light stays on a plane surface. A number of activities with 'Light-Life' may engage students to observe the phenomena of light reflection and diffusion on different kinds of surface. In this form students are asked to put a diamond in the right place where the light beam can meet it, and then to compare the angle of incidence with the angle of reflection (Figure 5). The amount of light and the way it reflects on an object largely depends upon the smoothness or texture of its surface.

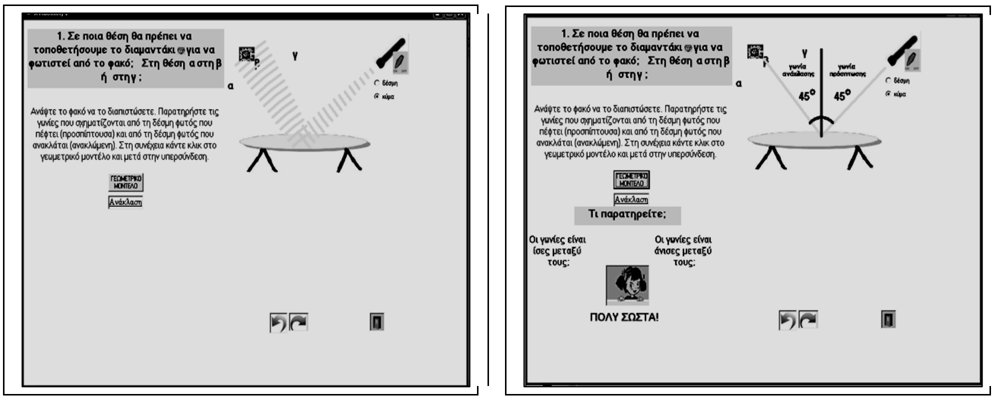


Figure 5. 'Light-Life': the path of a light beam interacting with an object is demonstrated by turning on the light source simulating the relevant phenomenon considering the angle of incidence

When the surface imperfections are smaller light reflects according to the Law of Reflection. Also, students can activate the applet http://micro.magnet.fsu.edu/primer/java/reflection/specular/index.html, which initializes with a beam of white light being reflected by a plane or a rough surface demonstrating diffuse reflection. They can use slider bars to adjust the texture of the surface appearing in the window between a range of 0 (smooth) and 100 percent (maximum roughness).

Third category: In order to cope with students' misunderstandings about shadows the software 'Light-Life' includes the following features: For the 2nd grade there are the following sub-sections.

Sun and night and day alteration: Students go on a virtual journey into space to a point from which they can observe the earth in relation to the sun. They are asked to make hypotheses about why they see the earth half in darkness and half in light. They can also change the position of the earth in relation to the sun to observe the change in brightness of an area of the earth.

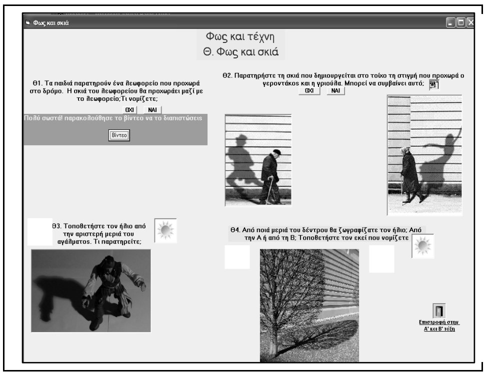


Figure 6. Activities aiming to identify the objects that correspond to their shadows

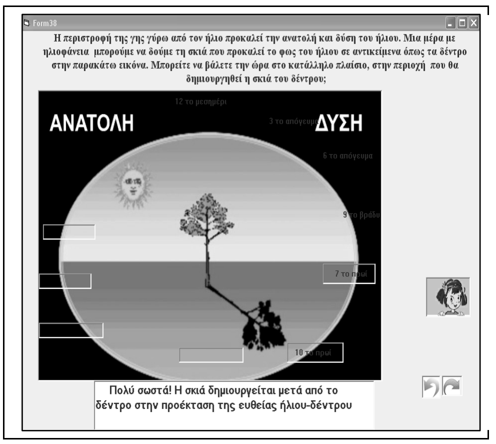


Figure 7. Giving the right orientation of the object's shadow

Light and art: This subsection includes shadow-creating games and other activities aiming to identify the objects that correspond to a series of shadows (Figure 6). It also aims to provide the correct orientation of the object's shadow in relation to both the object and the light source (Figure 7).

For the 4th grade, students can carry out some virtual experiments on the orientation of shadows. The students are asked to predict where the shadow of an object will be formed, in one case with one light source and in another with two light sources (Figure 8). They can then test their predictions by switching on the virtual light sources, overturning any misconceptions they may previously have had. The initial investigations showed that students assumed that the size of a shadow would be relative to the brightness of the light source.

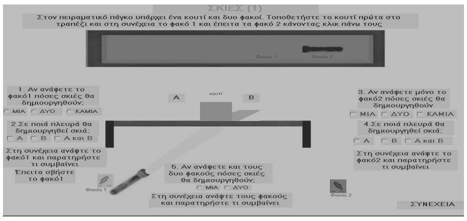


Figure 8. Virtual experiments looking at the orientation of shadows

The next screen shot allows students to test this hypothetical model ('run my-model', see Raghavan and Glaser, 1995), encouraging them to question their primitive ideas and help them adopt the scientific model. They can also activate an applet changing the distance of a light source from an object to investigate the way this changes the size of the shadow (Figure 9).

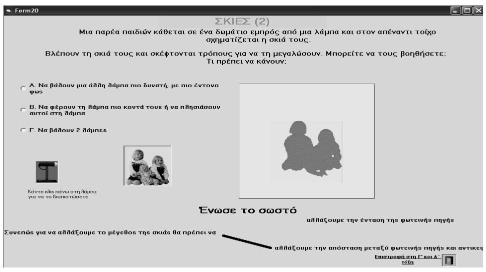


Figure 9. Activating the applet testing the size of the shadow

<u>Fourth category</u>: Our initial research indicated that the majority of the 5th and 6th grade students believed that refraction was due to some property of objects themselves. When asked about the change in the appearance of a pencil when it is partly submerged in a glass of water, they attributed this to the shape of the pencil itself. 'Light-Life' includes the following features to help students confront and re-evaluate these initial conceptions. In the first instance students can formulate their own interpretation for the phenomenon of refraction as they can observe the change in the appearance of a pencil submerged in a glass of water. After that, they are engaged in a virtual experiment in which they fill a tank with water and see how the route taken by the light ray is changed as it comes in the water (Figure 10).

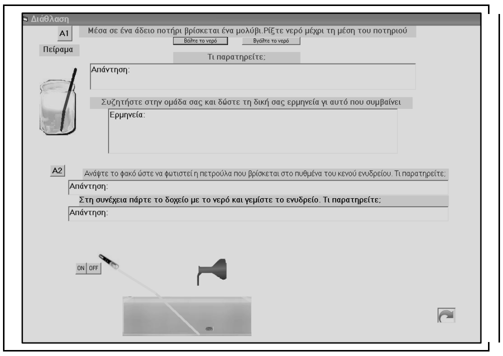


Figure 10. Observing the phenomenon of refraction

After formulating their own hypothesis, the students can activate the scene to compare the time taken for the lifeguard to follow the two possible routes. They are also able to see an applet on the internet (http://micro.magnet.fsu.edu/primer/java/particleorwave/refraction/index.html) where they can observe how the course of a light ray alters as it passes from a medium to a denser one. Finally the students are prompted to draw their conclusions about the refraction phenomenon and reconsider the answer they gave to the question initially. Aiming to help students construct an analogy, on the next screen shot (Figure 11) students are presented with a hypothetical scenario in which they must choose the quickest route which a lifeguard in a swimming pool must take to reach an individual who is at risk of drowning (Hewitt, 1997). They see that he will reach the individual in distress quicker not by taking a direct route but by running further along the pool so that the distance he has to swim is kept to an absolute minimum, bearing in mind that the lifeguard can run faster than he can swim.

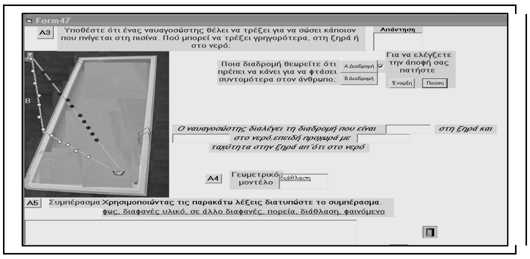


Figure 11. Hypothetical scenario with the lifeguard

Fifth category: From our initial research it seemed that children aged 10 and 11 had no awareness of the directionality of light in sight processes; instead of representing light they drew a geometrical connection between the eye and the viewed object. Also, when we asked students to show the direction of the light beam in the classical triangle (observer's eye, light lamp, object) on their worksheets, the emission model was the dominant model in their drawings. In order to cope with these students' alternative ideas the software "Light-Life" provides animated graphic renditions, representations of vision, which depict the directionality of light. Bearing in mind that a single arrow is highly schematic and thus might not be representative enough of the idea of light transmission (Winer et al., 1996) multiple arrows were used to represent light emanating from a seen object, some of them reaching the eye. In a drawing showing a child watching a flower, students were asked to predict the direction of light by choosing the correct arrows and then to test their hypothesis by activating the animation (Figure12).

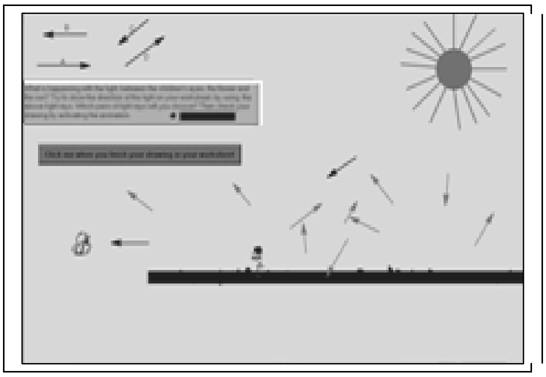


Figure 12. Animated graphic renditions of vision

2.5 Pilot Implementation in 6^{th} Grade Primary Class

A provisional evaluation of the software was made by using it in a primary classroom with 56 6^{th} grade students, 26 in the Experimental Group (E.G.) and 30 in the Control Group (C.G.) The students had equal potentials in academic performance, as according to their school records and teachers' opinions. After teaching, all the students answered a post-test questionnaire, which was similar to the initial one. The students of both groups answered to this questionnaire two months after the 6-hour teaching sequence. The teaching sequence with the use of the above mentioned computer tools and had positive learning results in the E.G.

It was revealed that the majority of students in the E.G. revised their initial views about light: Analysis of responses in the E.G. to the post-test question "*Where is light?*" and "*What do you think light is?*" showed there was increase 24.12% (N=7) of the E.G. students who adopted the scientific interpretation versus 8.5% (N=2) of the C.G. students.

Regarding light reflection and diffusion the results showed that after the teaching instruction in the C.G. some of the initial students' misconceptions remained (i.e. light stays on the surface it falls on).

Also for light diffusion in the atmosphere after teaching 26.9% (N=16) of the E.G. students revised their initial ideas and gave scientific explanations involving scattering of light on dust or the air, versus 10% (N=3) of the C.G. students.

Referring to refraction of light we had encouraging results too: a) for written interpretation of light refraction, 15 students in the E.G. revised their ideas versus 12 in the C.G., b) 19 E.G. students provided drawings depicting light refraction according to the scientific model, versus 10 C.G. students, and c) for answers to a given scenario, 21 students in the E.G. answered correctly versus 9 in the C.G. (Figures 13, 14, 15).

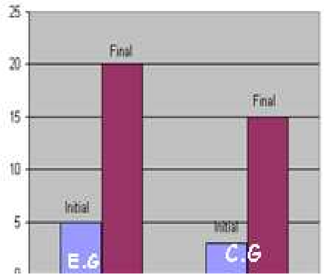


Figure 13. Written interpretations according to scientific ideas

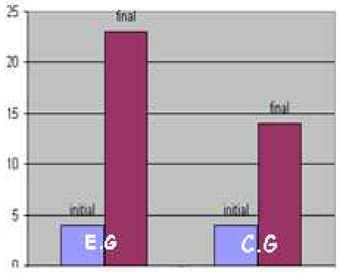


Figure 14. Drawings according to scientific ideas

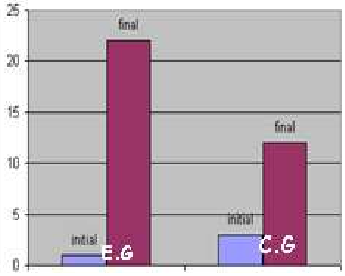


Figure 15. Accepted answers given to a scenario

Regarding vision more than half of the students in the E.G. adopted scientific interpretations in terms of vision depicting light rays emitting from a light source, reflecting on non-luminous objects and reaching into the observer's eye (16 in the E.G. versus 8 in the C.G). There was also increase of the written descriptions which indicated the 'receptive role' of the observer's eye (17 students in the E.G., versus 8 in the C.G.) (Figures 16, 17).

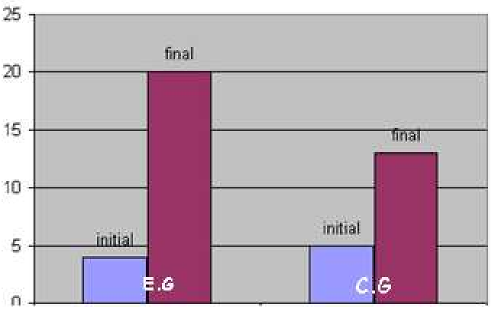


Figure 16. Students' drawings adopting scientific ideas

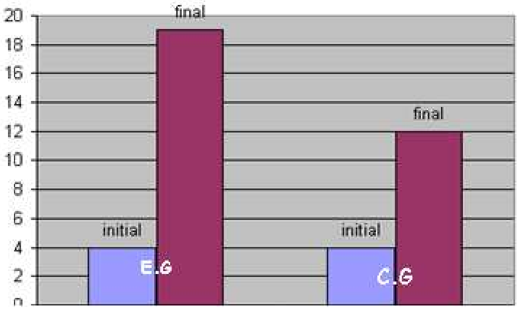


Figure 17. Descriptions indicating the receptive role of the observer' eye

3. CONCLUSIONS

'Light-Life' is multimedia educational software that was developed as a tool for enhancing learning with understanding of Geometrical Optics by primary school students. The initial research with 40 students using clinical-type personal interviews revealed students' alternative conceptions grouped in five categories. Based on those outcomes, we designed this software, which aims to cope with students' alternative conceptions. The software's main characteristics are students' engagement in real problem solving activities, prediction and testing of hypotheses, creating and comparing their own models with the scientific ones, simulations of real life situations. In order to bridge the 'zone of proximal development' (Vygotsky, 1978), we provide scaffolding by referring to common everyday situations, providing challenging authentic activities requiring reflective thinking to construct a suitable analogy, and also providing students with opportunities to work in collaborative groups. Students do not process the full complexity of the problem from the very beginning, but face a simpler version of it.

So, scaffolding takes place and students achieve better learning outcomes. Basic regularities provided by the software allow students to recode the information pertaining to the complex problem. We thereby aim to lead students to successful reformulation, and explanations of daily problems.

The initial results of this study are very encouraging, as the students found the software easy to use, achieving effective learning results regarding the nature of light, light reflection diffusion and refraction, and vision. The next step is to use of the software in more than one class and over a range of different grades. The aim is to test the effectiveness of the software using a larger sample of primary school students and to compare those outcomes with the outcomes achieved using more traditional teaching methods. Such an evaluation should be of significant assistance to teachers who seek to improve their teaching, to designers of educational software, and to those looking to improve both the teaching materials and methods for these areas of education. We also aim to look more closely at how the software can be presented on the Web as a distance- and open-learning tool for a much larger number of students, teachers, practitioners and researchers. This would involve paying further attention to the design of the software and the technology used to present it on the Web.

REFERENCES

Andersson, B. and Karrqvist, C., 1983. How Swedish pupils, aged 12–15 years, understand light and its properties. *European Journal of Science Education,* Vol. 5, No 4, pp. 387–402.

Bendall, S. et al, 1993. Prospective elementary school teachers' prior knowledge about light. *Journal of Research in Science Teaching,* Vol. 30, pp. 1169-1187.

Bransford, J. et al, 2000. *How people learn: brain, mind, experience, and school*. Washington, D.C., National Academy Press.

Driver, R. and Oldham, V., 1986. A constructivist approach to curriculum development in science**.** *Studies in Science Education,* Vol. 13, pp. 105–122.

Driver, R., 1989. Students' conceptions and the learning of science. *International Journal of Science Education,* Vol. 11, No. 5, pp. 481–490.

Driver, R. et al, 2000. *Making sense of secondary science: research into children's ideas.* Routledge, London.

Feher, E. and Rice, K., 1988. Shadows and anti-images: Children's conceptions of light and vision. *Science Education*, Vol. 72, No. 5, pp. 637-649.

Fetherstonhaugh. T. and Treagust DF., 1992. Students' understanding of light and its properties: teaching to engender conceptual change. *Science Education*, Vol. 76, No 6, pp. 653-672.

Fetherstonhaugh, T. et al, 1987. Student alternative conceptions about light: A comparative study of prevalent views found in Western Australia, France, New Zealand, Sweden and the United States. *Research in Science Education,* Vol. 17, pp. 156-164.

Feynman, et al, 1964. *The Feynman lectures on physics*. Reading, MA: Addison-Wesley.

Galili, I. and Hazan, A., 2000. Learners' knowledge in optics: interpretation, structure and analysis. *International Journal of Science Education,* Vol. 22, No. 1, pp. 57–88.

Gregory, R. L., 1979. *Eye and Brain.* Princeton, NJ: Princeton University Press.

Guesne, E., 1985. Light. In R. Driver, E. Guesne & A. Tiberghien (Ed.) *Children's Ideas in Science* (pp. 10-32) Philadelphia: Open University Press.

Hewitt, P., 1997. *Physics Concepts* (1) (E. Sifaki, trad). Heraklion: University Publications of Crete (in Greek).

Hosson, C. and Kaminski W., 2002. Les yeux des enfants sont-ils des 'porte-lumière'? *Bulletin de l'union des physiciens,* Vol. 840, pp. 143–160.

Jonassen, D.H., 1993. *Computers in the Classroom: Mind tools for Critical Thinking*. Englewood Cliffs, New Jersey, Prentice Hall.

Jonassen, D.H., 1999. Designing constructivist learning environments. In: Reigeluth CM (Ed.) *Instructional-Design Theories and Models,* Vol. II, pp. 215–239. Lawrence Erlbaum Associates, New Jersey.

Langley, D. et al, 1997. Light propagation and visual patterns: pre-instruction learners' conceptions. *Journal of Research in Science Teaching,* Vol. 34, No. 4, pp. 399-424.

Osborne, J. et al, 1993. Young children's (7–11) ideas about light and their development. *International Journal of Science Education,* Vol. 15, No. 1, pp. 83–93.

Osborne, J. F., 1996. Beyond constructivism**.** *Science Education,* Vol. 80, pp. 53–82.

Piaget, J. 1928. *The Child's Conception of the World.* London: Routledge and Kegan Paul.

Raghavan, K. and Glaser, R., 1995. Model-based analysis and reasoning in science: The MARS curriculum. *Science Education*, Vol. 79, pp. 37–61.

Ravanis, K., 1999. Représentations des élèves de l'école maternelle: le concept de lumière. *International Journal of Early Childhood,* Vol. 31, No. 1, pp. 48–53.

Ravanis, K. et al, 2002. Social marking and conceptual change: the conception of light for ten-year old children. *Journal of Science Education,* Vol. 3, No 1, pp. 15-18.

Ronchi, V., 1970. *The Nature of Light.* Cambridge, MA: Harvard University Press.

Selley, NF., 1996. Children's ideas on light and vision. *International Journal of Science Education,* Vol. 18, No. 6, pp. 713–723.

Solomon, J., 1994. The rise and fall of constructivism. *Studies in Science Education,* Vol. 23, No. 1, pp. 1-19.

Solomonidou, C., 2006. *New trends in educational technology. Constructivism and new learning environments*. Athens: Metaihmio editions (in Greek).

Tekos, G. et al, 2008. Teaching light reflection and diffusion using constructivist digital tools and methods in Greek primary school*. ED-MEDIA* AACE, Luka, J. and Weippl E. (Ed), Vienna, Austria, pp. 138-139.

Tekos, G. and Solomonidou, C., 2009. Constructivist learning and teaching of Optics concepts using ICT tools in Greek primary school: A pilot study. *Journal of Science Education and Technology* ,Vol. 18, No. 3, pp. 415-428.

Tiberghien, A. et al, 1980. Conceptions de la lumière chez l'enfant de 10–12 ans. *Revue Française de Pédagogie,* Vol. 50, pp. 24-41.

Vygotsky, L.S., 1978. *Mind in society: the development of higher psychological processes*. Cambridge: Harvard University Press.

Watts, M., 1985. Student conceptions of light: a case study. *Physics Education,* Vol. 20, pp. 183-187.

Winer GA, et al.,1996. Images, words, and questions: variables that influence beliefs about vision in children and adults. *Journal of Experimental Child Psychology,* Vol. 63, No.3, pp. 499-525.