Year 12 Students' Mental Models of the Nature of Light

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Abstract

This paper reports on the third year of a three-year longitudinal investigation into six Year 10 secondary students' understanding of optics at a secondary school level. During the first two years of the study the students' understanding of geometrical optics was explored with the adoption of constructivist teaching and learning strategies. The students' understanding of geometrical optics following the Year 11 teaching stage then formed the basis of exploration of their mental models of the nature of light. This exploration occurred before, during, and following a Year 12 teaching stage where the students studied physical optics and quantum ideas. Before the Year 12 teaching stage the students had constructed mental models of light that related to their understanding of a ray. Over the Year 12 teaching stage the students' mental models changed to conceptualizations of a photon. There was evidence in the students' mental models of a hybridization of the particle and wave scientific models. That is, they conceptualized the photon as having both wave and particle characteristics. The variation in the students' hybrid models also suggested a variation in the way they conceived of the nature of scientific models.

Introduction

The models of science are representations of objects, events, ideas, systems or processes (Gilbert, 1995). Scientific models are one of the main products of science (Gilbert, 1994; Halloum, 1996) and play a crucial role in reducing the complexity of phenomena by allowing a more visual reproduction of abstract theories so that predictions of behavior can be made and tested (Gilbert, 1995). Scientific models help individuals conceptualize reality and serve as a bridge between the mind and the material world. For example, in conceptualizing the behavior of light secondary school students study two scientific models, referred to as the wave and particle models.

In interacting with the environment individuals construct mental models that are interpreted and understood in relation to existing mental models. The constructed mental models provide the individual with predictive and explanatory powers for understanding the interaction (Driver, 1995; Norman, 1983). Mental models are mental representations which individuals generate during cognitive functioning and have structures that correspond to, but do not directly represent, a structure in reality (Johnson-Laird, 1983; Vosniadou, 1994). Therefore, before studying the scientific models of light secondary school students will have constructed mental models of light, which may have some impact on their understandings of the scientific models. The purpose of this study was to investigate the impact on students' mental models of light as a result of a teaching sequence where the students studied the particle and wave models of light.

This paper reports on one aspect of the third year of a longitudinal case study of six Year 10 students' understanding of optics with the adoption of a constructivist teaching and learning strategies in three separate teaching stages over a three-year period. This aspect relates to an investigation of the students' mental models of the nature of light during their 12th year of schooling. The researcher acted in the dual roles of teacher and researcher. The longitudinal nature of the study allowed for the tracking of the students' understandings of several key concepts of geometrical optics over the first two years. The students' understandings of geometrical optics then formed the basis of exploration of their mental models of the nature of light in addition to their views of the nature and function of scientific models over the students' 12th year of schooling. It must be noted that the findings as they relate to the students' views of the nature and function of scientific models is not reported in this paper. During the Year 12 teaching stage the students studied physical optics and quantum ideas and engaged in discussions about the role of models in science. The pertinent research question relating to this part of the study was, 'What mental models do students have about the nature of light and how do they change in response to a teaching sequence about the scientific models of light?'

Methods

The research design relating specifically to the exploration of the students' mental models of light centered on three semi-structured interviews and three questionnaires administered over a period of several months in the students' 12th year of schooling. The teacher/researcher also made classroom observations. The first two interviews occurred before the teaching stage and the third interview was held after the teaching stage. The questionnaires were administered before and during the teaching stage.

The first of the interviews explored the mental models of the nature of light constructed by the students in explaining situations as they related to the key concepts addressed in the first two years of the study. The data from this interview revealed three different models used by the students to explain various phenomena of light. These models then formed the basis of a questionnaire that was administered to the students some three months after the first interview. It contained questions that centered on students selecting an appropriate model, with reasons, for different phenomena of light. The interview and questionnaire data for each student was fed back to them in the second interview. Students were asked about their own models and their thoughts about opposing models. The final interview occurred one month after the teaching stage and probed the students' mental models of light in the context of several phenomena of light.

The first part of the Year 12 teaching stage involved eliciting and discussing the students' mental models of the nature of light on the basis of their responses to the questionnaires. For the rest of the Year 12 teaching stage the different scientific models, including the student-generated mental models, were evaluated in terms of their scope, and predictive and explanatory power in explaining various phenomena of light already met in Year 10 and Year 11 as well as new phenomena. The new phenomena included diffraction and interference effects of light, and the photoelectric effect. Difficulties encountered with any of the scientific or student's mental models in the explanation of specific phenomena of light were discussed and possible changes to models were explored. The opportunity was given for students to alter and revise their existing mental models as well as invent new ones.

Results

During Year 10 and 11 the students had expressed a high level of confidence in having a scientific understanding of several key concepts of geometrical optics that they showed on many occasions (Hubber, 2005). However, they had developed a mental model of light that related to their understanding of rays, which was inconsistent with scientific understanding. They believed that rays are actual constituents of light, conceptualized as continuous streams of material that can vary in size depending on the strength of the ray; the brightness of the light is then related to the strength of the ray or its concentration of number.

When asked about the nature of light at the beginning of Year 12 all students had maintained rays as part of their mental models of light but three of the students now believed that rays were representations of light rather than actual constituents (refer to Table 1). There was evidence of three distinct models described as the standard ray model, beam ray model and particle ray model. The standard ray model matches the scientific view of a geometric construction, in the form of an arrow, to show the direction of light propagation represented as water waves, the beam ray model represented light as continuous streams of material, while the particle ray model represented light as particles. When these models were presented to the students to explain various phenomena of light there was variation in their preferred models (refer to Table 2).

During the Year 12 teaching stage the students compared and tested their own personal models of light against the scientific models for different light phenomena. This resulted in each student achieving a scientific understanding of the nature of light in terms of the application of the particle scientific model or the wave scientific model to explain various light phenomena. Table 3 shows their preferred models to explain various light phenomena. The students were confident in using either particle or wave ideas depending on the phenomenon to be explained and were aware that their mental models of the nature of light had changed over the teaching period.

The students' mental models had changed from conceptualizations of a ray to that of a photon. Just as there was variation in the mental models of a ray there were also quite subtle differences in their mental models of a photon (refer to Table 1). Four of the students had constructed hybrid models whereby photons acted separately to account for particle like behavior of light but acted collectively in waves to account for wave-like behavior.

Conclusions and Implications

This study found that students construct their own mental models of the nature of light, some of which are different to the scientifically acceptable scientific models, before and during the teaching of the scientific models. Prior to Year 12 the students held a mental model where rays were actual constituents of light but at the same time were able to successfully account for a whole range of geometrical optical behavior. By the end of the Year 12 teaching sequence the students could successfully account for different optical phenomena in terms of a particle or wave model of light. That is, they chose either a particle idea or a wave idea to explain a specific light phenomenon (refer to Table 3). However, in thinking about the nature of light, the students had constructed a hybrid model of light that related to the photon. This model had the photon with both wave and particle characteristics. One could argue that the students achieved a scientific understanding of light behavior despite holding a mental model of light which varied from the scientific models. On the other hand, one may view the students' understanding of light as limited as it does not contain a scientific view of the nature of light.

The construction of hybrid models raises an issue related to the students' understanding of the nature and function of scientific models. Alan had a view that light is actually composed of photons which he replaced from a model that he and the other students had, that light consists of rays. Alan's thinking is consistent with a 'naive realist' epistemology (Nadeau & Desautels, 1984), where models are direct copies of reality. On the other hand the other students changed to a more sophisticated epistemology where their hybrid photon models are considered representations of reality. However, three of the students, Christine, Evan and Frank, melded two quite distinct ideas into the one model, and extracting a particle idea when thinking about individual particle-like photons and a wave idea when particle-like photons act in great numbers. Such a thinking reflect a view that models are representations of reality, rather than a more scientific view that models are representations of ideas, or concepts, one has about reality. Beth's hybrid model maybe considered closest to the scientific view of the nature of models as her 'wavicle' view of a photon (refer to Table 1) was considered as a convenient image to think about light either as a particle or a wave.

*Student	Mental Models of the Nature of Light		
	During Year 10 & 11	During Year 12	
		Before Year 12 Teaching Stage	Following Year 12 teaching Stage
Alan	Light is composed of rays	Light is composed of rays that are continuous streams of material	Light is composed of photons that are particle-like in nature but act as a wave or ray in great numbers.
Beth	Light is composed of rays	Light is composed of rays that are streams of particles	Light acts like waves or particles. Photons are theoretical entities that can be imagined as a 'wavelet' which metamorphose into particles or waves depending on which of a particle or wave idea is required to explain a specific phenomenon.
Christine	Light is composed of rays	Light acts like waves or particles	Light acts like waves or particles. Light is composed of theoretical particle entities called photons with electrical characteristics that act like a wave in great numbers.
Danielle	Light is composed of rays	Light acts like waves or particles	Light acts like waves or particles. The particles are theoretical entities called Photons. Waves are like water waves.
Evan	Light is composed of rays	Light is composed of rays, called ray beams, which are continuous streams of material	Light acts like waves or particles. Light is composed of theoretical entities, called photons, which have both particle and wave characteristics.
Frank	Light is composed of rays	Light travels like waves in a direction shown in diagrams by arrows called rays	Light acts like waves or particles. Light is composed of theoretical particle-like photons, which have electrical characteristics and behave as a wave in great numbers.

Note: * Pseudonyms have been used for students in this study.

Table 1 Students' mental models of the nature of light

Phenomenon	Student					
	Alan	*Beth*	*Christine*	*Danielle*	*Evan*	*Frank*
Light spreads out in all directions from the light source.	Beam	Particle	Beam	Beam	Beam	Wave
Each point on a luminous object emits light in all directions.	Beam	Particle	Beam	Beam	Beam	Wave
Light bends and slows down in going from air into glass.	Beam	Particle	Wave	Beam/ Wave	Beam	Wave
White light is composed of different colors.	Beam	Particle	Wave	Wave	Beam	Wave

Table 2 Students' preferred model(s) for various light phenomena before the Year 12 teaching stage

Phenomenon	Student					
	Alan	*Beth*	*Christine*	*Danielle*	*Evan*	*Frank*
Light spreading out from a luminous object	Particle	Wave	Wave	Wave	Particle	Wave
Isotropic emission of light from each point on a luminous object	Particle	Wave	Wave	Wave	Particle	Wave
Specular reflection	Particle	Wave	Wave	Wave	Particle	Particle
Diffuse reflection	Particle	Wave	Wave	Wave/ Particle	Particle	Particle
Color	Particle	Wave	Wave	Wave	Particle	Wave
Rectilinear propagation	Particle	Wave	Particle	Wave	Particle	Particle
Refraction	Wave	Wave	Wave	Wave	Particle	Wave
Photoelectric effect	Particle	Particle	Particle	Particle	Particle	Particle
Diffraction	Wave	Wave	Wave	Wave	Wave	Wave

Table 3 Students' preferred model(s) for various light phenomena following the Year 12 teaching stage

In teaching of the scientific models of light, care needs to be taken to make clear distinctions between the models, highlighting the view that they represent different ideas. Therefore, the teaching of the scientific models should occur at the same time the teaching of the nature and function of scientific models occurs. In respect of the teaching of light, the teaching about the nature and function of scientific models should occur at the same time geometrical optics is taught as the ray scientific model is used extensively. In addition, there is a need to explicitly focus on students' mental models as part of the pedagogical strategies adopted in optics as a mental model of light that was formed prior to or on entering school may be guiding students' thinking about the nature of light.

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