IOPscience iopscience.iop.org

Home Search Collections Journals About Contact us My IOPscience

Context-based questions: optics in animal eyes

This article has been downloaded from IOPscience. Please scroll down to see the full text article.

2011 Phys. Educ. 46 323

(http://iopscience.iop.org/0031-9120/46/3/012)

View the table of contents for this issue, or go to the journal homepage for more

Download details:
IP Address: 194.27.72.122
The article was downloaded on 26/03/2013 at 09:10

Please note that terms and conditions apply.

Context-based questions: optics in animal eyes*

Derya Kaltakci[1] **and Ali Eryilmaz**

Department of Secondary Science/Mathematics Education, Middle East Technical University, Turkey

E-mail: kaderya@metu.edu.tr

Abstract

Context is important as a motivational factor for student involvement with physics. The diversity in the types and the functions of animal eyes is an excellent context in which to achieve this goal. There exists a range of subtopics in optics including pinhole, reflection, refraction, and superposition that can be discussed in the context of the animal eye. In addition to ordinary textbook optics questions, the use of context-based questions that model the real world may increase the students' motivation toward optics concepts and their understanding of them. In this article, different optical systems in animal eyes are discussed as a context to teach optics topics with context-based questions.

Introduction

Generally physics is perceived as difficult by students from all grade levels. The main reason for this is the complexity of understanding different representations, such as experiments, formulae, graphs, and explanations and transformations among them. Student difficulties mainly stem from physics concepts, the way in which a physics course is taught, physics problems which are sometimes very vague (Ornek *et al* 2008) and the missing connections between the real world and these concepts. Mostly physics has been taught in a traditional, didactic manner with well structured algorithmic problems and confirmatory laboratory works in which knowledge is transmitted from the teacher or textbook to the students in a passive way. Recently, however, the importance of students' construction of their own knowledge has been emphasized, and several methodologies for knowledge construction have been introduced into the literature. There have been attempts to improve the teaching and learning of physics in schools so that the students become more engaged and see the relevance of the physics knowledge through more real-life practical activities.

Context is important as a motivational factor for student involvement with physics. With this aim, many countries in the world, such as New Zealand, Australia, the UK, Germany, Turkey, and the Netherlands, include context-based approaches in their physics education programmes. By teaching physics in context, students can link physics to their lives in the real world, so that they become more motivated by instruction (Pilot and Bulte 2006). In a context-based approach, teachers begin their teaching with the central context and content is taught on a need-to-know basis. Hence, introducing new contexts to curriculum

* The preliminary version of this study was presented at the International Conference of GIREP 2008 in Cyprus.

[1] On behalf of Department of Secondary Science/Mathematics Education, Kocaeli University, Kocaeli, Turkey.

0031-9120/11/030323+05$33.00 © 2011 IOP Publishing Ltd

developers, textbook writers and teachers becomes crucial.

Optics in physics is a field which can easily be related to students' experiences and real lives, and the concepts in that field can be taught in different contexts. In that way students become more motivated to learn and therefore enhance their understanding of related optics concepts. Optical instruments such as cameras, microscopes, telescopes, projectors, periscopes, kaleidoscopes, etc are generally applicable contexts to teach basic optics-related concepts. One or more optics-related concepts are included in the function of all these instruments.

Animal eyes may be an interesting biological context for teaching basic optics in a physics class. In physics textbooks and in physics classes usually the human eye is discussed with the cornea and lens system to focus an image on the retina. However, the huge diversity of animal eye types and functions, which are usually not considered in optics teaching, can provide rich contexts. In the animal kingdom there are at least ten different ways that eyes form images, such as through a pinhole, lens, mirror, superposition, and so on (Land and Nilsson 2002). In optics classes, discussing the diversity of eye types with the adaptation of the animals' eyes to their habitats will probably enhance students' interest toward and understanding of related concepts.

There are some studies in physics education research discussing similar biological contexts. Steele (1997) asked a tutorial-type problem: 'why can humans not see effectively underwater?' and discussed the focusing ability of the human eye above and below the water. In that article, the accommodation strategies of bird, reptile and fish species that live both in air and water were also discussed. Colicchia (2006), (2007) developed eye models for the nautilus' pinhole eyes and amphibious fishes' cornea-lens eyes to show qualitatively the performance of the eye in introductory optics.

In the present study, examples of different animal eye functions will be presented in relation to optics concepts through context-based questions. Therefore, curriculum developers, textbook writers or teachers can improve and include them in their context-based teaching programmes. Instead of traditional optics questions, the use of context-based questions that model the real world can increase students' motivation toward and understanding of optics concepts.

The general context-based question that guides us and leads to the discussion of optics in animal eyes may be: 'how do different animals' eyes form images, considering their habitats and lives?' In answering this general question, students may be encouraged to work in groups in and out of class. Their provision of evidence that relates the optics-related concepts to different eye function mechanisms of animal species may be encouraged by the instructors. Collaboration with other disciplines such as biology and chemistry may also be promoted. Some of the contexts for animal eyes to discuss several optics concepts are eyes with pinholes, lenses and mirrors, and superposition eyes.

Optics in animal eyes

Eyes with pinholes

To the bathypelagic zone of the ocean, which is below 1000 m, almost no daylight can penetrate, so it is cold and dark except for bioluminescent flashes produced by other animals. The eyes of deep-sea fishes living in that zone are perfectly designed for life in the dark with point-source illumination from bioluminescent flashes. Therefore, their eyes and pupils are typically larger for catching as much light as possible (Warrant 2000).

The cephalopod, nautilus, is an animal with a shell that lives on the ocean bottom of low light intensity. The nautilus eye is one of the most primitive aquatic animal eyes without lens and cornea. The eyes are nearly a centimetre in diameter, and the pinhole pupil can vary its diameter with light intensity between 0.4 and 2.8 mm (Land and Nilsson 2002).

The pinhole pupil lets the sea water go into the interior part of the eye, so the refractive index for media both in and out of the eye is the same. The pinhole eyes of the nautilus have advantages over other eye types such as no chromatic or spherical aberration problems, but they are optically poor. Increasing the pupil size results in a loss of sharpness of the image; on the other hand, decreasing the pupil size results in a loss of brightness (Colicchia 2006). For this reason, two features of a 'good eye', resolution and

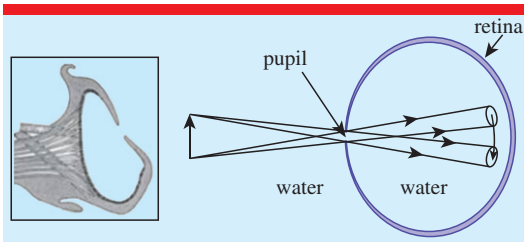


Figure 1. The pinhole eye of *Nautilus* and its model.

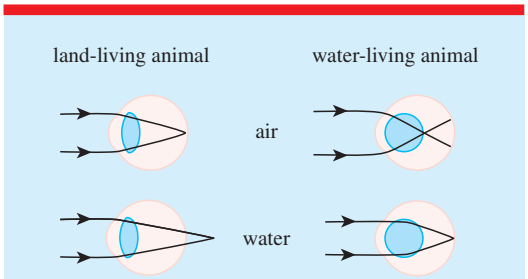


Figure 2. Effect of medium on the eyes of land- and water-living animals.

sensitivity, which are defined by Land and Nilsson (2002), cannot be reached at the same time in this simple pinhole eye. Figure 1 illustrates the pinhole eye of the nautilus and its image formation.

Eyes with lenses

Some other animals, including humans, use biological lenses made of protein to bring light to a focus. However, the lenses of animals differ based on whether the animal lives on land or in water. Figure 2 shows the effect of the medium on the refraction of land- and water-living animal eyes. On land, apart from the lens, the cornea of the eye is responsible for image formation. The refractive index of the interior chamber of the eye is very similar to the refraction index of water; for this reason, in water the cornea has little or no optical effect. For land animals, on the other hand, there is a large refractive index difference at the interface of air to eye in the passage of light. Actually, for land animals nearly 70% of the refraction of light occurs at the cornea. For these reasons, the lenses and corneas differ for different animals. For aquatic animals, such as fishes, spherical lenses with shorter focal length, or lenses with refractive index gradients with the highest index in the centre exist. For land animals, eyes with both cornea and fish-like lenses would result a myopic eye. For this reason, animals living on land adapted their eyes differently. Some animals may abandon the lens altogether and use the cornea alone, others keep the lens but flatten the cornea, or they shrink the eye to fit the shorter focal length.

A special group of vertebrates, called amphibious (seals, penguins, diving birds, four-eyed fishes), which see well both in water and in air, can be discussed with their accommodation to their habitat, along with the reasons why humans cannot see clearly underwater. For example, a diving bird, *Mergus cucullatus*, can increase its lens curvature considerably through the pupil underwater, four-eyed fishes have two pupils in each eye for use above and below water, seals have a flatter cornea and thus the cornea has little or no refracting power above water. Steele (1997) discussed the blurred vision of humans underwater in detail to dispel the student misconception that the lens in the human eye does all the focusing of light onto the retina.

In the special eye designs of some terrestrial vertebrates (domestic sheep, Indian python, red fox) the problem of chromatic defocusing is solved with multifocal lenses. These animals have multifocal lenses with concentric focuses of different focal lengths, each of which focuses a different spectral range onto the retina. To compensate for colour dispersion and obtain a sharp colour image, multifocal lenses refract short (blue) and long (red) wavelengths of light differently and focus them to a single point onto the retina (Malmström and Kröger 2006). In these biological contexts, the passage of light in different media with refraction and image formation in lenses can be discussed with context-based questions in physics classes.

Eyes with mirrors

In nature, generally the eyes of animals have optical systems based on refraction by the cornea and lenses; however, there are a small number of animal species that have eyes forming images with mirror reflections. The scallop's eye has a concave mirror at its back similar to a Newtonian telescope. Land (2000) and Land and Nilsson (2002) state that if you look into the scallop's eye through a microscope, you will see an inverted image of yourself looking through a microscope.

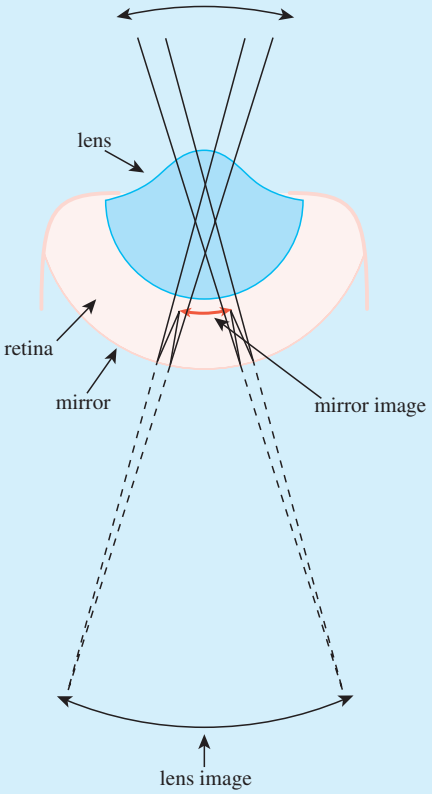


Figure 3. Image formation in a scallop's eye with mirror.

Scallops have 60–100 small eyes each 1 mm in size between their two shells. In their eyes the retina lies between the lens and the mirror at the back of the eye. The lens has little refractive power, so it focuses the image beyond the eye, but the back concave mirror reflects light and focuses it on the retina. The scallop's eye allows it to see moving objects such as approaching predators in the sea, but does not provide a complex vision. Figure 3 models image formation in the scallop's eye. Colicchia *et al* (2009) discuss the scallop's mirror eye in the biology concept further.

Some of the mirrors in animal eyes do not focus light, but reflect the light already focused by the lens and return it to the retina. In this way they give the receptors a second chance to capture the photons missed in the first passage (Land 2000). In particular, animals such as sharks, living in dark, deep water, or cats that are active at night have such eyes, as modelled in figure 4.

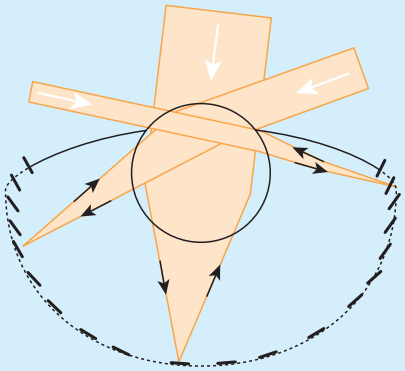


Figure 4. Light reflecting mirror eyes.

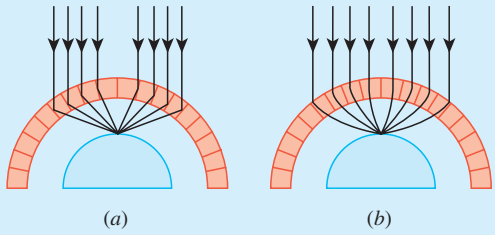


Figure 5. Reflecting (*a*) and refracting (*b*) superposition eyes.

Superposition eyes

Two types of superposition eyes, which are reflecting and refracting, exist in animals. Figure 5 shows image formation in reflecting and refracting superposition eyes. Reflecting superposition eyes are seen in long-bodied crustaceans, such as shrimps, crayfish and lobsters. In the reflecting superposition type of eyes, mirrors are arranged radially in a square array (Land 2000, Land and Nilsson 2002). In refracting superposition eyes, many lenses are arranged radially and these lenses contribute to the image at each point on the retina. This type of eye is found in animals from dim environments such as moths and krill.

Conclusion

In summary, teaching physics in a context allows students to link physics to their lives in the real world, so that they become more motivated by instruction and gain a good understanding of the concepts. In the present study, curriculum developers, textbook writers and physics teachers

are presented with a new biological context to teach optics. Discussion of the physics within the diversity of each animal eye type and function is a good way of accomplishing these goals. Any interested reader can look further into these animal eye types and adapt them to his/her optics teaching.

Acknowledgments

We appreciate the ongoing financial support of the Scientific and Technological Research Council of Turkey and the Faculty Development Programme at Middle East Technical University for this study.

Received 21 November 2010, in final form 9 February 2011
doi:10.1088/0031-9120/46/3/012

References

Colicchia G 2006 Ancient cephalopod scavenges successfully with its pinhole eye *Phys. Educ.* **41** 15–7

Colicchia G 2007 Vision of fish in air *Phys. Educ.* **42** 189–92

Colicchia G, Waltner C, Hopf M and Wiesner H 2009 The scallop's eye—a concave mirror in the context of biology *Phys. Educ.* **44** 175–9

Land M F 2000 Eyes with mirror optics *J. Opt. A: Pure Appl. Opt.* **2** R44–50

Land M F and Nilsson D E 2002 *Animal Eyes* (New York: Oxford University Press)

Malmström T and Kröger R H H 2006 Pupil shapes and lens optics in the eyes of terrestrial vertebrates *J. Exp. Biol.* **209** 18–25

Ornek F, Robinson W R and Haugan M P 2008 What makes physics difficult? *Int. J. Environ. Sci. Educ.* **3** 30–4

Pilot A and Bulte A M W 2006 Why do you 'need to know'? Context based education *Int. J. Sci. Educ.* **28** 953–6

Steele A L 1997 Vision underwater *Phys. Educ.* **32** 387–92

Warrant E 2000 The eyes of deep-sea fishes and the changing nature of visual scenes with depth *Phil. Trans. R. Soc.* B **355** 1155–9



Derya Kaltakci is currently a PhD student and research assistant at the Department of Secondary Science and Mathematics Education at Middle East Technical University in Turkey. She has focused her research interest on studies of student understanding in physics.



Ali Eryilmaz is currently an assistant professor at the Department of Secondary Science and Mathematics Education at Middle East Technical University in Turkey. He received his PhD in science education from the Florida Institute of Technology in 1996. His works focuses on student understanding in physics.