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Models in science and for teaching science: Data from an intervention programme

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Abstract

Currently, implementing models and modelling activities in science teaching is considered to be essential. Apart from being crucial as an auxiliary aid to the construction of scientific knowledge, they also play a major contribution in the development of adequate views of nature of science and models, as well as in the development of scientific inquiry competencies. However, many studies disclose that science teachers do not rely on models in their classes very often, thus revealing some lack of knowledge regarding them. With the intention of improving prospective science teachers' views of the nature of science, emphasising the nature of models, as well as their role in science and for teaching science, an intervention programme was conducted and evaluated. Nine prospective science teachers voluntarily attended the intervention programme and responded to previously validated questionnaires and interviews about models before and after it. Data was analysed with the help of the Q.S.R. NVivo 10 qualitative data analysis package. In general terms, prospective science teachers improve their views regarding models in science and for teaching. Nevertheless, the observation of their classes will be an invaluable asset for future research.

Keywords: Intervention programme, modelling, models, prospective teachers' views, science teaching.

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1. Introduction

Scientific models are considered to be crucial in scientific enterprise, being considered "not only products of science but also tools and processes of science" (Cheng & Lin, 2015). In fact, scientific models play a fundamental role in scientific knowledge construction and development, as they are used to describe, explain and to predict natural phenomena, as well as to communicate scientific ideas to others (Oh & Oh, 2011).

In spite of the existence of diverse definitions and different types of scientific models, they may be defined, in general terms, as simplified representations of a target, which are built according to a particular portion of that target and with specific purposes (Chamizo, 2013; Giere, 2010; Torres & Vasconcelos, 2015).

Given the relevance of scientific models in science, models and modelling activities are currently considered to be fundamental in science teaching. As Justi and Gilbert (2002-2003) state, models and modelling activities should promote the learning *of* science, of *how to do* science and *about* science.

In fact, models and modelling may help students to develop mental models that are in accordance with the major models that are the products of science. Moreover, students may develop inquiry skills and understand how scientists work by creating, testing and revising their own models (Namdar & Shen, 2015; Vasconcelos, Moura, Torres, Moutinho, & Lima, 2015) and may also develop a better understanding of the nature of models and the nature of science. In fact, as models and modelling are considered to be an important aspect of science, the understanding of the nature of models will contribute to the understanding of the nature of science and, consequently, to a better conceptual learning in science (Cheng & Lin, 2015).

There are many studies that reveal the positive effects of employing models in science teaching. Halloun (2007) claims that students achieve, for example, better conceptual understanding of scientific knowledge; better performance in the exams; better views about the nature of science and acquire better learning styles when using models in science classes. Furthermore, this author states that students develop stable inquiry skills, tools and learning styles that may be used in other situations and courses.

Haugwitz and Sandmann (2010) claim that the use of models in science classes simplifies the learning process and promotes better conceptual understanding, while prompting the interest of the students. Moutinho, Moura & Vasconcelos (2014) emphasize the relevance of modelling activities in the restructuration of students' mental models. In this regard, Gilbert and Ireton (2003) also add that the reliance on multiple models contributes to a richer mental model construction.

In spite of the relevance that it is attributed to models and modelling in science education, some studies reveal that science teachers' understanding of models and modelling is limited and that they do not use models very often in science classes (Khan, 2011; Krell & Kruger, 2016). In a study conducted in Portugal, it was demonstrated that science teachers and high school students do not possess a consistent definition of models and that models are only used in science classes as contributors to the learning *of* science (Torres, Moutinho, & Vasconcelos, 2015).

Some inconsistencies regarding the definition of models were also found in a study conducted with prospective science teachers in Portugal (Torres & Vasconcelos, 2015). Moreover, an analysis of the syllabus of geology and biology education subjects of seven Portuguese universities showed that prospective teachers do not deeply deal with models in their initial training. In fact, it was demonstrated that little relevance was attributed to models and modelling activities in their training (Torres & Vasconcelos, 2014).

In view of this, we consider it fundamental that prospective teachers (and even in-service teachers) improve their views of models in science and for teaching and that they recognize their full potential when used in science classes. In fact, it is crucial that teachers understand how important it is to engage students in modelling activities that reflect scientists' activities and that prompt the development of scientific knowledge, inquiry skills and accurate views of

the nature of science. In this regard, Oh and Oh (2011), after a literature review, suggested five subtopics that science teachers should know about models: (i) meanings of a model; (ii) purposes of modelling; (iii) multiplicity of scientific models; (iv) change in scientific models; (v) uses of models in the sciences classrooms.

Having the above mentioned aspects in mind, we planned an intervention programme, which primarily aims to improve science teachers' views of nature of science, emphasising the nature of models, as well as their role in science and for teaching science. The intervention programme was organized in five classes, of five hours each.

Starting with activities that intended to promote a better understanding of what scientific models are and with which purposes they are used, a set of modelling activities was developed. These activities were designed in order to foster a better understanding of the importance of models and modelling activities in the development of accurate mental models, and in the understanding of scientific activity and of the nature of science.

Some activities with historical models were also developed, mainly for teachers to recognize their relevance in the understanding of certain aspects of the nature of science. Furthermore, we engaged teachers in a critical analysis of Portuguese science textbooks and science standard documents and in some discussions concerning the advantages and precautions to take when using models and analogies in science classes.

It was expected that, at the end of the intervention programme, teachers be prepared to present a lesson plan that must include a modelling activity and must contribute to the development of conceptual knowledge and inquiry skills, as well as to the understanding of the nature of models and of the nature of science.

In this study we started to work with prospective science teachers that will teach biology and geology subjects in middle and high schools. Thus, we will analyse how the intervention programme influenced their views about models, by comparing the views they held before and after it.

2. Methods

The study presented in this article is part of a broader research which aims to deepen prospective science teachers' views of the nature of science (emphasising the nature of models, as well as their role in science and for teaching science), and to understand the factors that mediate the translation of teachers' views into their practices in classes. Concerning the former aim, an intervention programme was prepared and applied to prospective teachers (which was briefly described in the introduction). With this study we mainly intended to evaluate how this intervention programme influenced prospective teachers' views concerning models in science and for teaching science.

Nine prospective science teachers voluntarily attended the intervention programme and responded to a questionnaire and interview before and after the intervention programme. The questionnaire was validated in a previous study and comprises fourteen open-ended questions which mainly evaluate prospective teachers' views regarding models in science and for teaching science, as well as their conceptions concerning the use of models in science classes (Appendix A).

In the interviews, prospective science teachers were asked to better explain and clarify their answers and to add some needed information (some examples of questions are provided in Appendix B). The interviews were audiotaped and transcribed and the data (obtained through questionnaires and interviews) was analysed with the help of the Q.S.R. NVivo 10 qualitative data analysis package.

These prospective science teachers will teach biology and geology subjects in middle and high schools and are designated, in this study, by fictional names: Maria, Vera, Andreia, Bárbara, Sofia, Francisco, Carolina, Inês and Rita (8 females and 1 male). This sample comprises

prospective teachers between the ages of 21 and 38 (average = 23.89 and mode = 21). When they participated in the intervention programme, they had already concluded either a BSc degree in Biology, or a BSc in Geology, or a BSC in Biology and Geology and were enrolled in the master's course in biology and geology teaching.

3. Results and discussion

With this study, it was verified that after attending the intervention programme, prospective science teachers improved their views about models in science and for teaching science. As shown in table 1, prospective teachers greatly developed their views regarding scientific model concept and purposes.

Before the intervention programme, prospective teachers had presented confusing definitions of models, viewing them as tools to use only in school or as copies of reality. After the intervention programme, all of them had recognized models to be representations of some aspects of reality, as well as their relevance in scientific development. For example, Vera stated:

> *"Yes, I change a lot my view concerning model definition. In the first questionnaire, I just pointed out that scientific models mirrored an event. Now I understand that a model is not a mirror, i.e., it is not a copy of reality, it is influenced by other things".*

Furthermore, the vast majority of prospective science teachers (88.9%) also improved their views regarding the purposes of scientific models. In fact, before the intervention programme, all prospective teachers had mentioned that models were solely used to describe or explain certain aspects of reality.

After the intervention programme, eight prospective teachers pointed out the relevance of models in scientific knowledge development, either by describing, by explaining or by predicting some phenomenon or aspect of reality. Concerning this change of perception, Francisco stated:

> *"Yes [I change my view about the purposes of scientific models]. I had only associated scientific models with classes. Now I understand that scientific models are used in science".*

Moreover, after the intervention programme, all of the prospective teachers possessed informed views concerning what may be represented by scientific models, the multiplicity of scientific models and their change over the course of time (Table 1). The majority of prospective teachers only failed to improve their view concerning "the relationship between scientific model and theory" aspect. In fact, after the intervention programme, only four prospective teachers expressed a belief that scientific models establish a bidirectional relationship with a scientific theory.

Table 1. Prospective teachers' views about models in science, before (Pre) and after (Post) the intervention programme

Views Analysed aspects		Uninformed		Informed	
		Pre	Post	Pre	Post
Scientific model concept	Example	In my opinion, a scientific model is a set of ideas, theories and methods to follow towards a problem to solve. Q_Sofia (Q – questionnaire' answer)		A model is an approximated representation of a real thing. Q_Francisco	A scientific model is a demonstration of a phenomenon. It intends to represent certain phenomena of reality that we are trying to explain. I_Sofia (I – interview' answer)
	F (%)	6 (66.7)	---	3 (33.3)	9 (100)
Scientific model purposes	Example	The main purpose is to explain the reality in a simple manner, in a way that everyone understands it. Models are used in the classroom or in the training context. A teaching or learning context may be completed with scientific models. Q_Rita Models are used as an orientation to a better understanding and learning. Q_Sofia	Trying to explain phenomena of reality, trying to represent them. I_Sofia		Scientific models are used to explain and represent ideas or phenomena. In science they are also used to predict. (…) Models are very important in geology, as it is a science that deals with aspects that are not directly observed. QI_Rita (QI – questionnaire and interview' answer)
	F (%)	9 (100)	1 (11.1)	---	8 (88.9)
What can be represented by a scientific model	Example	A scientific theory, I think that it is a theory, I think so. I_Sofia Theories. I_Bárbara		A geological mechanism, geological phenomena (…) [a model] may represent the DNA molecule. It may represent many objects of analysis for a certain scientific area. I_Inês	A phenomenon of reality, a process of reality. I_Sofia Many things. Phenomena, events, (…) systems, like the endocrine system (…). I_Bárbara
	F (%)	2 (22.2)	---	7 (77.8)	9 (100)

Relationship between scientific model and theory	Example	A scientific model is almost the practical demonstration of a scientific theory. When we construct a scientific model it is to support a scientific theory. (…) To construct a model, we must have a theory beforehand. QI_Bárbara	The scientific model may try to demonstrate a process, a phenomenon, structure that it is integrated in the scientific theory. Q_Carolina	(…) A theory may be explained through model construction. However, it may also be the opposite. (…) mainly for us to explain a theory or to verify if a theory really works, we may construct a model. By constructing a model we may also understand the errors of theories and reformulate it. I_Rita	A scientific model establishes a bidirectional relationship with a scientific theory. A model may function as the basis to the elaboration of a theory or to support or to prove it. (…) through scientific models we may construct theories or through theories we may construct scientific models. QI_Bárbara
	F (%)	8 (88.9)	5 (55.6)	1 (11.1)	4 (44.4)
Change in scientific models	Example			Yes [models may change] if the scientific theory, which is related with model construction, also changes. Q_Maria	Yes because science is tentative. If there are new discoveries, they will contribute to the change of scientific models, for them to correctly represent the target. Q_Maria
	F (%)	---	---	9 (100)	9 (100)
Multiplicity of scientific models	Example	(…) I am trying to compare this situation with the heart function, but the heart is what it is (…). No, there are no multiple models to study the same target. I_Maria		Yes, multiple models may exist to study the same target and different aspects of the same target. I_Bárbara	Yes, multiple models may exist to study the same target and different aspects of the same target. With different materials, for example. I_Bárbara
	F (%)	2 (22.2)	---	7 (77.8)	9 (100)

The majority of prospective science teachers also improved their views concerning the relevance of models in science teaching. In fact, only two prospective science teachers continued with the limited view that models are just used to prompt a better understanding of scientific knowledge. The other prospective science teachers understood that models may be used to prompt not only the understanding of scientific knowledge, but also the understanding of the nature of science and the development of inquiry skills (Table 2).

Table 2. Prospective teachers' views about models for teaching, before (Pre) and after (Post) the intervention programme.

Views Analysed aspects		Uninformed		Informed	
		Pre	Post	Pre	Post
Models contribution in science teaching	Example	*Models may help students in the understanding of how certain things happen, certain natural phenomena. (…)* *I_Andreia* *In science teaching, models are used to reify some subjects that are difficult to understand. The construction of models requires theoretical knowledge, prompting the learning of concepts.* *Q_Vera*	*Models may have an important role in science teaching. (…) They may be a useful tool to prompt students' learning. (…) With models, knowledge becomes more significant for students. Models also allow the visualization of events that are difficult to understand.* *Q_Vera*	*Models are very important for students to visualize what happens in reality and, sometimes, what is difficult to teach. When building models, students develop their critical thinking, their capability of constructing them (…). They may also understand how the construction of models happens from theories.* *Q_Rita*	*Models may be use to explain phenomena that are complex for students.(…) Modelling may help students to interpret scientist role. Through modelling, students may observe, question, critically think and suggest solutions.* *Q_Rita* *Models allow students to reflect scientists' activity. In classes, models allow students to better understand that activity and to better understand reality.* *I_Andreia*
	F (%)	7 (77.8)	2 (22.2)	2 (22.2)	7 (77.8)
Favourable conditions for students to develop models	Example	*For students to construct models they should be completely informed concerning the theoretical content in which a scientific model is based.* *Q_Sofia*	*I think that students need a theoretical contextualization (…) I think that the first step is the understanding of what they are going to represent.* *I_Sofia*	*Creativity, for example. Also the understanding of what they are going to do. Also, a little bit of teacher's orientation is also very important.* *I_Maria*	*Students must know what they want to represent, which variable they are going to represent, they must gather information. Of course, to construct they must have the information for doing so. (…) They also need creativity and imagination.* *I_Maria*
	F (%)	7 (77.8)	1 (11.1)	2 (22.2)	8 (88.9)
Differences between models in science teaching and models in science	Example	*I think that from a model that is used in science, we can use it in science teaching. They must be equal (…)* *I_Andreia*		*They must be different, as they should be adapted to the school grade in which they are used. By using a scientific model, students may not understand and tend to lose interest.* *Q_Carolina*	*The models that are used in teaching must be adapted to the school grade in which they are used and they must be, in general terms, simpler and clearer. They must be related with the theme.* *Q_Andreia* *Absolutely [they must be different]. The purpose of models in teaching is to teach and reflect scientist's work, and not to do research. Models in teaching must be adapted according to students (…).* *Q_Carolina*
	F (%)	3 (33.3)	---	6 (66.7)	9 (100)

Furthermore, after the intervention programme, the majority of prospective teachers recognized that apart from scientific knowledge, there are other important conditions (needs) for students to develop models, such as imagination and creativity, as well as the ability to select, choose and integrate a set of items, depending on a particular goal. All of them also recognised that models in science teaching are usually different from models in science, as models in science teaching must be adapted according to the level of students and to the science teaching objectives, which are certainly different from those of models in science (Table 2).

The second part of the questionnaire was more focused on prospective teachers' views about the use of models in science teaching and the precautions to take when using them. Regarding prospective teachers' views about the use of models in science teaching, all of them indicated that they consider it important to present models, as well as to ask students to construct models, either before or after the intervention programme.

When it comes to the difficulty of constructing or understanding (previously constructed) models, the majority of prospective science teachers (66.7% before the intervention programme and 55.6% after the intervention programme) considered that the construction of models entails more difficulties. Only one prospective teacher (after the intervention programme) mentioned that the understanding of a previously constructed model involves more difficulties, while 3 prospective teachers (before and after) considered that both options entail difficulties.

When asked about the most advantageous option, the majority of prospective teachers (55.6% before the intervention programme and 66.7% after the intervention programme) chose the construction of models. We may say that the results are similar before and after the intervention programme. However, we observed that after the intervention programme prospective teachers gave more emphasis to important aspects when justifying their options, such as the development of creativity and inquiry skills, the understanding of scientists' activity, and the understanding of the role and limitations of models in science. For example, Bárbara stated:

> *"It is more advantageous that students construct models. In spite of being a challenge to overcome, the construction of models provides students with new abilities to work or to do future research (…) Also, students may reflect the role of scientists, in order to understand how scientific knowledge evolves and also to understand the role of models, or to understand the reality, or to predict (…)"*

Concerning the characteristics of good models, prospective teachers mainly stated that models in science teaching should be clear, simple, rigorous, pertinent and adapted to the level of students of the class in which they are used (Table 3).

Table 3. Characteristics of good models in science teaching.

Main characteristics	Frequency (%)	
	Pre	Post
Clear	7 (77.8)	8 (88.9)
Simple	7 (77.8)	7 (77.8)
Rigorous	6 (66.7)	7 (77.8)
Pertinent	7 (77.8)	4 (44.4)
Adapted to the level of students	5 (55.6)	6 (66.7)
Attractive/ motivator	7 (77.8)	1 (11.1)

As shown in table 3, there are no substantial differences in the main characteristics mentioned before and after the intervention programme. Also, in these two moments the majority of prospective teachers emphasized the need for models to be clear in order to avoid the development of misconceptions. Nonetheless, it is important to highlight that after the

intervention programme, five prospective teachers also added the relevance of warning students of what models are, their limitations and how they are used in science:

> *We should indicate that models are not copies of reality, they may not be correct, as the theoretical framework that originated them may also not be correct (…). What we observe may not correspond to reality (…)* – ***Vera (after the intervention programme)***

> *When developing modelling activities, we should explain what modelling is and students should reflect and understand for what purposes models are used (…)* - ***Rita (after the intervention programme)***

Moreover, prospective science teachers also displayed a greater awareness, after the intervention programme, for the importance of students to have an active role when using models.

Additionally, they specifically mentioned that they change their views about models, especially their views concerning the definition of models and their contribution to science teaching.

4. Conclusions

With these results, we may conclude that the prospective science teachers who attended the intervention programme improved their views regarding models in science and for teaching science. In fact, they greatly developed their views regarding the concept (definition) and purposes of scientific models and greatly widened their views regarding the relevance of models in science teaching. We also demonstrated that when justifying their options concerning the use of models in science classes, they expressed a greater awareness of both the potential and nature of models.

These results are rather exciting, as they may contribute to the effective use of models in science classes in the future, in a way that enables students to develop not only conceptual knowledge, but processual and epistemological knowledge as well.

However, we considered it of the utmost importance to observe the forthcoming classes of these prospective students, in order to understand the challenges they will inevitably face when implementing modelling activities in their classes.

Given the satisfactory results obtained in this study and considering the lack of knowledge that in-service teachers revealed in several other studies, we also think that it is important to broaden the scope of this type of intervention to include them as well, in order to contribute to the effective implementation of modelling activities in science classes.

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Appendix A. Questionnaire about model

Question 1.	In your opinion, what is a scientific model?
Question 2.	What are the main purposes of scientific models? In what circumstances are they used?
Question 3.	What is the relationship established between scientific models and theories? Justify your answer.
Question 4.	Do you believe that scientific models change over the course of time? Justify your answer with examples.
Question 5.	In your opinion, how can models be used in science teaching? What is the relevance of using models in science teaching?
Question 6.	Do you consider it important that students build models? Why?
Question 7.	What do students need to construct models?
Question 8.	In your opinion, may (or should) models that are used in science teaching be different from models that are used in science? Why? What may be the main differences?
Question 9.	How are you thinking of using models in science classes? By presenting your models to students or by giving them the opportunity to construct models? Justify your answer.
Question 10.	What do you consider to be more difficult for students: the understanding of a model (either presented

	by the teacher or one encountered in a textbook, …) or the constructing of a model? Why?
Question 11.	In your opinion, which is the most advantageous situation for students: the understanding of a presented model or the constructing of a model? Why?
Question 12.	When constructing models for science teaching, what aspects should we take into consideration? What precautions should we take when using models in classes?
Question 13.	In your opinion, what are the characteristics of a good model in science teaching? Why?
Question 14.	After the classes that you attended during this academic year, do you feel that you have changed your views about scientific models and regarding the use of models in science classes? If so, identify and explain the main changes and the main reasons (and sources) for those changes.

Appendix B. General interview script about models

Question 1.	Can you read and better explain your answer?
Question 2.	Do you want to add something more to your answer?
Question 3.	What do you mean by (…)?
Question 4.	How does your answer to *question a* relate to your answer to *question b*?
Question 5.	Have your views changed since you wrote your answer? If so, how?
Question 6.	From those options, which one do you chose to define scientific model?
Question 7.	What can be represented by a scientific model?
Question 8.	Can different models exist to represent different aspects of the same target?
Question 9.	Can different models exist to represent the same target?
Question 10.	(…)