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Understanding Scientific Models within an Optics Context

Dr Peter Hubber
Deakin University,
221 Burwood Highway,
Burwood, Victoria, 3125
Ph: (03) 92446408
Email: phubber@deakin.edu.au

Introduction

The new Physics Study Design (2003) emphasises models and modelling in almost every Area of Study across all Units; there are over 80 references to 'models' or 'modelling' in the Unit descriptions. This emphasis on models and modelling is reflected in two of the aims for the study, namely:

> This study is designed to enable students to:
>
> - Understand the ways knowledge is extended, organised and revised in physics, in particular the role of conceptual and mathematical models applied to physical phenomena; and
> - Identify and assess the validity and reliability of underlying assumptions and/or limitations of models, data, and conclusions;
>
> Physics Study Design, 2003 p. 7

There is clear evidence to suggest that a significant role of the physics teacher is to explain physical phenomena by way of the conceptual models developed by scientists to explain their observations of nature. There is also reference to a requirement to teach about how models are used in a generic manner. This requirements is reflected in the very first 'knowledge and skills' dot point in Outcome 1, Area of Study 1 in Unit 1 which states that the student should demonstrate the knowledge and skills to, 'explain how models are used by physical scientists to organise and explain observed phenomena' (Physics Study Design, 2003 p. 13).

These requirements in the study design suggest that the students need to not only understand how the individual models explain their corresponding physical phenomenon but also the nature and function of models in physics or, more generally, in science. What then is the nature and function of models in science? The rest of this paper attempts to answer this question within the context of the topic of optics. In addition this paper will draw on research into students' understandings of models and the implications of this research for the teaching of models in physics. Before discussing the nature and function of models in science we first of all need to consider the nature of science itself. The next section discusses how scientific knowledge is constructed.

Scientific Knowledge

The widely accepted traditional view of science is one where:

- Science knowledge is unproblematic,
- Science provides right answers,
- Truths in science are discovered by observing and experimenting,
- Scientists gather objective data, and
- Choices between correct and incorrect interpretations of the world are based on common sense responses to objective data.

This traditional view contrasts with a more recent view of science where:

- Science knowledge is tentative,
- Science provides viable interpretations of the world,
- Science is not a set of truths which exist independently of people,
- Observations in science are theory laden,
- Choices between different interpretations of the world are based on the notions of elegance, parsimony and greater connectedness as well as those of plausibility, intelligibility and fruitfulness.

(Carr et al, 1992).

The traditional view of science knowledge as a collection of truths about an observer-independent world can no longer be valid. One cannot claim science to be an activity that involves the unlocking of the 'secrets of nature'. There does exist a reality but scientists, or anyone for that matter, can never know it entirely. All we can do is to make viable interpretations to the observations we have with reality.

Scientific knowledge can be described as public knowledge that is symbolic in nature and also personally and socially constructed. From this perspective, "the objects of science are not the phenomena of nature but constructs advanced by the scientific community to interpret nature" (Driver, Asoko, Leach, Mortimer & Scott, 1994, p. 5). These constructs have been devised by scientists as they attempt to make sense of their experiences and are then shared and negotiated with the scientific community until a consensus view is reached. This consensus view becomes part of the 'taken for granted' ways of interpreting nature. As a result, scientific knowledge is symbolic so that it is "...now populated with entities such as atoms, electrons, ions, fields and fluxes, genes and chromosomes; it is organised by ideas such as evolution and encompasses procedures of measurements and experiment" (Driver et al, 1994, p.6).

As individuals bring their own meaning to any social construct situation (Solomon, 1988) each individual that engages in the discourse of the construction of scientific knowledge will attach their own meaning to the symbolic entities of science using their own conceptual framework. The only way scientists can make sense of their experiences with the phenomena of nature is to construct theories which incorporate scientific models. The development of models and the actual modelling process then becomes an important part of the process and products of science. If we cannot get direct access to reality then our understanding of reality can only be through interpreting our observations through the use of models. What then are the key features of models in science? The next section attempts to answer this question.

The Nature and Function of Models in Science

The products of science are seen as hypotheses, laws, models and theories. While hypotheses may be considered to be tentative statements of anticipated relationships, laws are descriptions of repeated observations. Theories and models provide explanations of what is observed about the world. Theories are stories related to ideas and concepts that scientists have about phenomena and models provide the representations of the ideas and concepts. Scientific models are representations of ideas scientists have about reality rather than reality itself. Theories and models are important in science as, according to Gilbert (1994), "for any phenomena of nature, the progress [of science] is normally marked by the production of models, each associated with a distinctive theory, of increasing scope of application and predictive power" (p. 9). In fact, Gilbert (1991) suggested it would be helpful to define science as a process of constructing predictive scientific models, as this definition incorporates both the process of science and the nature of its product.

Models occupy the core of science and play a crucial role in reducing the complexity of phenomena by allowing a more visual reproduction of abstract theories so that predictions of behaviour can be made and tested (Gilbert, 1995). This view is supported by Gilbert and Boulter (1995) who have suggested that the role of the scientific model in science should be seen as "an intermediary between the abstractions of theory and the concrete actions of experiment, helping to make predictions, to guide enquiry, to summarise data, to justify outcomes, and to facilitate communication" (p. 3).

Whilst the role played by models in science is significant, the actual process of constructing models represents a major element of scientific methodology (Gilbert, 1993). Modelling is seen as a systematic activity for the development and application of scientific public knowledge in science (Halloum, 1996). The process of modelling is, according to Gilbert (1993) "...the process by which a model is produced. It involves identifying the need for a model, establishing the purpose that the model is to serve, identifying a suitable source from which it may be derived, and producing the representation" (p. 8).

Progress in science has been viewed by Gilbert and Boulter (1995, p.1) as "stretching models too far" thus necessitating the need to modify existing models or replacing them. Stretching models extend them beyond their original purpose which may arise in circumstances where observations do not match predictions derived from the model or where a novel phenomenon is observed which appears to fall within the scope of the theory but cannot be explained by the existing model. In these circumstances a modified or new model may be sought to incorporate into the theory or, if this cannot be achieved, then a new theory and model may be developed (Kuhn, 1970). The change of one model, or theory and model, to another is at the heart of Kuhn's (1970) paradigm shift and occurs abruptly. However, Gilbert and Boulter (1995) have suggested that any change is more iterative where only some aspect of current theories or the methodological rules of enquiry are altered in any one time period.

Modelling in science is consistent with the view that one cannot gain direct access to the real world (von Glaserfeld, 1988) so the comprehension of any interaction one has with reality must be a model (Goldin, 1990). Thus the construction of views about the world must be a modelling process which in turn highlights the tentative nature of scientific knowledge (Gilbert & Boulter (1995).

The general view held by several authors in relation to models in science (Smit & FInegold, 1995; Grosslight, Unger, Jay & Smith, 1991; Gilbert, 1994; Gilbert & Boulter, 1995; Gilbert & Boulter, 1995) can be characterised as:

1. Models are the constructions of the human mind and are temporary by nature.
2. Models are not viewed as pictures of the underlying reality but as representations of concepts or ideas we have about reality.
3. Modelling is an element of scientific methodology.
4. Models are one of the main products of science.
5. An important role is played by models in the construction of knowledge and understanding the phenomena of nature.
6. A clear distinction is made between a model and a physical theory. Theories are stories related to ideas and concepts that scientists have about phenomena and models provide the representations of the ideas and concepts.
7. Models help the scientist to predict, describe and explain natural phenomena, particles and structures. The descriptions are never complete. They simplify phenomena or make them easier to deal with. Different models can be used to describe the same entity.
8. There are seven categories that constitute a composite definition of model:
    - **Scale models** are used for planning purposes and testing. These models usually resemble just the external structure of the object being modelled. Examples, scale models of plane, skeleton.
    - **Analogical models** are constructions to reflect point-to point correspondence between the analogue and the target for the set of attributes that the model is designed to elucidate. The source of the model is some other object than that which is the target. For example, ball and stick models of the chemical structure, hydrodynamics models of electric circuits.
    - **Mathematical models** consist of physical properties, physical changes and processes. The sources of the model are symbols which are manipulated within equations using the rules of mathematics. For example, $F = ma$, $PV =$

nRT. Graphs can also come within this category and can be used to represent equation relationships.

- **Chemical formulae and equations model** composition and chemical reaction.
- **Theoretical models** used to analogically represent nonmaterial phenomena like magnetic field lines or photons.
- **Standard model** is something to be imitated. A fashion model, or role-model, represents ideals that can be imitated. In science the concept of an ideal gas and the relevant kinetic theory models of temperature, pressure and phase changes. The concept of blackbody radiation and associated models.
- **Maps and diagrams** represent patterns and pathways. Like electric circuit diagrams, weather maps, nervous system and circulatory patterns.

The modelling process involves identifying the need for a model, establishing the purposes that the model is to serve, identifying a suitable source from which it may be derived, and producing the representation. All types of model listed above have in common their dependency on the use of analogy and metaphor.

Given that the modelling process is a significant part of the process and products of science then it is important for students in schools to obtain some sense of models in science and their role in the construction of scientific knowledge. The literature in relation to student understanding of models is not extensive. However studies that have undertaken research in this area have pointed to a serious lack of experience by students with models (Grosslight, Unger, Jay & Smith, 1991; Smit & Finegold, 1995). The next section discusses this literature.

Students/Teachers Understanding of the Nature and Function of Scientific Models

Grosslight, Unger, Jay and Smith (1991) undertook a study to determine how secondary school students conceptualise the nature of models. Clinical interviews were undertaken with 33 mixed ability 7th grade students (12-13 years) and 22 students from an 11th grade (16-17 years) honours class. Four adult experts, consisting of a museum director, high school physics teacher, professor of engineering and education, and a cognitive science researcher, were also interviewed. The researchers found the experts in the study represented models in terms of actively formulating and testing ideas about reality, whereas the students tended to point to a more immediate transparency between reality and models.

Grosslight, Unger, Jay and Smith (1991) identified three levels of thinking about models which emerged from the interviews and which reflected different views about models and their use in science. These different levels of understanding of models are described as:
***Level 1 understanding*:** views models as essentially simple copies of reality. The usefulness of models is seen as providing copies of actual objects or actions and there is a view of a general 1:1 correspondence between the model and reality. Level 1 modellers acknowledge that some real attributes are missing in the model but this is only due to a conscious decision not to do so by the modeller. Level 1 modellers do make a distinction between the model and the thing being modelled but only in the context that the model represents little copies of reality. The purpose of the model is to be like the real thing and level 1 modellers only vaguely appreciate that models may be wrong. A level 1 modeller does not clearly distinguish the ideas and/or purpose underlying the model, the model itself, and the experimental data which would support or refute the validity or usefulness of the model.
***Level 2 understanding*:** has a realisation that there is a specific purpose that mediates the way the model is constructed. The modeller makes a conscious decision on how to achieve that purpose. There is no longer a need for a one-to-one correspondence between the model and reality. The main focus is still on the model and the reality modelled, of the ideas portrayed.

Tests of the model are not thought of as tests of underlying ideas but of the workability of the model itself. At level 2 students distinguish between the ideas and/or the purposes motivating the model and the model itself and realise that the purpose of the model dictates some aspect of the form of the model. Level 2 modellers appreciate that the model may need to change where new experimental data surfaces.
A level 2 modeller:

- Still fundamentally see models as representations of real-world objects or events and not as representations of ideas about real-world objects or events.
- Different models are thought to capture different spatiotemporal views of the object rather than different theoretical views.
- Models are seen primarily as a means to communicate information about the real-world events rather than as a means to test and develop their ideas or theories about the world.

Level 3 understanding: is characterised by three important factors.

- Models are constructed in the service of developing and testing of ideas and explanations about phenomena rather than serving as a copy of reality itself.
- The modeller takes an active role in constructing the model in constructing the model and evaluating which of several designs will best suit the model's purpose.
- The model can be manipulated and subjected to tests that provide information about how the model may need to be revised. Models provide information within a cyclic constructive process.

The researchers found each of the adults operating at a Level 3 understanding but there were no students operating at this Level or even a mixed 2/3 Level. The majority of the 7th graders were at a pure Level 1 whereas the 11th graders were equally divided between pure Level 1, mixed Level 1/2 and pure Level 2 understanding. The interviews also revealed that the students appeared to have very limited experiences with scientific models as evidenced by the limited number of models provided by both the 7th, and 11th graders. The main function of scientific models, as perceived by the students, was just to transmit information about the world as it really is and to make such information more understandable.

In a recent study of student understanding of models Smit and Finegold (1995) administered a questionnaire dealing with physics models in general and with specific models in optics to 196 South African post-graduate Higher Education Diploma students studying to become physical science teachers. The results of the study (see **Appendix 1**) revealed that the students had very little knowledge of the origin, nature and function of models in physics. Some of the alternative conceptions with regard to models in general were listed as:

- The most important function of models in physics is not in the construction of scientific knowledge but in a teaching strategy for learning,
- There is no clear distinction made between scientific models and the models produced by engineers in technological development,
- A model is depicted as very nearly similar to the real entity, and
- There is confusion about the relationship between theory and a model.

The implications of both Grosslight et al (1991) and Smit and Fingold’s (1995) studies for the teaching of science are that students need more extensive experiences working with models and more time reflecting on those experiences. Smit and Finegold (1995) argued that models are central and play a vital role in scientific thinking so that a sound knowledge of the nature and function of scientific models will certainly contribute to a better understanding of the concepts of physics. He also pointed to a shortcoming in the teaching of models as a fundamental reason why students find physics difficult to understand. Smit and Finegold suggested the theory of models should be integrated into the content of the topic undertaken; for example, optics or electricity. It is also important that students have experiences solving problems to appreciate that a model can be used as a tool of inquiry and not just an aid to understanding phenomena (Grosslight et al, 1991). Grosslight, and others (1995) also suggested students need more experience with models that provide contrasting conceptual views of phenomena, and more discussions of the roles models play in scientific inquiry.

Research into Students' Understanding of Models of Light and Scientific Models: A Case Study

The new Physics Study Design (2003) emphasises a wave model in teaching light phenomena in addition to a requirement to teach about how models are used by physical scientists. The previous Physics Study Design had no such emphasis or such a requirement. It was under this Study Design that a case study of six physics students' understanding of models of light and nature of scientific models was undertaken (Hubber, 2002).

In undertaking geometrical optics in Unit 1 the students were introduced to the concept of a ray via a wave model of light. The rest of the unit relied heavily on the ray model. The ray itself is a geometrical construction (arrow) that provides the direction of light energy emanating from luminous objects and interacting with other objects. Ray diagrams provide a very useful mechanism for students to explain a whole range of optical phenomena from shadows to virtual image formation. What was not emphasised throughout the topic is was study of the nature of light. This was the essence of Unit 4 optics.

After teaching the students optics in Year 10 and Year 11 they all showed evidence of mental models where light actually consists of rays. Table 1 provides excerpts from various pieces of work completed by the students; these included concepts maps, assignments and tests.

Table 1: Students' Mental Models of the Nature of Light during Year 10 & 11

Student	Evidence of Mental model of Nature of Light
Alan	"LIGHT travels in the form of RAYS; RAYS travel to our EYES". "The green filter only lets green rays through the filter".
Beth	"LIGHT is given off in RAYS". "Depends if the rays enter his eyes from the cat".
Christine	"RAYS pass through TRANSPARENT MATERIALS; RAYS reflect in all directions in DIFFUSE REFLECTION; LIGHT is RAYS". "[The candle] gives off the same amount of light, but at day, the sunlight is stronger so it fills in the candle's rays".
Danielle	"MIRRORS reflect a RAY". "The rays must enter your eye from the object for you to see".
Evan	"LIGHT travels in RAYS". "A ray is just a single beam of light".
Frank	"LIGHT makes RAYS; RAYS hit objects and make REFLECTIONS; RAYS don't shine in SHADOWS, RAYS don't hit UMBRA". "[The brightness] ...determines how many rays are being produced. The more rays the brighter the light".

Just prior to the teaching of optics at Unit 4 level the students were interviewed as to what they though light was like. Three different models were found. These are listed in Table 2.

Table 2 Types of Students' Mental Models of Light

Model Type	Description
Standard Ray Model	Light travels out from a luminous object like water waves in all directions from a central point. Rays are directed lines that point in the direction of wave propagation. To explain the directional change in light passing from one material into another, one side of the wave hits the optically denser material first and slows thus changing the direction of the wave. Different colours of light are characterised by waves of different wavelengths.
Beam Ray Model	Light travels out from a luminous object like thin beams of continuous material called rays. To explain the directional change in light passing from one material into another, one side of the ray hits the optically denser material and slows, swinging the ray into a different direction. Different colours of light are characterised by rays of different width.
Particle Ray Model	Light travels out from a luminous object like particles in all directions. Rays constitute streams of particles. To explain the directional change in light passing from one material into another, one side of the particle hits the optically denser material and slows, swinging the particle in a different direction. Different colours of light are characterised by particles of different width.

The students were then surveyed as to their preference for each model with respect to various phenomena of light. Table 3 shows their preferences.

Table 3: Students' preferred Model(s) for various Light Phenomena

Phenomenon	**Preferred Ray Model**					
	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	Wave/Beam	Beam	Wave
White light is composed of different colours.	Beam	Particle	Wave	Wave	Beam	Wave

Not only did the students vary in their preference for a particular model they had different views as to the nature of light. Table 4 below shows that some of the students believed their models act like the behaviour of light, which is the scientific viewpoint, but others believed their model was light itself; this indicated a non-scientific thinking.

Table 4: Students' Mental Models of the Nature of Light before the Year 12 Teaching Stage

Student	Mental model of the Nature of Light
Alan	Light is composed of rays that are continuous streams of material.
Beth	Light is composed of rays that are streams of particles.
Christine	Light acts like waves or continuous streams of material.
Danielle	Light acts like waves or continuous streams of material.
Evan	Light is composed of rays that are continuous streams of material.
Frank	Light propagates like waves in a direction shown in diagrams by arrows called rays.

Following the Unit 4 teaching of physical optics and quantum ideas the students had changed their view about the nature of light to include the photon. Their views are listed in Table 5 below. Only one student, Alan, continued to believe that light was the model. Alan believed that light actually consists of photons. The rest of the students believed that light behaved like particle or waves, which is the scientific viewpoint but had misconceived views about the nature of the photon. Most condensed both the particle and wave ideas of light into their conceptualisation of a photon. That is, the photon could have both wave and particle characteristics. Their photon model was a hybrid model of the wave and particle models of light.

Table 5: Students' Mental models of the Nature of Light following the Year 12 Teaching Stage

Student	Mental models of the Nature of Light
Alan	Light is composed of photons that are particle-like in nature but act as a wave or ray in great numbers.
Beth	Light acts like waves or particles. Photons are theoretical entities that have particle and wave characteristics. Rays are little packets of energy that travel in waves.
Christine	Light acts like waves or particles. The particles are theoretical entities called photons with electrical characteristics that act like a wave in great numbers. Rays are waves or particles moving in a straight line.
Danielle	Light acts like waves or particles. Photons are theoretical entities that have particle characteristics. Rays are streams of energy particles.
Evan	Light acts like waves or particles. The particles, called photons, have particle and wave characteristics. Rays consist of photons.
Frank	Light acts like waves or particles. Photons have wave, particle and electrical characteristics. Rays give the direction of light propagation.

The findings of the case study described above are similar to other research in this area. That is, research has found is that many students, and adults, believe that rays are actual constituents of light. Instead of being considered a mathematical tool that indicates the direction of light propagation, there is a view that light rays actually exist. Such a view is often reinforced in everyday language. Health professionals warn of the “dangerous rays from the sun”, while beach resorts seek holidaymakers wishing to “soak up the sun’s rays”.

In thinking that light rays actually exist, a Year 11 student can still show a good understanding of many aspects of geometrical optics. This was the case in the case study – the students understood geometrical optics very well. However, some researchers point to such a view as responsible for some difficulties associated with aspects of geometrical optics (for example, image formation in lenses and mirrors). What is very clear is that in believing that light rays actually exist a student will confront a number of difficulties in understanding physical optics and quantum ideas as a Year 12 student.

In understanding Year 12 optics the student needs to gain an understanding of the:

- Nature and function of scientific models, and
- Nature of light in terms of the particle and wave models.

Both of these areas provide a significant cognitive leap for a student who believes that light is actually composed of rays.

Another aspect of the case study was the exploration of the students' views as to the nature and function of models in science. Just before the Unit 4 topic relating to physical optics and quantum ideas the students were surveyed as to their views about models in general and the nature and function of scientific models. You are referred to **Appendix 2** for examples of some of the responses give by the 13 students who constituted the Year 12 class. The responses suggest that some of the students had a limited understanding of the nature and function of scientific models whereas other students had quite sophisticated views. Given that the students were nearing the end of Year 12 physics they had been exposed to many scientific models in learning about science. However, many did not have a full understanding of the true nature and function of these models.

Teaching and Learning Strategies for Physical Optics and Quantum Ideas

In teaching and learning of the scientific models of light, namely the wave and particle models, it is important for students to have a sound knowledge of the nature and function of scientific models. In terms of a Level 3 thinking (described above) this maybe quite difficult to achieve. What is important is that there is a clear distinction between the scientific model, reality and ideas or concept about reality. Levels 1 and 2 thinking relate to the view that scientific models are representations of reality. Scientific models, from a Level 3 perspective, represent ideas or concepts we have about reality, rather than reality itself.

A view that light rays actually exist represents Level 1 thinking about scientific models. That is, the model is an exact replica of reality. Level 2 thinking that light rays represent light suggests that one can gain direct access to reality (for example, a toy car is modelled on the real car). The teaching of Year 12 optics will most probably change this view. However, the views may change to other non-scientific beliefs.

Following the Year 12 teaching of optics the student may replace rays for light waves or photons for what actually constitute light. In other words, the students will believe that light actually consists of light waves or photons. As the teaching of waves precedes the teaching of photons, students may progress through a series of views from one where light consists of rays, which is replaced by light waves, then finally to be replaced by photons.

In reconciling the wave and particle models of light the student may believe that the true nature of light is such that it is composed of (i) photons that have wave characteristics, or (ii) waves with particle characteristics. In bringing together wave and particle ideas researchers have found the following thinking:

- Photons are viewed as 'wavicles' (or wavelets).
- Photons have electrons connected to it, they move backwards and forwards to travel like a wave (the electron accounts for the electromagnetic behaviour and the vibratory movement entails a longitudinal wave phenomenon).

- Photons are electrical particles that act together to move as a wave front spreading out from a light source.
- Photons are particles. They have a specific width and when they move away from a source they are more or less frequent (more or less frequent gives rise to the concept of frequency – this provides the connection to the wave model).
- Photons move through space in sinusoidal paths (the photon traces out a wave path).

Level 1 and 2 thinking about scientific models impress on the students that there should be only one true model for the nature of light. Either photons or light waves actually exist (Level 1) or because one can gain direct access to reality, the best model is one that incorporates both particle and wave ideas. What students need to understand is that one cannot get direct access to reality – we do not know exactly what light is. However, scientists have constructed two different ideas, waves and particles. The representation of these ideas gives waves and photons – they are merely theoretical entities that do not actually exist.

The teaching of physical optics with quantum ideas usually occurs at the end of Year 12. This is usually a very busy time in terms of students busily preparing for examinations. Therefore, there exists little time to discuss the nature and function of scientific models in addition to fully exploring the scientific models of the nature of light. However, the following two activities (**Appendix 3** and **Appendix 4**) can be useful, particularly if pressed for time in completing Unit 4 on time. **Appendix 3** elicits the students' ideas about the nature of light. This is best done before you begin the Year 12 optics topic. **Appendix 4** is a checklist that the students fill out over the period of the Year 12 teaching of optics.

In **Appendix 3** the students are presented with three models. All use the concept of a 'ray' in some way. From these three models the students match a preferred model to a phenomenon they have already encountered in Year 11. There should be no right or wrong models. When discussing the preferred models you will find which students lean more to wave ideas or more to particle ideas. Those with a mixture tend to have a more scientific view about the nature of light – that is, one can use wave ideas to explain some phenomena and particle ideas for other phenomena. From this initial activity the students build up their own model for the nature of light. They can then use this model when completing the checklist (**Appendix 4**). In **Appendix 4** the students are given the sheet very early in the topic. As each new phenomenon is discussed they can tick of the models that can explain it. The listing of phenomena is in no particular order. One may well start with a blank table and fill it in as discussions arise.

The students find that the wave and particle models are successful in explaining a number of phenomena (usually more than the students' own model) but that no model explains all phenomena. The emphasis is that after the Year 12 optics topic the students should be comfortable in switching from one model to another (including their own) knowing that they will never know what light actually is but have various models to explain it.

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Appendix 1

Items in a Questionnaire on Models in Physics and Student Teacher Responses

The survey was conducted in universities in South Africa on 196 Higher Education Diploma students studying to be physical science teachers (Smit & Finegold 1995, p. 624-5)

	Statement	**Correct %**	**Incorrect %**	**Unsure %**
1	All models are creations of the human intellect.	59	13	28
2	All models are representations. Some, like drawings on paper, are purely visual, others made of material like plastic, wood, polystyrene, metal etc. can be seen and felt.	51	11	38
3	Any representation that one makes of an object of a structure or a process is called a model.	47	12	41
4	Models exist in nature	53	32	15
5	All models are mental images (i.e. models only exist in the human mind)	51	23	16
6	Models are aids that are used to obtain knowledge of nature.	25	11	64
7	A model always provides a complete description of the object, structure, or process in nature that it models.	64	15	21
8	This statement refers to the origin of models: a model is formulated using facts obtained through experiment and/or observation.	53	7	40
9	The term model and theory are synonymous.	6	37	57
10	The only function of models in science is in teaching.	49	26	25
11	Models are of a temporary nature. Scientists use a model for a time, but as a consequence of the increase of scientific knowledge the model becomes obsolete or useless and is either adapted or replaced by another model.	62	9	29
12	A scientist always has more knowledge of an object, process or structure than is represented by the model itself.	50	26	24
13	An important function of any model is to describe something (an object or a structure or a process) in nature.	64	5	31
14	Models play an important role in the explanation of phenomena.	52	6	42
15	Models can be used to predict phenomena structures or processes that had not been observed before.	50	20	30
Optics Statements				
16	Light rays occur in nature.	13	84	3
17	Light beams occur in nature.	76	13	11
18	Light is electromagnetic waves.	22	78	11
19	Light is propagation of particles.	14	77	9
20	Light is either a wave phenomenon or a particle phenomenon	50	38	12
21	Light possesses certain properties of transverse waves.	74	8	18
22	Light possesses certain properties of moving particles.	87	6	7
23	The wave and particle models are not applied simultaneously to explain a particular optical phenomenon.	53	35	22
A number of optical phenomena are listed below. Write the name of a model or models, which can be used to explain or describe each phenomenon.				
25	Photoelectric effect	25	75	
26	Interference	33	67	
27	Diffraction	30	70	
28	Polarisation	29	71	
29	Image formation by lenses	20	80	
30	Image formation by mirrors	19	81	

The alternative conceptions found in the study that dealt specifically with optics are listed as:

1. No distinction is made, in the case of the ray model, between the model which constitutes the ray and reality as light beams. This conception was also found in secondary school students in a studies undertaken by Goldberg and McDermott (1987) and Galili, Bendall and Goldberg (1993).

2. The wave and particle models of light are seen as one model. This was seen by Smit as a consequence of the conception that models are seen as portrayals of entities in nature and is evidence of what Grosslight et al (1991) described as a Level 1 understanding of models. There were three mental images associated with the representation of light that were identified. The first one was where the students saw light as wave packets. The second representation views light as a transverse wave motion where this motion propagates in particles. The third representation has light as a hybridisation of the wave and particle models so that the trajectory of the photon is not a straight line but maps out a transverse wave.

Appendix 2

Survey on Models

This questionnaire asks questions about your understanding of the term 'model'.

1. What comes to mind when you hear the word 'model' ?

- The idea of something which approximates or provides an explanation of a more complex process etc.
- A scaled down replica of a full sized objet, a toy, a beautiful female, any sought of replica which acts like the real thing.
- A smaller scale representation of an object.
- Something on display, or used to represent something.
- Something that demonstrates or represents an experiment or a real life situation in a smaller or simpler way.
- Something that is a scaled down version of something else.
- It is something that explains ideas better.
- Women, toys, physics examples eg a model for sound waves.
- Something on display.
- Something used to explain theories or to see if the theory is true.
- Something used to show the concept of something, or to show how something works.

2. From the following list of items circle whether you believe the item is a model or not and provide a reason if you can.

	Item	**Type**	**Yes**	**No**	**Unsure**
1	An engineer's construction of a bridge out of match sticks	Scale	13	0	0
2	Elle McPherson	Standard	11	2	0
3	A scientific formula, like F = ma	Mathematical	2	6	5
4	Plastic spheres connected by rods that are found in a chemistry laboratory	Analogical	12	0	1
5	A Mercedes Benz toy car	Scale	9	3	1
6	Blueprint plans for a house	Diagrammatic	2	9	2
7	Water flowing in pipes as a representation of electric current in wires	Analogical	11	0	2
8	Graph with a line of 'best fit' showing how the bounce height of a basketball changes with the pressure inside the basketball.	Mathematical	1	6	6
9	Computer software used by weather forecasters	Mathematical	2	9	2
10	A chemical formula like NaCl	Mathematical	1	8	4
11	A person you admire and would like to be like in some way	Standard	8	3	2
12	Magnetic field lines around a magnet	Theoretical	5	6	2
13	Sound waves	Theoretical	4	6	3
14	A chart found in the biology classroom showing parts of the eye	Diagrammatic	3	6	4
15	Light rays	Theoretical	6	5	2

3. What would you describe what a model is to someone who didn't know what a model is ?

- Something that can be used to explain things by simplifying and visually representing them, or to predict or approximate something.
- A model is a simple picture of how something works, enabling us to understand how it works in real life.
- Think of something that relates to the real-life situation and babble on about that.
- A more simplistic way of showing what something looks and operates like, but usually on a smaller scale.
- A way of describing what something looks like by showing them a version of it (i.e. a smaller version), or relating something we know what looks like to something that works in a similar way.
- A model is something that is used to explain something in a clear, simple way, with a

somewhat cheaper way.

- A model is something that describes how something acts reacts and looks like.
- A model is something that copies the way a thing works but on a different scale.
- I would say a model is something that explains the theory a lot easier and helps you understand it.
- Something showing you what something is like, eg. a smaller version of a house.
- A model is something that has the same characteristics as the suspect. But it is easier to see these characteristics in the model.
- Something used to show the concept of something, or to show how something works.

4. Given that models are used in science

(i) What are they for?

- To provide concepts with simpler explanations.
- To replicate a real situation and show or help explain how it works.
- For students to understand how it works in real life.
- To predict what might happen in experiments.
- So a person can understand what is happening.
- To help people understand what is happening.
- To understand concepts in an easier way.
- To visually describe something to someone else.
- Help understand how things work/to produce something on a smaller scale.
- To explain the science of something.
- To show the structure of something larger or smaller.
- To explain things better that are too hard to study themselves.
- To show the concept for something.

(ii) Why would a scientist have a need to develop a model ?

- To predict or explain something.
- To replicate a real situation and show or help explain how it works.
- A model bridge, say, would be needed because he isn't going to go to the West Gate Bridge and do his experiments there.
- So he/she can find formulas, study the effect of variables on things etc.
- A simplistic way of showing something.
- To make things easier to describe what is occurring.
- To prove or show and experiment.
- To prove what he was saying was correct.
- Make sure calculations were correct and to see what should happen.
- For you to understand it and do problems that use that model.
- To show structures of atoms at a larger scale or a model of the universe on a smaller scale.
- Because the real thing is too small or too hard to study so they build a model.
- To back up his theories and explain something better.

(iii) Do you think scientists would ever have more than one model for the same thing?

- If different conditions could apply.
- Yes - but they would be slightly different - in the way it is carried out - and it's effectiveness.
- Yes. Most likely.
- I think that they probably would.
- Yes.
- Probably until they sorted out which one is better.
- Yes, to prove something with confidence.
- Depends on which way they look at the situation.
- Yes as it may be put in different circumstances.
- I don't know probably.
- Yes.

(iv) Would a scientist ever change a model ? Why ?

- If other factors were considered or boundaries were extended.

- Yes if it works better or has some positive features.
- Yes. If a new discovery is found which may make the current formula untrue. So changes need to be made to the model.
- Maybe. Depends whether it benefits a real-life situation.
- Yes, because if more knowledge is gained about the model then it would need to be changed.
- Yes, because they could find out that it doesn't work like the model.
- Yes if the students did not see the relationship.
- Yes, because it might be wrong.
- Yes, if a variable wasn't present or to improve the model.
- Maybe, because they might know a better one.
- I don't know.
- Yes because the first model may not work for all cases.

Appendix 3

Models of Light

How would you describe a 'ray'?

____

____

In thinking about the nature of light researchers asked secondary school students to draw pictorial representations (models) that he/she used to explain various phenomena of light they had studied. The three student models, shown pictorially below, are described as:

Model 1

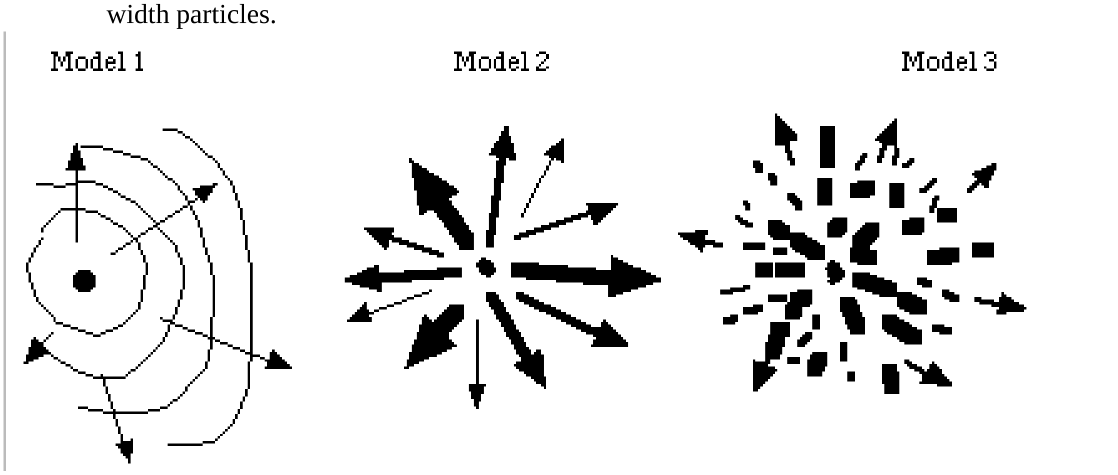
Light travels out from a source like water waves in all directions from a central point. The arrows are rays and only point in the direction the waves are moving. To explain refraction one side of the wave hits the denser material first and slows down. Different colours of light are characterised by waves of different wavelengths.

Model 2

Light travels out from a source like thin beams of continuous material we call rays. To explain refraction one side of the ray hits the denser material and slows down swinging the whole ray into a different direction. Different colours of light are characterised by rays of different width.

Model 3

Light travels out from a source like particles in all directions where the particles make up what we call rays. To explain refraction one side of the particle hits the denser material and slows down swinging the particle in a different direction. Different colours of light are characterised by different width particles.



For each of the following phenomena select which student model you think best suits the phenomena of light of light given. If you think of another model that helps you explain the phenomenon then explain this.

1. *Light spreads out in all directions from a small light source.*
My preferred model is__________ because______________________________________

____

____

Do you think any of the other models could explain the given phenomenon? Please explain

____

____

2. *Light spreads out in all directions from each point on a light source.*
My preferred model is__________ because _____________________________________

____

____

Do you think any of the other models could explain the given phenomenon? Please explain____

____

3. *Light can change direction in going from air into glass. Light slows down in the glass.*
My preferred model is__________ because______________________________________

____

____

Do you think any of the other models could explain the given phenomenon? Please explain

____

____

4. *White light is composed of different colours.*
My preferred model is__________ because _____________________________________

____

____

Do you think any of the other models could explain the given phenomenon? Please explain

____

____

Appendix 4

Models of Light Checklist

Phenomenon	Wave Model	Particle Model	Personal Model
Light travels in straight lines.			
Light beams cross without disturbance.			
Light keeps travelling until it hits something.			
At a transparent surface light changes speed.			
At a transparent surface light partially reflects and partially transmits.			
Snell's Law is obeyed.			
Light slower in water than air.			
Light is composed of the colours ROYGBV			
Light reflects according to the rule i = r.			
Light comes in different energies.			
Light diffracts.			
Light produces interference effects.			
Light initiates the photoelectric effect.			
Light has pressure.			
Light is polarized.			