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Enhancing student teachers' epistemological beliefs about models and conceptual understanding through a model-based inquiry process

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ABSTRACT

In this study we present the structure and implementation of a model-based inquiry teaching–learning sequence (TLS) integrating expressive, experimental and exploratory modelling pedagogies in a cyclic manner, with the aim of enhancing primary education student teachers' epistemological beliefs about the aspects, nature, purpose and change of models as well as their conceptual understanding of light phenomena related to properties of optical fibres. The subjects were 16 prospective primary teachers involved in modelling activities, employing both hands-on experiments and computer modelling activities, based on the application of the ray model. Student teachers were tested before and after the implementation of the TLS by semi-structured interviews and a written questionnaire. Results show that before the TLS most students adopted epistemologically naïve realistic beliefs about models, whereas after the TLS there was an overall significant transition from naïve to more sophisticated epistemological beliefs, as well as significant improvements in their conceptual knowledge about light phenomena. Nevertheless, the relation between epistemological beliefs and conceptual understanding seems to be aspect-dependent, so our evidence suggests that more educational effort is required in order to establish a coherent relationship between them.

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Model-based inquiry; cyclic modelling; epistemological beliefs; conceptual understanding

Introduction

Science educators and researchers have acknowledged the prominent part models play in science education and the role of modelling as a key process in teaching and learning science (Gilbert & Boulter, 2000; Halloun, 2006; Justi & Gilbert, 2003). A model is a set of representations, rules and reasoning structures that allows one to generate predictions and explanations (Schwarz & White, 2005). A model, in this sense of the term, is considered to be a non-unique partial representation of an object, an event, a process or an idea that can be changed, used for enhancing visualization, as a means of supporting creativity and fostering understanding, and as a tool for expressing scientific theories in a form

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that can be used for purposes such as prediction and explanation (Justi & Gilbert, 2003; Petridou, Psillos, Hatzikraniotis, & Kallery, 2013). Moreover, models could be considered as research tools which can advance students' model-based reasoning (Nersessian, 2008) and as effective pedagogical tools for teaching scientific literacy (Halloun, 2006). Model-based inquiry is intended to enhance learners' epistemological understanding about models and modelling and the development of their conceptual scientific knowledge (Schwarz et al., 2009; Windschitl, Thompson, & Braaten, 2008). Students' involvement in modelling practices concerning model use in science may enhance their epistemological awareness of the nature and purpose of scientific models (Petridou, Psillos, Hatzikraniotis, & Viiri, 2009).

There are researchers who have emphasized the diverse ways modelling is practised in science classrooms. Mellar and Bliss (1994) distinguished between *expressive modelling*, where students engage in the construction of models in order to express and test their own ideas about the world, and *exploratory modelling*, where students have to explore and test the ready-made models with which they are stimulated to interact. In the first case, where students have to express and test their own ideas about the world, the problem becomes how to develop those ideas towards the scientific models to be taught, while in the second, that of exploring and testing a given model, the question is how to connect this properly to students' ideas about the world. van Joolingen (2004) considers expressive and exploratory modelling as two ends of a continuum, with more forms of modelling in between, and proposes the term *inquiry modelling*, where students form hypotheses and predictions from models and test them through experimenting with phenomena. Expanding van Joolingen's (2004) pedagogical conceptualizations for modelling, Oh and Oh (2011) suggest two more modelling approaches, referred to by them as modelling pedagogies: *evaluative modelling*, where students compare alternative models addressing the same phenomenon or problem, assess their merits and limitations, and select the most appropriate one(s) to explain the phenomenon or solve the problem, and *cyclic modelling*, where students are engaged in ongoing processes of developing, evaluating and improving models to complete rather long science projects. Campbell, Oh, and Neilson (2013) propose cyclic modelling as the major modelling pedagogy, which integrates four modelling pedagogies: *exploratory, expressive, experimental* (referred as *inquiry modelling*, originally in van Joolingen, 2004) and *evaluative*, as basic components which are not considered exclusive to each other, meaning that two or more can be combined to address a single science topic. A research review of modelling pedagogies conducted by Campbell, Maughn, and Zuwallack (2015) found that *expressive modelling* was the most frequently used and that sequences which connected *exploratory* and *experimental modelling* were the most frequently observed combination of modelling pedagogies, while *expressive* and *exploratory* modelling pedagogies were most often supported or mediated by technology.

Epistemological beliefs (or personal epistemology) are conceived by cognitive psychologists as personal beliefs about epistemology, that is, beliefs about the nature, source and justification of scientific knowledge (Hofer & Pintrich, 1997). From this perspective, epistemological beliefs about models and modelling could be considered as a subset of epistemological beliefs about knowledge and knowing. There is a strong argument that epistemological beliefs are metacognitively oriented (Bromme, Pieschl, & Stahl, 2010; Hofer & Sinatra, 2010) and can be enhanced through implicit and/or explicit instruction

(Holliday, 2006). Implicit instruction occurs when the teacher prompts metacognition without explicitly acknowledging or discussing it, whereas explicit instruction takes place when the teacher prompts and explains or discusses the benefits of metacognition (Kistner et al., 2010). Considering the enhancement of epistemological beliefs about nature of science (NOS), the implicit approach contends that by doing science students will come to understand epistemological aspects lacking explicit references to NOS aspects, whereas the explicit – reflective approach of NOS recognizes that the goal of improving students' views of the scientific endeavour should be carefully planned for and structured, instead of being anticipated as a side effect or secondary instructional product (Hodson, 2014). Barab, Hay, Barnett, and Squire (2001) argue that students' beliefs about models may be improved through appropriate supportive activities that serve as a scaffold enabling students to dialogue with their peers, encouraging epistemological beliefs about scientific models and modelling. In the above study, students experienced model use but there was no explicit theoretical teaching about scientific models, which suggests that certain learning contexts scaffold or foster learner's epistemological beliefs so that learners no longer need epistemological knowledge to successfully engage in the learning activity. However, Schwarz and White (2005) implemented an inquiry modelling approach using an explicit metacognitive instruction about models and modelling. The results indicated that engaging students in simply developing models is not enough to develop epistemological awareness of models and modelling, and explicit instruction about models and modelling need to be added in order to develop not only scientific models but also epistemological awareness about their nature and purpose.

There are a fair number of studies that have examined the relationship between students' epistemological beliefs about models and their relationship to content learning. For example, using correlational techniques Smith, Maclin, Houghton, and Hennessey (2000) and Sins, Savelsbergh, van Joolingen, and van Hout-Wolters (2009) both showed that advanced epistemological beliefs may facilitate better learning of science content and processes. The results from other studies that have investigated the relation of epistemological beliefs about the nature of models to science learning and understanding were not consistently positive (Gobert & Discenna, 1997; Gobert et al., 2011). The above studies show that model-based inquiry is important for promoting students' conceptual understanding and epistemological beliefs concerning models and modelling, but how this happens needs further investigation.

Research methods to reveal epistemological beliefs about models usually vary among related studies, and various frameworks have been provided for analysing epistemological beliefs about models and modelling (Crawford & Cullin, 2005; Grünkorn, Upmeier zu Belzen, & Krüger, 2014; Justi & Gilbert, 2003). For example, recently Grünkorn et al. (2014) provide an empirically tested theoretical framework integrating research findings comprising five aspects: *nature of models*, *multiple models*, *purpose of models*, *testing models* and *changing models*, as a common basis for future science education research. Three levels may be distinguished in each aspect, naïve, intermediate and sophisticated. Although a consensus for the naïve and sophisticated levels of these different aspects of epistemological beliefs has been well documented by scholars, there is an overall confusion for the confirmative description of the 'intermediate' level(s) between the two ends of this continuum. These 'intermediate' levels have been occasionally defined by authors as *pre-scientific* and *emerging scientific* (Crawford & Cullin, 2005) or *models as media* (Krell & Dirk Krüger, 2015). The problem arises when scholars have to decide which elements or attributes override the naïve level or what more is needed for a sophisticated level to be reached. Besides, regarding the assessment of these different aspects of epistemological beliefs research provides ambiguous answers to the question of whether understanding models and modelling should be regarded as global or aspect-dependent (Krell, Upmeier zu Belzen, & Krüger, 2014).

Moving to the conceptual level and the field of optics, light is conceived by students – and even by prospective teachers – as a material entity located in the space between its source and its effect, as a 'sea of light' that fills space and that does not travel (Galili & Hazan, 2000). Research has shown that it is difficult for students to overcome these intuitive ideas and to develop a consistent descriptive and explanatory model for light propagation, covering rectilinear propagation, absorption, reflection and refraction (Heywood, 2005). Understanding the nature of light as an entity propagating in space and the role of reflected and diffused light in seeing is of prime importance in understanding such other phenomena as image formation, daylight and how we see things (Andersson & Bach, 2005). Studies of students' reasoning about optical phenomena have consistently shown that existing practices in the teaching of optics do not lead to satisfactory application of geometrical models and have pinpointed the deficiency in students' ability to draw and interpret ray diagrams for explaining and predicting optical phenomena (Langley, Ronen, & Eylon, 1997).

Within this context, the present study draws on the application of a research-based teaching–learning sequence (TLS) in which student teachers were engaged in cyclic modelling activities with the ray model in optics to explain light phenomena and its impact on their epistemological beliefs about the nature, purpose and change of models and their conceptual understanding in the field of optics. The research questions were:

(1) Did the student teachers who followed the TLS enhance their epistemological beliefs concerning the nature, purpose and change of models?
(2) Did the student teachers who followed the TLS improve their conceptual understanding of optics phenomena?
(3) Is there any relation between the student teachers' conceptual understanding and their epistemological beliefs concerning the nature, purpose and change of models?

The teaching–learning sequence

An inquiry-based TLS about the optical properties of materials employing both hands-on experiments and computer model activities was originally developed in Italy (Testa, Lombardi, Monroy, & Sassi, 2011). A TLS is '… both an interventional research activity and a product, usually lasting a few weeks, comprising well-validated teaching-learning activities empirically adapted to student reasoning and often including well-documented teaching suggestions and expected student reactions' (Psillos, 2015 p. 1036). The TLS lasted for 10 hours, was structured in five sessions over a period of about 1 month and was addressed to 15/16-year-old students. It was context-based, and designed to introduce upper secondary school students to the study of the optical properties of materials and geometric optics.

The TLS implements an innovative teaching approach in which the behaviour of the chosen application, that is, the optical fibre, is iteratively explored and modelled by means of a combination of hands-on experiments and computer simulations. One innovative feature was that it aimed at motivating secondary students to investigate a specific behaviour of a techno-object (optical fibre) and study under what conditions its behaviour can be modelled. In addition, refraction of light was treated before reflection, whereas the reverse is more common in curricula. Exemplar experiments included observation of the pathway of laser beams in water jets and during refraction and total internal reflection phenomena in a water tank. Digital photos of experiments were imported into and treated in the Cabrì Géomètre microworld. The ray model was introduced during the virtual experiments in the Cabrì Géomètre modelling environment. No explicit instruction was provided regarding the nature and purpose of the ray model. Details of the TLS and its original iterative development have been published elsewhere (Testa et al., 2011; Testa & Monroy, 2016).

This original TLS was revised and adapted to the Greek context by a working group of researchers and experienced teachers. Adaptation took place through an iterative process involving cycles of design and classroom implementation in order to empirically adapt the revised TLS to the students' knowledge and reasoning and contextual factors (Psillos, 2015, p. 1036; Psillos & Kariotoglou, 2016). The adapted TLS was structured in 6 sessions, lasted about 12 hours, and was applied to primary education student teachers, called hereafter students, as detailed further on. In the adapted inquiry-based TLS basic aspects of the content were retained, while a cyclic modelling approach was functionally integrated in order to prompt students to express their ideas of how light behaves, apply the ray model using segments, angles and geometrical rules, evaluate their expressed models during experimentation and refine their initial beliefs. *Expressive, experimental* and *exploratory modelling* activities made up for the *cyclic modelling* and were combined all through the TLS. The cyclic modelling approach was implemented through three successive phases comprising the (i) introduction, (ii) revision and (iii) expansion of the model.

In the first phase, students were engaged in *expressive modelling* activities, where they were looking for patterns and regularities and for appropriate ways to represent the ray model in order to interpret and predict light behaviour during qualitative experiments with light sources and common objects, which elicited their initial mental models about light. For example, they drew segments representing the existence and rectilinear propagation of light in space after hands-on activities with a torch pointing at a wall of their classroom in which particles of chalk dust were thrown into the air in between. Next, in an *exploratory modelling* mode, students investigated the question of 'how we see', using a flash simulation of a cyclist seeing a coin illuminated by a streetlamp at night (see Figure 1). The Flash simulation is part of the OptiLab Learning Environment (OLE), which includes virtual labs in Geometrical and Physical Optics as well as flash simulations, a model space and measurement tools, and was used to enrich the activities of the adapted TLS. A detailed presentation of OLE is published elsewhere (Hatzikraniotis, Bisdikian, Barbas, & Psillos, 2007). Users of the simulation can turn the light on and off, observe the light beams coming from the light source reflecting off the coin and reaching the cyclist's eye, and realizing that while there are a lot of beams of light around a source, they had the opportunity to observe only the one that helps to explain a single phenomenon. It was expected that by modelling the path of light students would become able to

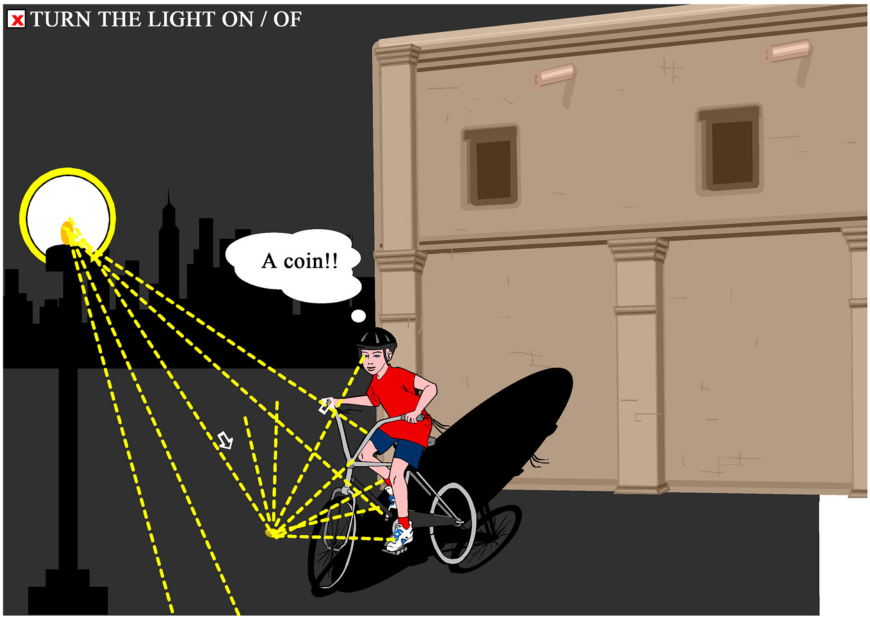

Figure 1. The Flash simulation of how we see.

understand that we can see objects because emitted or diffused light from them enters our eyes, and should become aware that this process constitutes an abstraction from reality for the achievement of a goal.

In the second phase, an *experimental modelling* procedure took place, where a link between phenomena and model was pursued, aiming at enabling students to become aware of the advantages and limitations of applying the ray model to optical phenomena. Students were engaged in applying and testing the ray model, as well as in reflecting on the applicability of that model. Students conducted qualitative experiments with optical fibres, optical fibre lamps, rubber tubes and fishing lines, and evaluated the initial ray model during activities interpreting the light guide in optical fibres. As a consequence, when the students tried to represent the path of light in optical fibres, they realized that the ray model does not satisfy all requirements and see its strong and weak points. Furthermore, when the students applied the ray model to predict light path before the water jet experiment and observe the path of light, they realized that more empirical evidence was needed for the light guide to be modelled. They thereupon attempted a more coherent linking of the light beam (laser beam) with the ray model through drawings made during the water tank and laser experiment. The students observed refraction and total internal reflection phenomena in the water tank and laser experiment and applied the ray model to describe and interpret refraction and total reflection phenomena. More specifically, the students put smoke in the air and milk in the water to observe the path of the laser beam in hands-on experiments, draw segments in order to describe the path of light in various situations and establish the features of the model across various phenomena (e.g. rectilinear propagation, internal reflection, refraction, etc.). Modelling the path of light by applying the ray model allowed the students to externalize and reflect on evidence and experiences and realize that light can be deviated from its rectilinear path.

Finally, the third phase involves the refinement and extension of the optical ray model for the interpretation and mathematical expression of more complex phenomena relating to the properties of optical fibres. The students engaged in *expressive* and *exploratory modelling* activities expanded the interpretive and predictive power of the ray model, taking into account additional evidence from activities in the Cabrì Géomètre and OLE virtual environment. Specifically, adopting an *expressive modelling* approach the students imported digital photos from experiments into the Cabrì modelling environment, traced rays, conducted measurements, interpreted regularities, formulated laws, and defined refraction index and critical angle of internal reflection (Testa & Monroy, 2016). In addition, exploratory modelling activities were applied in which Cabrì simulations for controlling variables affecting refraction index and critical angle and OLE simulations for interpreting refraction based on Fermat's principle of least time and different speeds of light were introduced. Simulation-based *exploratory modelling* activities were combined with *expressive* ones, focusing students' attention on particular aspects of phenomena and providing an opportunity to realize the reliance of models on empirical data for making conclusions and developing interpretations.

This cyclic modelling approach assumes that introducing the ray model for interpreting and predicting the underlying mechanism of light phenomena leads students to engage in a different kind of thinking, shifting from relation-based to model-based thinking. The cyclic modelling approach was applied with no direct reference to the nature and purpose of scientific models. This means that, although students created, used, revised and refined models, no explicit instruction was provided concerning the role of models in endorsing the products of scientific inquiry.

Method

Participants

A total of 16 prospective teachers, students at the Pedagogical Academy for Muslim Minority Teachers at Thessaloniki, attended this innovative, roughly 12-hour TLS, over a period of about 1 and a half months (2 hours a week). These students were bilingual (Greek and Turkish), with Turkish as their mother tongue, or trilingual (Greek, Pomak – a dialect – and Turkish), with Pomak as their mother tongue, and were trained to teach in the schools of the Muslim minority in Thrace. All of them had taken basic science courses in Greek upper secondary schools but opted not to choose science and mathematics as their primary subjects for the national exams. Geometrical Optics was treated in an obligatory physics course in compulsory Lower High School (9th grade) and to some extent in Upper High School (12th grade) as part of the general education physics course. The scientific knowledge of these students was about the level of 9th grade, according to their experienced science professors. Moreover, these students were unfamiliar with modelling activities. Students' participation was part of their typical obligations for the first semester's science education course. No extra credits or bonus were given to them for supporting motivation.

Instrumentation

Interviews about models. Three aspects of models, namely nature, purpose and change, were chosen from the five aspects framework proposed by Grünkorn et al. (2014) as a basis for evaluating epistemological beliefs about models. The *multiple models* aspect was excluded from our analysis, because only the ray model was treated in TLS and the students had not experienced any different model in practice (i.e. physics models). Also, the *testing models* aspect was embedded into the *change of models* aspect. In order to elicit student teachers' beliefs about models and modelling, semi-structured interviews were conducted with all the students before and after the TLS, in order to reveal their ideas about three aspects of models through appropriate prompts, such as:

> *Nature of a model*: (e.g. 'What do you believe that a scientific model is?', and 'How accurately should a scientific model represent the reality?'
> *Purpose of a model*: (e.g. 'What could be the purpose of a scientific model?', and 'How it might be useful?')
> *Change of a model*: (e.g. 'Is it possible for a scientific model to change? Yes or no? Why?' and 'How could this happen?')

The purpose of the interview was for clarification and to provide an opportunity for in-depth probing into participants' understandings. Interviews were conducted before and after the TLS in a quiet room in the school and lasted approximately 15 minutes for each participant. The interviews were tape-recorded, coded into interview protocols and qualitatively analysed.

Questionnaire about light and vision. The students' conceptual understanding was also tested before and after the implementation of the TLS by means of a written questionnaire comprising five tasks focusing on light phenomena related to the properties of optical fibres:

> Task 1. Vision – Students had to say whether they can see in absolute darkness and justify their answers.
> Task 2. Vision – Students had to choose among four options which depict how we see in a room lighted by an artificial light source, and explain briefly why.
> Task 3. Diffused reflection on rough surfaces – Students had to explain why there is natural light in a room.
> Task 4. Reflection on a plane mirror – Students had to choose which objects in front of a mirror the observer is able to see from an angle, and explain why.
> Task 5. Coexistence of reflection and refraction – Students had to choose the correct answer, from multiple choices, to the question of what happens when light hits a still water surface, and justify their choices.

The questionnaire was administered to the students in their classroom before and after the implementation of the TLS, in the presence of their teacher and the researcher, and took about 45 minutes to complete. The students were asked to perform the tasks and justify their answers in writing and drawing, after the necessary instructions and clarifications had been given to them.

Data analysis

Levels of epistemological beliefs about models. A 3-level coding scheme was used to analyse the interview protocols examining students' epistemological beliefs concerning the nature, purpose and change of models. The interview protocols were analysed for each aspect of the models separately, in order to reveal the three levels of the students' epistemological beliefs (1 = naive, 2 = intermediate, 3 = sophisticated). Based on the conjoint theoretical framework portrayed and evaluated by Grünkorn et al. (2014), the authors outline the levels and the description of the coding scheme. Table 1 shows the classification of students' epistemological beliefs concerning the nature, purpose and change of models and determines the level of impact with the respective references. Each cell contains the characterization and description of the level for nature, purpose and change plus extracts from students' replies.

In particular, this coding scheme adopts an aspect-dependent framework, whereas level II referred as 'intermediate' level, and the two extreme levels (Levels I and III, respectively) were defined as the naïve and the sophisticated level. Our evidence suggests that 'intermediate' level (Level II) students understand models as idealized and/or simplified representations of the original but have not still moved from the realistic belief about nature of models. For instance, in Level II, although students overcome the belief that models are exact replicas of the original in order to depict or explain it better, the notion that a model has to be closer to and more accurate than the original has not faded away. Besides, students consider models more as interpretative tools rather than as generative of research and instructional tools that could change in some details in order to become more teachable and understandable by students. All these beliefs demonstrate that in the 'intermediate' level students have made considerable progress towards a more sophisticated and elaborated understanding of models but do not yet consider them as abstract and theoretical tools for scientific research.

Two independent coders, that is, one in-service science teacher with a PhD in science education, and a university professor who had published on students' understanding of models, were invited to examine the patterns identified and code the data based on the coding scheme previously outlined by the authors. Inter-coder agreement (Cohen's *kappa*) reached $k = ..93$, .91 and .87 for nature, purpose and change, respectively, which is regarded as excellent. Next, in order to resolve any differences between the two coders, they discussed the data throughout the case until an agreement was reached.

Rubrics of conceptual understanding questionnaire. The students' replies in each task were classified at levels from 0 to 3 based on their conceptions concerning light phenomena. The coding scheme took advantage of the analysis in science education literature concerning the main alternative conceptions held by students about vision and geometrical optics (Galili & Hazan, 2000; Heywood, 2005; Langley et al., 1997; Singh & Butler, 1990). More specifically, concerning the intuitive conceptions about how we see in the first and second tasks, research has shown that students consider the eye as an active agent that either reflects or emits a light beam that finally reaches the object, or, in other cases, that there is no direct connection between eye and object, provided it is luminous (Heywood, 2005). In the third task, focusing on interpreting the existence of light in a room, students think that light fills the space 'like a sea' and does not propagate, remaining near the source; only for a minority of students does light propagate along a rectilinear path (Galili & Hazan, 2000). With regard to the fourth task, students think that mirrors reflect all the incoming light and that the image is resident on the mirror or just behind it, and they have

Table 1. Levels of epistemological beliefs concerning the nature, purpose and change of models.

	Levels' categorization and characterization	Student teachers' replies
Nature of models	*Level 1* *Models as exact replicas of the original* • The model is an accurate representation of an object • A prototype or a scientific artefact • A general idea that does not characterize a model	'which can depict something else, for example the earth' (ST2) '[…] is an object made by scientists' (ST7) 'something related to scientific issues' (ST4)
	Level 2 *Model as an idealized representation of the original* • The models is a simplified representation of a phenomenon, a process or a system • An interpretative tool for understanding the original	'the representation of some phenomena without corresponding to reality' (ST6) 'something scientists study and explain to others' (ST12)
	Level 3 *Models as abstract communicative research tools* • The model is an abstract representation of a phenomenon, process, system, idea or theory • A research tool for hypothesis testing, guiding and communicating our ideas or theories	'an idea or a theory about how something could happen to something' (ST6) 'something for guiding our ideas in order to draw conclusions about a phenomenon or a process in science' (ST11)
Purpose of models	*Level 1* *Representing the original* • To represent an object • To clarify an issue under study • To make our life better	'to see something which we can't see in the real world' (ST1) 'to represent the reality' (ST10) 'to make our lives more comfortable' (ST7)
	Level 2 *Explaining the original* • To interpret a phenomenon for didactical reasons • To explain something	'to explain to other people what is happening, the rationale of this' (ST12) 'to be used for better exploration of a phenomenon' (ST16)
	Level 3 *Predicting phenomena* • As a tool for formulating a hypothesis and construction of scientific knowledge • As a scientific communicative tool	'to make generalizations or assumptions for a phenomenon' (ST11) 'to acquire a common understanding about these things' (ST6)
Change of models	*Level 1* *The model cannot be changed* • Because it is an accurate representation of the original • Because it is a scientific artefact	'No, because it represents the reality' (ST10) 'No, because it has been made by a scientist' (ST7)
	Level 2 *The model could be changed somehow* • To represent or explain better the original • To add something for to be more accurate and more detailed	'We could add something to be more understandable' (ST16) 'to be more contemporary, more analytic, more detailed' (ST8)
	Level 3 *The model is temporary in its nature* • If it is not in agreement with observational data from the real world. • A scientist would change a model in order to help carry out his research.	'It could be changed if new or false evidence has been found' (ST3) 'It could be changed if a new theory or idea arises' (ST6)

certain difficulties with image construction via the 'ray diagram', regarding rays as real entities (Langley et al., 1997). Considering the fifth task, students fail to recognize reflection and refraction as due to the interaction of light with matter and think they are two mutually exclusive phenomena: when there is reflection no refraction can take place, and *vice versa* (Singh & Butler, 1990).

When coding the students' conceptual understanding about the light phenomena represented by each task, results from the above relevant research were used to confirm the feasibility of the categorization scheme. Categorizations were further validated through students' drawings applying the ray model to tasks and explanations. Rubrics were formed separately for each task, taking into account students' perception of the applicability of the ray model with regard to their ideas about light phenomena produced under its impact:

1. No application of the ray model, which leads to the potential dominance of intuitive ideas about light.
2. Limited or false application of the ray model, followed by the appearance of synthetic mental models.
3. Correct application of the ray model and formulation of scientific interpretations.

Incomplete replies and nil answers were scored 0. Rubrics and some illustrative answers for each task are cited in Table 2.

The same two independent coders who had categorized the levels of the epistemological beliefs undertook to rate cognitive performance with regard to each task, reaching excellent inter-coder agreement ($k = .84$ to $.91$). Next, the coders discussed the data of the cases where agreement failed until any discrepancy was resolved.

Results

The data from interviews and questionnaires were treated in a qualitative and quantitative manner. For the quantitative analysis, the non-parametric Wilcoxon signed-rank test was applied and effect size was calculated with regard to both the epistemological and the conceptual data. The quantitative analysis described used non-parametric tests, because the data were qualitative and the quantification could only result in rank-ordering score. Moreover, effect sizes (Cohen's r) were calculated to describe the data in a sample and also potentially estimate the corresponding population parameter. Conventional definitions of effect size have been offered by Cohen (1988, p. 83), as follows: small $r = .10$, medium $r = .30$ and large $r = .50$.

Students' epistemological beliefs concerning models

Analysis of the interview protocols showed that before the TLS most students (15, 14 and 12 out of 16 for nature, purpose and change, respectively) held the naive belief (Level I), as extracted from Table 3. For example, they believed that a scientific model represents an object or a replica of an object that is made by scientists, or something related to scientific issues, that its function is the accurate representation of an object or phenomenon in order to see something that we cannot see in the real

Table 2. Rubrics and illustrative answers for conceptual understanding

	Model-based interpretation	References
Task 1	*Score 1* The eye as an active agent – No connection between objects and light	'Human eyes don't function in absolute darkness'
	Score 2 Reference to rectilinear propagation of light – Establishing an initial connection between light and objects	'We can't see in absolute darkness because there is no light coming'
	Score 3 Correct interpretation of mechanism of vision – Reference to diffuse reflection on objects	'Because there aren't light beams to hit the objects and then some of them reach our eyes'
Task 2	*Score 1* The eye as an active agent – No connection between objects and light	'We will see because the light hits us and the object the same'
	Score 2 Reference to rectilinear propagation of light – Establishing an initial connection between light and objects	'We can see because light hits the book'
	Score 3 Correct interpretation of mechanism of vision – Reference to diffuse reflection on objects	'The correct mechanism is depicted by picture b, because light represented as light beams bumped into the object and arrived at our eyes'
Task 3	Score 1 The 'sea of light' model	'There is natural light, because light can be everywhere'
	Score 2 Reference to rectilinear propagation of light	'One of the properties of light is passing through clear objects, like window glass'
	Score 3 Reference to diffuse reflection on objects	'Because light hit the objects and diffused in space'
Task 4	*Score 1* The 'holistic' model	'The observer will see all the items because the mirror can show him everything'
	Score 2 Light from objects is reflected by the mirror without taking into account the incident and reflected angles	'Because (objects b and c) are in front of the mirror and the observer can see in the mirror'
	Score 3 Considering the equivalence of incident and reflected angle (Snell's law)	'He (the observer) will see items b and c because the incident and reflected angles must be the same'
Task 5	*Score 1* Light hits and comes back due to high density of water or water absorbs light	'Light returns to air because of dense water'
	Score 2 Light travels and deviates from its path (reflected or refracted)	'Light keeps on track, only deviating from its path in water'
	Score 3 Reference to coexistence of reflection and refraction	'Because the water's plane surface is like a mirror, and part of the light will be reflected'

world, and that it is unchangeable. The rest (1, 2 and 4 out of 16 for nature, purpose and change, respectively) formulated intermediate replies (Level II), stating, for example, that a scientific model is a representation of an object or an event made in order to interpret some phenomenon scientifically, that the purpose of a model is to interpret scientific phenomena and that it could be changed to make it more detailed. It is worth noting that before the TLS no students held the sophisticated belief of models. After implementation of the TLS, a considerable shift in students' epistemological beliefs is observed. Of those that before the TLS had performed at level I, 4 rose to level II and 1 to level III. However, several others still remained at level I (10, 9 and 7 out of 16 for nature, purpose and change, respectively, see Table 3). Applying the non-parametric Wilcoxon signed-rank test, statistically significant differences before and after the implementation of the TLS were identified, regarding the nature $Z = -2.33$, $p < .05$, purpose $Z = -2.33$, $p < .05$ and change $Z = -2.53$, $p < .05$ of models. The effect size estimated for nature $r = .41$, purpose $r = .41$ and change $r = .45$, calculations which denote a medium-effect size.

In order to gain insights into these results, we decided to proceed to qualitative analysis in order to be able to clarify the way different aspects of epistemological beliefs changed under the impact of the TLS (see Table 3). Notably, the four students (ST6, ST8, ST11 and ST14) who before the TLS were classified at level II concerning change did not achieve a similar score with regard to the nature and purpose of models. For example, ST8, who argued that 'a model could be changed in order to be more useful and understandable', was classified at level I concerning the nature of models because he believed that a model is 'a device, something designed by scientists', and at level I concerning their purpose, judging them intended 'to make our lives more comfortable' (see Table 3). The belief that models can change remains more plausible and reasonable to students after the TLS.

Overall, we noted that there was a significant improvement in students' epistemological beliefs after the TLS, although seven of them (ST1, ST4, ST5, ST7, ST9, ST13 and ST15) still adopted a consistent naïve realistic belief for all aspects examined. In addition, three students (ST8, ST14 and ST16) held a coherent 'intermediate' belief and two students (ST3 and ST6) adopted a clear sophisticated belief for all aspects examined, whereas the rest of the students formulated mixed-level beliefs, with three of them (ST2, ST10 and ST12) performing at levels I and II and one of them (ST11) at levels II and III. An example of a consistent level II performance is ST8, who initially expressed more advanced epistemological beliefs (level II) for the aspect of model change compared to the other two aspects of epistemological beliefs examined, and improved those concerning the nature and the purpose of models to level II as well after the impact of the TLS:

Researcher: What do you believe that a scientific model is?
Student teacher: A scientific model is something we use, trying to prove something with experiments, in order to understand it.

Table 3. Pre – post levels of epistemological beliefs and conceptual understanding scores.

	Epistemological beliefs			Conceptual understanding				
Student Teacher	*Nature*	*Purpose*	*Change*	*Task 1*	*Task 2*	*Task 3*	*Task 4*	*Task 5*
ST1	I – I	I – I	I – I	1 – 2	1 – 3	1 – 2	1 – 2	1 – 2
ST2	I – I	I – I	I – II	1 – 1	1 – 1	1 – 1	1 – 1	1 – 1
ST3	I – III	I – III	I – III	1 – 2	1 – 3	1 – 3	1 – 2	1 – 3
ST4	I – I	I – I	I – I	0 – 2	1 – 2	0 – 2	1 – 2	1 – 2
ST5	I – I	I – I	I – I	1 – 2	1 – 1	1 – 2	1 – 2	1 – 2
ST6	II – III	II – III	II – III	1 – 2	2 – 3	1 – 3	1 – 2	1 – 2
ST7	I – I	I – I	I – I	1 – 1	1 – 1	1 – 1	0 – 1	1 – 1
ST8	I – II	I – II	II – II	3 – 3	3 – 3	2 – 3	2 – 3	2 – 3
ST9	I – I	I – I	I – I	1 – 2	1 – 1	1 – 2	1 – 2	1 – 2
ST10	I – I	I – I	I – II	1 – 2	1 – 1	1 – 1	1 – 2	1 – 2
ST11	I – II	II – II	II – III	2 – 3	2 – 3	2 – 2	1 – 2	1 – 2
ST12	I – I	I – II	I – II	1 – 2	1 – 2	1 – 2	1 – 1	1 – 1
ST13	I – I	I – I	I – I	1 – 2	1 – 2	1 – 3	1 – 2	0 – 2
ST14	I – II	I – II	II – II	2 – 3	2 – 3	2 – 2	2 – 3	2 – 3
ST15	I – I	I – I	I – I	1 – 2	3 – 3	3 – 3	2 – 2	2 – 3
ST16	I – II	I – II	I – II	1 – 2	1 – 3	1 – 2	1 – 3	1 – 3

Researcher: Should a scientific model represent the reality?
Student teacher: It is not necessary, but it should represent it as best it can, in order to be understood by others.
Researcher: What could be the purpose of a scientific model?
Student teacher: To understand better a thing, a phenomenon.
Researcher: What else?
Student teacher: To understand that which is represented, and to understand all the same.
Researcher: Do you think that is possible for a scientific model to change?
Student teacher: Yes, it is possible, in order to prove something in a different way or to represent it in another way.

It is worth mentioning that of those students who performed at level II (ST6 for nature, ST6 and ST11 for purpose and ST6, ST8, ST11 and ST14 for change) before the TLS, only one (ST6), who consistently scored at level II for all aspects of models, improved his score after the TLS to level III for all aspects of models. As for the rest, who had been classified at level II before the TLS, they maintained the same level of epistemological beliefs, except for one (ST11) whose performance seemed to improve only in the case of model change, where he reached level III. As an example we cite the case of a student teacher (ST3) who made a considerable step towards improving his pre-TLS epistemological beliefs, moving from level I to level III, who held a realistic belief about all aspects of models:

Researcher: What do you believe that a scientific model is?
Student teacher: An object which explains something, which we could not observe in real life.
Researcher: Can you give me an example?
Student teacher: A globe or human anatomy model.
Researcher: How accurately should a scientific model represent the reality?
Student teacher: It has to look like the object which depict.
Researcher: What could be the purpose of a scientific model?
Student teacher: To depict something not observable in order to learn about it.
Researcher: Do you think that is possible for a scientific model to change?
Student teacher: No, because it represent the reality.

This student teacher reached the accepted sophisticated belief (Level III), perceiving, for example, a scientific model as an abstract and theoretical entity for guiding our ideas in order to draw conclusions about a phenomenon or process in science that its purpose is to test and evaluate ideas or to make generalizations or assumptions concerning a phenomenon, and that it can be changed if new or false evidence has been found:

Researcher: What do you believe that a scientific model is?
Student teacher: A scientific model is an idea, a theory for something, which scientists can prove based on evidence. It is a scientific tool for explaining or predicting how things happen.

Researcher: How close to reality does a scientific model have to be?
Student teacher: There are things that are not observable, so scientific models represent things that we cannot see, and as I have just said, a scientific model is an idea, a thought about how things happen.
Researcher: What could be the purpose of a scientific model?
Student teacher: I thing … to explain and predict natural phenomena.
Researcher: How it might be useful?
Student teacher: It is useful when we share our thoughts with others, when we want to represent what we have inside our minds to others.
Researcher: Do you think that is possible for a scientific model to change?
Student teacher: Yes, it could be changed if new or false evidence has been found.

Conceptual understanding about light phenomena

Quantitative analysis was carried out in order to monitor student teacher's development of conceptual understanding. Table 3 illustrates the persistence and shift of students' scores for each task after the implementation of TLS. Pre-TLS, the results suggest that most students were classified at level 1 on all tasks (12, 11, 11, 12 and 12, for tasks 1 to 5, respectively). Some students were classified at levels 2 and 3, giving partially scientific or accepted replies (3, 5, 4, 3 and 3 for tasks 1 to 5, respectively). After the implementation of the TLS the results suggest that most students' conceptual knowledge improved for all tasks. The majority of them went up a level, giving partially scientific answers (score 2) and accepted scientific replies (score 3) for all tasks (14, 14, 12, 13 and 13 for tasks 1 to 5, respectively). Applying the Wilcoxon non-parametric statistical hypothesis test before and after the TLS, statistically significant differences were identified regarding Task 1 $Z = -3.50$, $p > .001$, Task 2 $Z = -3.22$, $p > .001$, Task 3 $Z = -2.92$, $p > .05$, Task 4 $Z = -3.42$, $p > .001$ and Task 5 $Z = -3.28$, $p > .001$. The effect size estimated for Task 1 $r = .62$, Task 2 $r = .57$, Task 3 $r = .51$, Task 4 $r = .60$ and Task 5 $r = .57$, calculations which denote a large effect size.

For further clarification of developments in conceptual understanding, a qualitative analysis was carried out. Students after TLS tended to improve their previously held intuitive views (see Table 3). For example, in the fourth task, students abandon the intuitive idea that the image is captured by the mirror and partially apply the ray model, making a considerable step towards the scientific explanation, recognizing that light arrives at the eye of the observer after being reflected by the mirror (Figure 2):

> The observer will see all the objects, because light from the objects is reflected on the mirror and the observer has the opportunity to see objects from any optical angle. (Task 4, ST5)

In the fifth task, when students tried to explain what will happen if a light beam hits a plane surface of water, they focused separately on reflection or refraction. For example, one student teacher (ST11) chose to refer to reflection and justified his choice with the explanation:

> The plane surface of water is like a mirror, so the light beam will be reflected and return to the air. (Task 5)

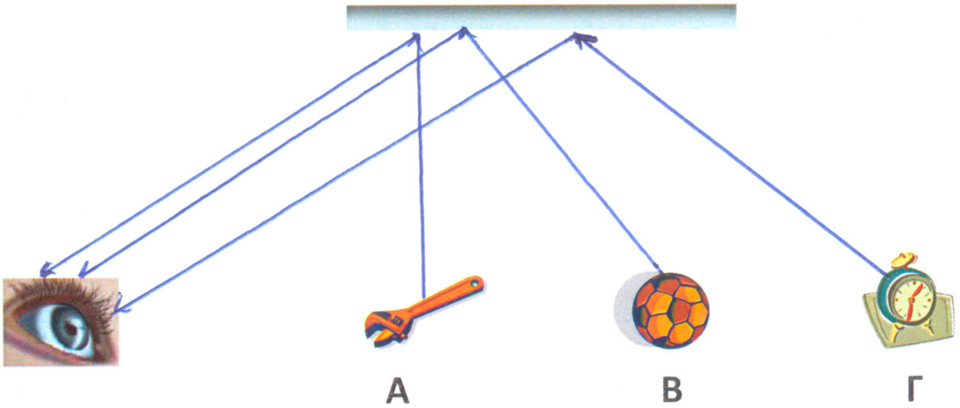

Figure 2. Partially scientific application of the ray model.

Another one (ST3) referred in the same way to refraction and partially justified his choice:

> The light beam will keep going through water, deviated from its rectilinear path. (Task 5)

These replies show appropriate behaviour for light rays but they are partially scientific (score 2) since they do not take into account the coexistence of reflection and refraction.

Some other students reached the accepted scientific level (score 3), showing full understanding of the ray model. For example, Task 2 (see Figure 3) attracted more accepted replies (score 3), since students considered figure b as the correct one. A typical explanation for this choice is given by one student teacher (ST6):

> Because the light first hits the object and afterwards we have the opportunity to see the object, like the example in the lab with the child on a bicycle, the path of light and the coin on the ground. (Task 2)

Another example where a student teacher (ST14) correctly applied the ray model, taking into account the geometrical rules of reflection and as a consequence reaching the scientific explanation, is cited below (Figure 4):

> He (the observer) will see items b and c because the incident and reflected angles must be the same. (Task 4)

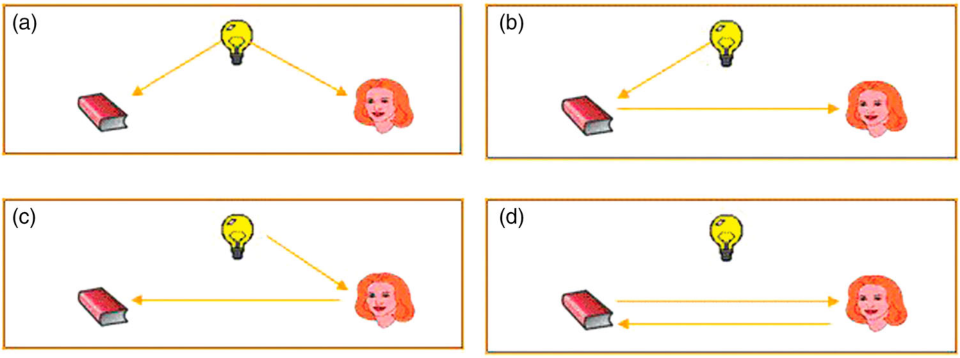

Figure 3. Student teachers' mental models about how we see.

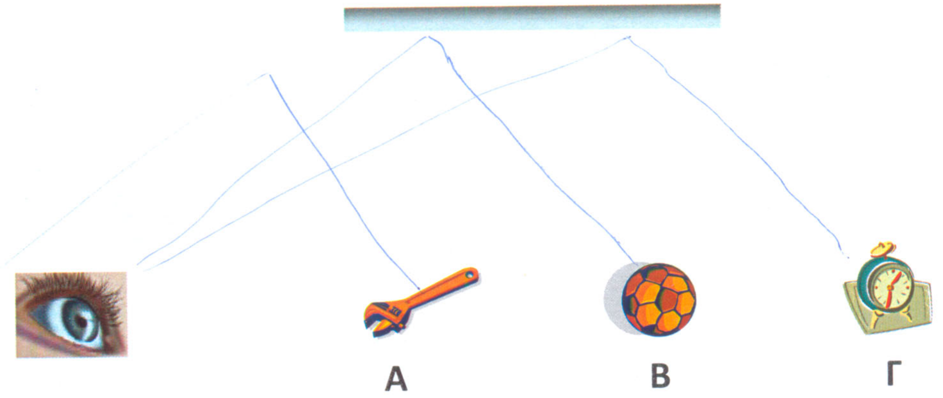

Figure 4. Correct scientific application of the ray model.

Correlations between epistemological beliefs and conceptual understanding

Non-parametric Spearman ρ correlations between conceptual understanding and epistemological beliefs about the nature, purpose and change of models were performed (see Table 4).

Before TLS significant positive correlations between epistemological beliefs and conceptual scores were not found for the nature and purpose of models. Surprising correlations were found for tasks 1, 2 and 3 in the case of model change. Post-TLS epistemological beliefs concerning the nature of models were all significantly correlated to the conceptual scores. Conversely, for the epistemological beliefs about the purpose and revision of models there were mainly no correlations for the purpose of models apart from task 2.

Discussion and conclusions

In this study we presented the structure and implementation of a model-based inquiry TLS integrating expressive, experimental and exploratory modelling pedagogies in a cyclic manner (Campbell, Oh, & Neilson, 2013), aiming at enhancing primary education student teachers' epistemological beliefs about the nature, purpose and revision of models as well as their conceptual understanding of light phenomena related to properties of optical fibres. Results show that before the TLS most students adopted epistemologically naïve realistic beliefs about models, whereas after the TLS there was an overall significant

Table 4. Spearman-ρ correlations between conceptual understanding and epistemological beliefs.

	Nature		Purpose		Change	
Tasks	*pre*	*post*	*pre*	*post*	*pre*	*post*
1. Vision – Seeing in absolute darkness	–.07	**.51*** p=.042	.27	.48	**.76**** p=.001	.35
2. Vision – How we see	.31	**.72**** p=.002	.45	**.64**** p=.008	**.79**** p=.000	.44
3. Diffused reflection on rough surfaces	–.10	**.50*** p=.046	.20	.50	**.57*** p=.020	.22
4. Reflection on a plane mirror	–.07	**.68**** p=.004	–.11	.50	.46	.30
5. Coexistence of reflection and refraction	-.07	**.68**** p=.004	–.11	.50	.46	.98

*$p < .05$.
**$p < .001$.

transition, from naïve to more sophisticated epistemological beliefs. Qualitative analysis of data suggested that such a shift was mainly due to a number of students who formulated 'intermediate' epistemological beliefs and a few who expressed sophisticated epistemological beliefs, whereas several others still adhered to naïve realistic beliefs. Such 'intermediate' advancements in students' epistemological beliefs after being engaged in an epistemologically oriented intervention are in line with our previous work concerning either student teachers or secondary students in another conceptual area, namely electrostatics (Petridou et al., 2013). We consider that engaging students in cyclic modelling activities enabled them to gradually distinguish a model (in our case, the optics ray model) from reality, identify the features of this model as well as its strong and weak points for dealing with phenomena, and facilitated an advance of their naïve beliefs concerning essential aspects of scientific models. It is also possible that the simulation-based exploratory modelling activities integrated into the cyclic modelling procedure worked as appropriate scaffolds in this direction (de Jong, 2011).

Comparing the three aspects of models examined, the change of models is to some extent easily adopted by students. This result is congruent with other studies and we consider that it supports the aspect-dependent nature of students' epistemological beliefs, meaning that epistemological beliefs and their change may vary across the various aspects of models examined (Gobert et al., 2011; Grünkorn et al., 2014; Krell et al., 2014). It is possible that the process of revising the initial model helped students to understand the need to evaluate and improve models in the light of new findings during experimentation and these in turn lead to the advancement of epistemological beliefs about change of models.

Significant improvements were identified in all tasks examining students' conceptual knowledge after the TLS, showing that they advanced their understandings of light phenomena. We note that conceptual development was greater in the cases in which the ray model concerned only the linear propagation of light. Rectilinear light beams were employed by most students to treat vision, reflection, diffusion and existence of daylight in a room, taking into account this feature of the ray model. However, in cases in which they had to take into account more features of the ray model, namely incident and reflection angles, some students did not manage to respond according to the scientific model. It is worth mentioning that the majority of students tended to change their beliefs after the TLS towards constructing synthetic mental models close to the scientific model, and this tendency seemed to be stronger in the second task. It appears that students' conceptual development involves a slow process during which the new, counter-intuitive, scientific information is assimilated to naïve physics, destroying its coherence and creating synthetic mental models (Vosniadou, 2007).

As regards the relationship between epistemological beliefs and conceptual understanding, before the TLS epistemological beliefs about the change of models and conceptual understanding had been found interrelated. One interpretation for this rather unexpected result is that the belief that a scientific model is unchangeable may influence conceptual understanding by constraining or rejecting any new information that does not concur with existing knowledge. Students who believe in unchanging knowledge may not aim at resolving inconsistencies between their prior knowledge and the new information, and as a consequence reject the new information when it is inconsistent with their prior beliefs, or just avoid the 'threatening' new information (Sinatra, 2005). Thus, the naïve realistic belief that a scientific model is unchangeable because it represents the reality or because it has been made by scientists is more likely to restrict any new idea elicited from students about how light behaves, lessening their ability to use the ray model.

Our results suggest that after the TLS students' sophisticated epistemological beliefs about the nature of scientific models were related to the application of the ray model and were employed to make inferences involving causal mechanisms about optical phenomena related to the properties of optical fibres. It appears more likely that those students whose level of epistemological beliefs about the nature of models is sophisticated after the intervention may perform better in conceptual tasks and *vice versa*. On the other hand, it was found that after TLS epistemological beliefs about the purpose and change of models were not related to conceptual understanding. These findings suggest that students' understanding of the nature of models is likelier to be related to conceptual understanding than their understanding of their use in science, that is, purpose and change of models. A possible explanation could be that the advancement of epistemological beliefs about the nature of models can give rise to awareness of certain critical components of the ray model that, in turn, can influence the interpretation of the phenomena under study. Regarding beliefs concerning purpose and change of models, one explanation could be that such beliefs do not relate to conceptual understanding. Another possibility is that purpose and change potentially relate to conceptual knowledge provided that such student beliefs are at the sophisticated level.

Overall we consider that the suggested cyclic modelling approach embedded into the TLS contributed to enhancing students' beliefs regarding models since changing from naïve to intermediate level constitutes progress for students, let alone changing to the sophisticated level. Besides, there were significant changes at the conceptual level. We consider that the different aspects of scientific models examined may be a crucial factor for the formation of students' epistemological beliefs, so that within this limited experience there were certain variations. Moreover, the students of our sample had a limited, even negligible, experience of models and modelling procedures before the implementation of the TLS. It is possible that the lack of change demonstrated by several students could be attributable to insufficient instruction time and inadequate practice in modelling extending over a lengthy period (Saari & Viiri, 2003). Besides, taking into consideration Krell's assumption (Krell et al., 2014) that sophisticated understanding of models is more likely to be related to better performance in school science subjects as well as in mathematics, the above findings suggest that more educational effort is required to help students construct a more coherent understanding of different aspects of the optical ray model.

Our cyclic modelling embedded in the TLS did not involve any specific teaching about models. In this regard, we may argue that the cyclic modelling approach we adopted acted as an implicit instruction in order to enhance students' awareness about the nature, purpose and change of scientific models as well as conceptual understanding concerning light phenomena. We suppose that if prospective teachers are to acquire more sophisticated epistemological beliefs about models then modelling pedagogies should be enriched with explicit teaching about models and modelling with reference to the specific model being used, for example the ray model (Schwarz & White, 2005). One important issue that needs further investigation is whether modelling pedagogies could combine both implicit and explicit instructional practices in helping students acquire more sophisticated epistemological beliefs about models and modelling (Holliday, 2006).

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