# Constructing models and teaching modeling: difficulties encountered by pre-service teachers

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## Abstract

Modeling ability is a basic scientific process that connects theories and scientific data. Models are scientific constructs used for assessing the applicability of hypotheses, forming hypotheses and developing the mechanisms supporting the functionality of the physical phenomena. In the Didactics of the Natural Sciences the importance of the modeling ability lies in the fact that it could act as a medium for supporting the learning process and the development of students' learning. This research study aims to identify the difficulties encountered by pre-service teachers (PsTs) during modeling-based learning and teaching. The participants of the study were 21 PsTs of a science specialization course at the University of Cyprus during spring semester 2007. The purpose of the course was twofold: help PsTs develop the modeling ability through model construction and refinement and guide them to develop teaching strategies for promoting modeling-based learning. Curriculum was developed for both purposes. A series of diagnostic tests administered prior and after the implementation of the curriculum, the transcripts of the synchronous discussions pertaining to critique of the current educational research about the modeling ability, and PsTs' reports regarding action research studies aiming to the development of the modeling ability of elementary students constituted the means of data collection. Techniques of Phenomenography and Content Analysis were used for the analysis of the qualitative data collected. Analysis of the results indicated that PsTs efforts to construct models and teach the modeling ability are distracted by specific epistemological and pedagogical difficulties. Further quantitative analysis indicated that these two types of difficulties are correlated (Figure 1). Based on the qualitative interpretation of this relationship, three theoretical didactical approaches regarding teaching the modeling ability were sketched out: linear (blue rectangle), object-oriented (red rectangle) and aesthetic (green rectangle) modelers. Educational implications of these results are discussed.

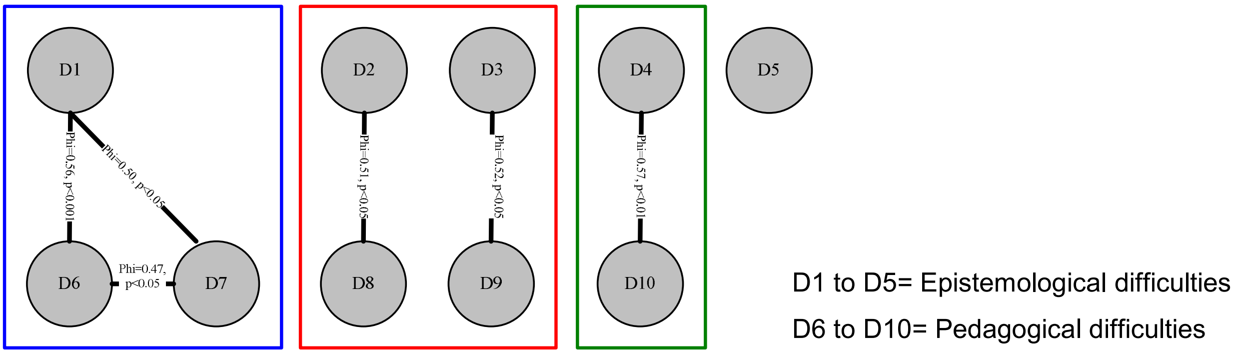


*Figure 1. The Relationship between Epistemological and Pedagogical Difficulties*

## Keywords (style: Keywords)

Modeling ability, teaching the modeling ability, learning difficulties, teachers´ education

# Introduction

Science teachers should learn about science, about current research on how students learn science, and about how to teach science. Typical undergraduate science courses don't promote these parameters and shove teachers to focus primarily on content (Duschl, Schweingruber, & Shouse, 2007) ignoring that students should be aware of the nature of science and participate in scientific practices. They ignore that teachers are learners that learn better and as a consequence teach better, when constructing knowledge or when teaching through knowledge construction (Papert & Harel, 1991). Modeling could constitute a way to overcome this drawback and promote scientific proficiency, as it is closely connected with understanding of the nature of science (Gilbert, 1991), and contributes to the active construction and revision of knowledge (models) by students themselves (Hestenes, 1987). Model construction is in line with the principles of constructionism, as teachers construct understanding of certain phenomena through the development of specific artifacts, models (Kafai & Resnick, 1996).

It is however possible that the construction process is obstructed by learning difficulties, which relate either to the content of the instruction or the pedagogical implementation of it. The study presented here is part of an on-going research program, through which we aim to investigate the development of the modeling ability of and the development of strategies to teach the modeling ability for PsTs working collaboratively. Specific modeling and pedagogical difficulties encountered by the PsTs are presented and their interdependence, as well as their role in knowledge construction process is discussed. The research questions investigated are: (1) Which are the difficulties related to modeling encountered by PsTs when constructing a model? and (2) Is there any interdependence of these difficulties with PsTs' effort to develop and implement interventions promoting modeling-based learning?

# Theoretical framework

## Models and the modeling ability

A *model* is a unit of structured knowledge used to represent observable patterns in physical phenomena. It acts as an external representation of a phenomenon that provides a mechanism accounting for the functions of the phenomenon and can be used for predicting the future behaviour of the it (Halloun, 2007). Moreover, models are scientific constructs used for assessing the applicability of hypotheses, forming hypotheses and developing the mechanisms supporting the functionality of the physical phenomena.

The *modeling ability* refers to the ability to construct and improve a model of a physical object, a process or a phenomenon (Hestenes, 1987). It is a basic scientific process that connects theories and scientific data. In the Didactics of Natural Sciences the importance of the modeling ability lies in the fact that it could act as a medium for supporting the learning processes and the development of students' learning. As a process of learning and teaching, it is compatible with constructionism (Kafai & Resnick, 1996), introduced by Seymour Papert and which is based on the constructivist ideas of Piaget, which support that knowledge is constructed by the experiences of the learner and suggests that humans learn when constructing new knowledge that involves tasks aiming to the development of artifacts, in this case models.

Moreover, modeling is an ability that includes reasoning skills necessary for the development of the learners' epistemological awareness. In order to facilitate the learning and teaching process, modelling, which is a complex ability, should be analysed in three constituent components:

*modeling skills, meta-cognitive knowledge, and meta-modeling knowledge* (Papaevripidou, Constantinou, & Zacharia, submitted). *Modeling skills* are: (a) Model formulation, (b) Identification of model components, (c) Comparison of models of the same phenomenon, (d) Model evaluation and formulating ideas for improvement, and (e) Model validation through comparison with phenomena in the same class. *Metacognitive knowledge about the modeling process* refers to the learner's capability to describe and reflect on the major steps of the modeling-based cycle. M*eta-modeling knowledge* refers to the learner's development of epistemic awareness regarding the nature and the purpose or utility of models.

Central to the process of teaching the modeling ability is the modeling-based learning cycle. The modeling-based learning cycle is a refinement of the learning cycle (Karplus, 1980) which consists of five nor discrete or linear parts (engage, explore, explain, elaborate and evaluate). As such, the modeling-based learning cycle is considered iterative in that it involves continuous comparison of the model with the physical system in reference. The purpose is gaining feedback for improving the model so that it accurately represents as many aspects of the system as possible. It is also cyclical in that it involves the generation of models of various forms until one can be found that successfully emulates the observable behavior of the system.

We consider that scientific modeling procedures can be simplified, so that they are coded in unison in the frame of one scientific framework. In other words, this research study does not refer to the possible differentiation of the scientific modeling procedures in different cognitive areas. This assumption is justified in the frame of a simplification for the purposes of teaching transformations for elementary education. This study focuses on inductive models and does not refer to construction of hypothetico-deductive models. This assumption is also justified in the frame of teaching transformations aiming to influence elementary education.

The role of teacher as central for learners to both use and understand the nature and role of models is emphasized by many researchers (Coll, France, & Taylor, 2005; Justi & Gilbert, 2002a; Justi & van Driel, 2005; Stylianidou, Boohan, & Ogborn, 2005). However, teachers do not hold scientifically correct ideas about models and modeling (Crawford & Cullin, 2004; Gilbert, 1991; Harrison, 2001; Justi & Gilbert, 2002b; Van Driel & Verloop, 1999, 2002). The next sections elaborate on the didactical obstacles and the consequent difficulties or ideas of teachers and students when constructing knowledge.

## Learning difficulties

Learning difficulties are organized in several categories, which are of the same nature with the constituent components of learning in the Natural Sciences. Learning pertaining to understanding of ideas, concepts and principles of the Natural Sciences and provides the means through which students can think about unknown and new physical systems, refers to *conceptual understanding*. The acquisition of experiences with natural phenomena (*experiences*) provides the basis for the subsequent development of concepts and skills (Wellington, 1994). *Positive attitudes* towards inquiry feed student motivation and safeguard sustainable engagement with the learning process (Gibson & Chase, 2002; NRC, 1996). When students' thinking and understanding is away from the scientific, with regards to one of these three areas (conceptual change, experiences, attitudes), students face conceptual difficulties. Students' understanding regarding the essential principles of the nature of science, the structure and the development of science and scientific learning relates to *epistemological awareness*. Obstacles that emerge during student's effort to capture the essence and the structure of the epistemological procedure and the nature of science in general fall under the category of epistemological difficulties (Halloun, 1998). *Reasoning skills* provide the strategies and procedures for making operational use of one's conceptual understanding, in order to analyze and understand everyday phenomena, but also to undertake critical evaluation of evidence in decision making situations. Reasoning difficulties dissuade students' effort to develop these skills and constitute students incapable of describing explaining or understanding the underlying mechanism of phenomena or physical systems (Hammer, 1996). *Practical and scientific skills* relate, among others, to students' ability to (i) predict, (ii) design and carry out fair experiments, (iii) conduct detailed observations, (iii) use instruments for collecting data, (iii) collect, code, organize and interpret data, (iv) communicate results, conclusions and other information, and (v) raise investigative questions (Gott & Duggan, 1995; Gott & Duggan, 1996). Students' weakness to capture these skills leads to (a) practical difficulties, which relate to students' handling of instruments or tools in a way which leads to distortion of the results of an experiment, and (b) reasoning difficulties, when for example students are incapable of raising investigative questions.

Research in students' understanding and therefore the identification of learning difficulties could constitute a means for serving multiple didactical goals. Firstly, the development of specific scaffolding steps aiming to the appropriate direct manipulation and confrontation of difficulties and the development of student learning is supported. More specifically, teachers' awareness of the existence of specific difficulties leads their moves and strategies in the learning environment and allows for the development of questions that guide students' thinking and therefore the construction of knowledge and understanding of the phenomenon under study. Secondly, identifying the learning difficulties serves some indirect goals. It helps towards the development of didactical strategies and activity sequences that deal with learning difficulties. Curriculum design should include the development of specific strategies that encourage students to express their views so that difficulties are revealed and become the subject of dialogue and discourse. Awareness of students' learning difficulties also leads the development of appropriate assessment tasks, which evaluate whether the curriculum is successful in confronting the difficulties identified and therefore whether it fulfilled its goals.

# Methods

## Sample and Intervention

The participants of this study were 21 fourth year elementary teachers of a science specialization course, which adopted a blended e-learning approach, at the University of Cyprus (spring semester 2007). The intervention was based on an iterative procedure, which involved the learners in an active process of constructing and deploying successive models of the moon phases collaboratively, within their group, among groups in class or through the internet (Blackboard Learning System). The first part of the curriculum included tasks related to (a) studying moon data, extracting patterns out of them and developing hypothesis explaining these patterns, (b) constructing models using Stagecast Creator© describing some of the identified patterns, and (c) deploying models. This procedure of constructing and deploying of models was supported by the Virtual Learning Environment. For example, Group A constructed a model and uploaded it on the *Tool for Exchange of Contributions for Peer Reviewing* and then deployed the original model, based on the feedback included in the Assessment form of Group B, also posted on the Tool. Finally, Group B had to deploy its model based on the feedback included in the Assessment form of Group A. This procedure was repeated in three cycles and finally each group constructed six successive models, which explained three patterns identified from the moon data. The second part of the curriculum pertained to the development of strategies for teaching of the modeling ability. This last part of the course called PsTs to develop and implement, in collaboration with upper elementary students, curriculum units concerning the development of successive models of a specific physical phenomenon aiming to promote modeling-based learning.

### Data collection

Three different means of data collection were used: (1) A series of *diagnostic tests*. These were administered to PsTs before and after instruction and assessed the constituent components of the modeling ability provided by Papaevripidou *et al.* (submitted) and discussed earlier in this paper. (2) The transcripts of the *synchronous discussions.* The discussions took place among PsTs once every two weeks beyond the actual class time and revolved around the critique of current educational research on the development of the modeling ability. (3) PsTs' reports regarding action research studies aiming to the development of the modeling ability of elementary students

### Data analysis

Phenomenographic analysis was used to categorize the PsTs' responses derived from *diagnostic tests* (Marton, 1986). The result of a phenomenographic analysis is a set of related categories or conceptions pertaining to the phenomenon under study. Usually the categories are formed in relation to the content and the level of scientific correctness and are distinct from the rest according to qualitative criteria. PsTs' responses to the pre- and post-tests were studied and included into a hierarchical list of ideas.

For the analysis of *the synchronous discussions* and the *PsTs' projects*, content analysis was used. *Content analysis* included the use of codes which were either predetermined (a priori coding analysis) or emerged throughout the coding procedure (emergent coding analysis) (Coffey & Atkinson, 1996).

## Results

### Modeling Difficulties: PsTs' difficulties during model construction

The data analysed in our effort to describe specific modeling difficulties were collected prior (pre-tests), during (synchronous discussions), or after instruction (post-tests). Five specific modeling difficulties were identified. We considered that a PsT did encounter a difficulty when it was traced both prior and after instruction. This assumption was made in order to be able to compare the modeling difficulties with the pedagogical difficulties encountered by PsTs (see next section). If the difficulty was not identified when analyzing the data of the test after the instruction, we considered that the instruction is responsible for that change, and therefore the PsT does not face that difficulty after the course. Due to space limitations we will only present two difficulties.

1. Difficulty 1: PsTs believe that when constructing a model someone should know exactly how the phenomenon under study works

During a synchronous discussion, PsTs compared teaching with simulations and teaching through model construction. Some of them expressed the view that a learner builds a model when she wants to represent what she knows, while, in contrast, a learner can use a simulation in order to gain knowledge about a phenomenon:

***PsT 10:*** *When building a model someone should be an expert of the phenomenon. By using a simulation she learns a lot about the phenomenon. This is why we should study the phenomenon of the moon phases (with the instructors' help) and then model it using the software.*

Four out of 21 PsTs encountered the idea that when constructing a model someone should know exactly how the phenomenon under study works. They also feel that external help, preferably by experts, reinforces a person's readiness to construct a model. In other words, they expect that the instructor or a book should provide the correct information to them and they capture modeling as a procedure of expressing knowledge and not a process of scientific improvement, which results to improved learning.

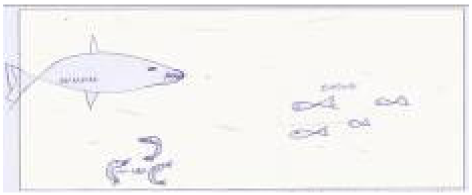
2. Difficulty 2: During model construction PsTs tend to place more emphasis on objects rather than any other element of the model

Diagnostic test 1 asked PsTs to observe a few minutes video about life in a sea ecosystem, then draw a sketch of their understanding of the phenomenon on paper and provide further explanation about it. In their effort to construct that (drawing) model they identified and included objects (e.g. shark, salmon, plants), variables (e.g. velocity of the fish, fish population), processes (reproduction, feeding) and interactions (e.g. the shark eats salmons, one fish attacks the other) in it. The frequencies of the elements of PsTs' models are presented in table 1. Both in pre- and post-test, PsTs tended to include more objects and interactions among models elements rather than variables and processes.

*Table 1:*
*Summary of the elements included in PsTs' models (diagnostic test 1)*

| Model Elements | Objects | Variables | Processes | Interactions |
|---|---|---|---|---|
| **Pre-test** | 72 | 23 | 47 | 64 |
| **Post-test** | 74 | 46 | 53 | 80 |

Here is a typical reaction of a PsT who constructed a model including more objects than any other form of elements (Figure 2):



***Model components:***
***Objects:*** *Living organisms (i.e. shark, salmons, shrimps)*
***Process:*** *Food chain (e.g. the shark eats the salmons and the salmons eat the shrimps)*

*Figure 2. Model of the sea ecosystem by PsT 17 (pre-test response)*

PsT 17 included three objects (shark, salmons and shrimps) and two object-object interactions (The shark eats the salmons and the salmons eat the shrimps) in her model. Moreover, she represented one process, nutrition. No variables were included in the model. We call this model object dominated. Other than the one process included in the model, this PsT developed a model which focuses on objects and their interactions. It warrants mentioning that the ideas of nine out of 21 PsTs fall into this category of difficulties.

3. Difficulty 3: When constructing a model, PsTs tend to include more interactions between objects rather than any other kind of interaction
4. Difficulty 4: When comparing models, PsTs tend to use superficial criteria like phenomenological characteristics or aesthetic criteria
5. Difficulty 5: PsTs fail to appreciate the comparison of a model and the phenomenon as an essential mechanism for improving the model

All five modeling difficulties are epistemological in nature. They fall under this category of difficulties as they relate to PsTs' epistemological awareness and more specifically, their inability to understand either the nature of models (e.g. difficulty 4) or the nature of the modeling process (e.g. difficulty 1).

## Pedagogical difficulties: PsTs' difficulties for promoting modeling-based learning

Analysis of PsTs' final projects revealed five difficulties that are pedagogical in nature, as they pertain to PsTs' inefficiency to promote the development of the modeling ability to elementary students. Due to space limitations we will only present two difficulties.

6. Difficulty 6: PsTs seem to misunderstand or take for granted the process of deployment during the modeling procedure

PsTs developed activity sequences and instructed the development of successive models of a certain phenomenon to an elementary student. Some of the PsTs did not implement or misunderstood the model deployment phase of the modeling procedure. Despite the fact that their students created multiple successive models, they didn't prompt fruitful circumstances for the students to feel the need for improving their model and therefore move from one model to a successive one. PsT 10, for example modelled the phenomenon of photosynthesis in collaboration with her student. Among her final comments about her teaching were the following: *"…with minor changes that she (the student) performed alone, she finally constructed six successive models, which really don't look very different compared to each other. The final model is the one that the student considered as the best one to represent the phenomenon of photosynthesis."* This PsT didn't really try to involve her student in the process of deploying her model, and even if she did, she didn't really manage to succeed in it. Careful analysis of the steps undertaken by all PsTs during their modeling-based instruction indicated that nine out of 21 PsTs encountered this pedagogical difficulty.

7. Difficulty 7: PsTs tend to assume the role of expert authority, and perceive that their professional responsibility is the transmission of the "correct" scientific information and models to the students

Analysis of the final projects of the PsTs indicated that three out of 21 PsTs seemed to perceive themselves as expert authorities. They assumed that their professional responsibility pertains to the transmission of the "correct" scientific information to the students, who are asked to use them in order to build (or deploy) their models. PsT 10 first asked her student to draw a model about photosynthesis on a piece of paper and afterwards a model on the program Stagecast Creator$^{TM}$. They conducted an experiment pertaining to the effect of sunlight to plant development and the student was asked to assess the model according to the new information. Until that point, the process seemed to be close to the scientific one. However, instead of structuring her instruction around the experiment and its results, after conducting the experiment, she provided the student with extra material (powerpoint presentation) regarding the: *"In order to help her, I provided the powerpoint presentation. I wanted her model to be more accurate. This is the reason I gave her the correct scientific information".* It seems that the PsT did not trust the results of the experiment and considered them as not clear to the student. Instead of repeating the experiment or treating them in a way that the student would understand, she provided the "accurate and correct" information through the presentation.

8. Difficulty 8: PsTs overemphasize the role of objects in their instruction
9. Difficulty 9: PsTs overemphasize the role of the interactions between objects than any other kind of interaction in their instruction about models
10. Difficulty 10: PsTs tend to place emphasis on aesthetical improvements of their students' models

## Interdependence of epistemological and pedagogical difficulties

A further analysis of the results revealed an interesting pattern described in Figure 1. We conducted a Chi Square Analysis for revealing the relationship among difficulties. Phi Coefficient indicated the correlations among them. The lines connecting different difficulties do not imply any causal relationship nor do they imply that one difficulty is causally related to the other. They rather indicate that PsTs tending to encounter the difficulty at the one edge of the line tend also to encounter the difficulty at the other edge of it. For example, it is assumed that PsTs encountering difficulty 3 (D3), construction of models with more interactions among objects rather than any other kind of interactions, tend to also encounter difficulty 9 (D9), they tend to guide their students to do the same by overemphasizing the role of the interactions between objects than any other kind of interaction.

We used the results of the statistical analysis to qualitatively describe PsTs' attempts to promote the development of the modeling ability of their students. These results suggest the existence of the following three theoretical didactical approaches regarding teaching the modeling ability:

a) *Linear modeler*s: teachers encountering a combination of D1, D6 and D7
b) Aesthetic modelers: PsTs encountering D4 and D10,
c) *Object-oriented modelers*: PsTs encountering the combinations D2-D8 and/or D3-D9

A modeler who uses the first theoretical approach for modeling (*linear modeler*) cannot conceive modeling as a cyclical procedure, which includes model construction and successive refinements of it after comparing it to the phenomenon. Instead, she considers modeling as a process with a starting and an end point, where she represents the phenomenon in the correct way. Even if she improves her model, the improvement is not a result of the comparison of the model and the data or the phenomenon. This theoretical approach to teaching also includes teachers' attempts to guide their students, who construct successive models of a specific phenomenon, to the same process. They design their instruction so as to follow a linear path where the student studies the phenomenon and construct one or more models which are not a result of comparing each model draft to the phenomenon, but rather a result of adding new information provided by the teacher or another source of information.

An *aesthetic modeler* is the one who construct models which are guided by aesthetic orientations. An *object oriented modeler* is the teacher who constructs models which include more objects or interactions among objects rather than any other model element. We consider teachers who use these two theoretical approaches to teaching as *superficial modelers*. They pay attention to surface characteristics of the phenomenon when modeling it and consider modeling as a representation process. Moreover, they ascribe, to modeler the responsibility of reproducing the obvious parts of the phenomenon and not the physical quantities or the underlying mechanism pertaining to it. Teachers who use this theoretical approach to teaching the modeling ability are more sensitive to guide their students to a process of model refinement, which is based on phenomenological features of the phenomenon rather than features that relate to physical quantities of it.

## Discussion

With regard to the first research question, which relates to the modeling difficulties encountered by PsTs when constructing models, five modeling and five pedagogical difficulties were identified. Abd-El-Khalick and Lederman (2000) argue that epistemological development must be an explicit instructional goal. The modeling difficulties presented here, which are epistemological in nature, tend to dissuade and hamper the process of learning. This is the reason why such difficulties should be made explicit and where appropriate confronted in a learning environment so that conceptual understanding and acquisition of skills are achieved. Very often in teacher preparation reasoning, epistemological difficulties are not identified and therefore remain in the ecology of the learners and affect or even determine both the learning process and the subsequent teaching practice.

The second question refers to the possible interference of the epistemological and pedagogical difficulties. The results showed statistically significant relationships between these difficulties encountered by PsTs when developing models and promoting modeling-based learning and indicated the existence of three theoretical didactical approaches regarding teaching the modeling ability (linear, aesthetic and object-oriented modeler).

*Linear modelers* are those who present students the right answers (Van Driel & Verloop, 2002) or even demonstrate the (scientific) models as static facts (Van Driel & Verloop, 1999) instead of stimulating students to construct their own schemes or explanations and elaborate on their own ideas. A possible explanation for this tendency could lie on teachers' belief that their students encounter many difficulties and express misconceptions regarding models; and therefore are not able to participate in the modeling procedure effectively. Teaching the modeling ability in a cyclical way is not an easy task. It is easier to have the students build one model using all the "correct" or "scientific" ideas the teachers or books provide. The complexity of this procedure is also expressed by Justi and Gilbert (2002a), who state that teaching to construct models *de nevo* should be the last step of the three phases of "learning to model" framework. During this last phase students should actually work like scientists, not knowing the outcome beforehand. This phrase emphasizes the nature of the linear modeler´s teaching approach; she lacks understanding not only about how to guide students though the modeling procedure in a cyclical way, but she also presents students the "truth" when attempting to model a phenomenon. Philosophically, this teaching approach is in accord with logical positivism (Van Aalsvoort, 2004), an approach about 'ready-made science', not about 'science in the making'. A teacher whose thinking is in that line tries to bring out the rationality of scientific results. She places emphasis on the scientific results and truth and not the scientific work. This philosophical stand considers the rational necessity of elaborating a logical model that allows for the assignment of meaning to scientific concepts obtained by scientific methodology within the structure of a theoretical system (Flores, Lopez, Gallegos, & Barojas, 2000). In contrast, the constructivist orientation of teachers lies on the other edge of the spectrum. Teachers displaying a constructivist orientation indicate, for instance, that different models can co-exist for the same target, dependent on the researchers' interest or theoretical point of view or prompt their students to ground their models on the data collected, on the phenomenon itself and not on the correct answers (Van Driel & Verloop, 1999). In modeling based teaching and learning, this entails that the remaining major challenge for the teacher is to guide the students through the modeling procedure (observation of the phenomenon-data collection, identification of new relationships, and continuous improvements of the model) and not follow the logical positivism philosophy.

In an effort to provide an explanation for the presence of learning difficulties, Tiberghien (1994) elaborates on the theoretical basis of physics knowledge and states that when physicists interpret and predict experimental facts, they do not directly apply a theory to the situation but, by using the theory, they construct a model of the experimental situation. From the learner's perspective, interpretation of a phenomenon or a material situation, takes place by the construction of a "model" of the situation on behalf of her. Like physicists, the learner selects objects and elements, which are relevant according to her own point of view. Related work of the same researcher with fifth graders about heat and temperature (Tiberghien, 1980, 1985) indicated that their models are very close to the objects and events which are directly observable and perceived. The difference of students' models and physicists' models lies on inclusion of objects and events. The latter do not include objects and events as such, but use physical quantities with mathematical formalisms. The results of the present study are in accord to the findings of Tiberghien. Superficial modelers (*object-oriented or aesthetic modelers)* perceive modeling as a process of representation of the phenomenon rather than an epistemological analysis of it. They don't realize the important role of physical quantities in the modeling process and therefore don't bother including them in the models. Instead, they emphasize in the inclusion of the directly perceived objects or the aesthetical aspects of the phenomenon.

Clark, Richard, Ravit Golan, Luke, & William (2008) investigated students´ ability to provide scientific explanations during modeling and resulted in that, among others, they tent to use communicative and aesthetical criteria when evaluating scientific models. The results of diSessa (2002) reinforce these findings as he presented a coding scheme regarding students ability to judge the quality of representations, in which aesthetic criteria were included as non-scientific. Likewise, Van Driel και Verloop (1999) recorded teachers views about models and identified that some of them emphasize the physical appearance of the models. Teachers of that scale appreciate for example that "a model has the shape of a drawing" or "the most important difference between a model and the target concerns the scale". *Aesthetic modelers,* as reported in the present research study, act like the teachers of Van Driel and Verloop (1999). These teachers assign their students the responsibility to include aesthetic characteristics of the phenomenon and not the physical quantities in their models. The discussion about using aesthetic criteria for evaluating models has its roots in the philosophy of science. On the one hand, many scientists note the importance of aesthetic factors for developing theories (Fleck, 1935; Goodman, 1981; Kuhn, 1962; McAllister, 1989, 1990; Wechsler, 1978; Welsch, 1997; Zee, 1986). On the other hand, other scientists oppose to the use of aesthetic criteria in theory choice (Engler, 1990; Lakatos & Musgrave, 1978; Maxwell, 1998).Whether we find something beautiful or ugly must depend, to some extent at least, on our personal, subjective, emotional responses to that thing.

Interpretation of the results that derived from the present research effort can be supported by both perspectives of the philosophy of science. We consider that aesthetic modelers do not necessarily think unscientifically. They might represent, for example, successfully the underlying mechanism of the phenomenon under study in the constructed models and at the same time focus on including an aesthetic feel. This does not detract from the scientific process of model construction. If we guide learners not to think aesthetically, it does not follow that they will think (more or less) scientifically nor that they are more likely to promote appropriate criteria. On the other hand, if teachers rely exclusively on aesthetic criteria for theory choice, they do deviate from the scientific process for construction and evaluation of models.

All teachers studied in the frame of the present research constructed knowledge through model building and deployment and tried to transform their knowledge into teaching by guiding their students to also construct knowledge through developing successive models of a phenomenon. We showed that this construction process is obstructed by certain learning and teaching difficulties, which should be confronted in the learning environment.

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