Contributions of Model-Based Learning to the Restructuring of Graduation Students' Mental Models on Natural Hazards

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ABSTRACT
Model-Based learning is a methodology that facilitates students' construction of scientific knowledge, which, sometimes, includes restructuring their mental models. Taking into consideration students' learning process, its aim is to promote a deeper understanding of phenomena's dynamics through the manipulation of models. Our aim was to ascertain whether the use of three different types of models, integrated into an intervention program whose goal was to teach the "seismic effects on soils and buildings", would influence the learning process of graduation students or not. For a better understanding of the results, the data were collected and analyzed through a combination of methods using, simultaneously, quantitative and qualitative method. And results not only confirmed the importance of the use of models, but also led us to the conclusion that despite the potential and limitations of all three models, mixed models are better for restructuring students' mental models and the development of meaningful learning.
Keywords: science education, mental models' theory, model-based learning, natural hazards, seismology

INTRODUCTION

Teaching science in schools and developing scientific literacy helps students to become more mature, productive and responsible members of society (Sato, Bartimoro & Elko, 2016). The entire school community is responsible for achieving this goal but teachers play the most crucial role. In spite of this relevance, many science teachers still consider students to be rather simplistic thinkers. This is an erroneous belief. If guided, students may develop an extremely sophisticated, precise and abstract thinking (Duschal, Schweingruber & Shouse, 2000). Accordingly, teachers are required to apply methodologies and strategies deemed suitable for

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State of the literature

- People develop mental models that lead them to understand all natural phenomena. Because of this they constitute their prior knowledge, and they are reconstructed during peoples' learning process;
- Model-Based Learning is a methodology that promotes the construction of students' mental models through the manipulation of different models in geosciences classes, named teaching models;
- There are different types of models that can be apply in geosciences classes, according the subjects in study, students characteristics, teachers preparation and the available resources.

Contribution of this paper to the literature

- According to the importance of Mental Models Theory, we examined students' mental models about the seismic effects on soils and buildings, in order to help us in the development of an intervention program that promotes the reconstruction of students' mental models;
- Given the variety of models to teach subjects related to natural hazards, we applied three different types and tried to analyzed their potentialities and limitations;
- We also determine which one of the three types of models is better to help students in the construction of their knowledge about the topics in study.

helping students to construct their scientific knowledge, together with the development of other important capabilities, such as scientific reasoning, critical analysis and reflection.

The use of models helps to explain phenomena and further prompts students to develop their own personal mental models. These are formed alongside a given theory, intertwining all the knowledge that is acquired during the learning process (Moutinho et al., 2013). Indeed, curricular models are quite useful and valuable when explaining an abstract scientific theory. They are scientifically consistent and yet simpler and more tangible than scientific models. As such, the process of teaching and learning scientific contents at school may benefit from the use of precise curricular models, which are consistent with scientific models (Moreira et al., 2002). Moreover, curricular models have an important role to play not only in scientific practice but also in Science Education, standing out as a powerful tool that helps to involve students in the process of thinking about science (Halloun, 2007; Justi & Gilbert, 2002; Oh & Oh, 2011).

Geosciences teachers use models as recognized tools that are capable of helping students in the process of knowledge construction and in restructuring their mental models, making them consistent with the curricular models (Rodhe, 2012). The use of models stimulates students to learn certain aspects of a particular curricular model. Since they are accurate representations of parts of reality, the phenomenon that is represented becomes less abstract and students become more motivated and interested in the learning process (Justi, 2006). Different types of models can be applied in geosciences classes. The choice will depend on the characteristics of the phenomenon under study. In this research, three different models were applied – a computational model, a physical model and a mixed model.

Computational models are computer programs that model processes. They are used to create images of the phenomena, to find and test relationships within complex systems, and to test multiple hypotheses (Gilbert & Ireton, 2003). Generally speaking, all students enjoy playing computer games. As such, all kinds of computational software are perceived as interesting and helpful. Alternatively, physical models are simulations used to recreate and communicate certain phenomena, while allowing students to directly manipulate all the variables that could influence the phenomenon. These models [computational and physical] are the most common models applied in science classes (Moutinho, Moura & Vasconcelos, 2014a). This research resorts to a physical model – a mechanical seismic shaking table.

The mixed model applied in this study included two components: a physical component (from the physical model) and a computational component (from the computational model). These models are quite relevant since they facilitate the presentation of complex concepts. Each component of the model refers to a different dimension of the same concept (Gilbert & Ireton, 2003; Vasconcelos et al., 2015).

The use of methodologies is believed to be capable of helping students to restructure their mental models, bringing them closer to curricular models.

According to Pirnay-Dummer and collaborators (2012), Model-Based Learning provides a good opportunity for knowledge restructuring since it induces a cognitive dissonance, by carefully introducing facts that contradict those believed by students. This cognitive conflict is required if new knowledge is to be constructed upon prior existing mental models (Pirnay-Dummer, Ifenthaler & Seel, 2012). Using models in the learning process simplifies (the understanding of) natural phenomena and promotes a deeper understanding of the dynamics and of the variables involved in natural processes. This methodology takes into consideration the way the learning process relates to students' mental models, i.e., the way students inherently build their knowledge (Moutinho, Moura & Vasconcelos, 2014a). Accordingly, Model-Based Learning is considered to be central to the process of constructing scientific knowledge and promoting scientific literacy. It holds a central role in the development of meaningful learning (Gobert et al., 2011).

Nonetheless, since curricular models taught in science classes may conflict with students' mental models, they may hinder conceptual change (Moutinho et al., 2013). Better saying, scientific contents used to describe curricular models may conflict with vocabulary and concepts that students recognize through the use of everyday language (Clement, 2000).

Lets not forget that mental models are internal representations that help to understand as well as to explain and predict phenomena (Greca & Moreira, 1997; Johnson-Laird, 1983). A few characteristics are noteworthy: i) mental models represent what is common within a distinct set of possibilities; ii) they are iconic and their structure corresponds as closely as possible to that they represent; iii) mental models are based on descriptions, and they represent what is true and observable. Moreover, the mental models we employ profoundly influence

our expectations, the way we go about solving problems, and how we acquire new knowledge (Halford, 2014).

According to the Mental Models Theory, as developed by Johnson-Laird (1983, 2001), many different models may represent one single concept. In order to better understand the process of knowledge construction of our students, firstly it is important to diagnose their mental models and subsequently to analyse them. According to this theory, mental models help students to develop their capacity to explain and to predict phenomena (Palmero, Acosta & Moreira, 2001). Mental models compel students to evaluate and restructure their mental models, making them more coherent with both curricular models and scientific knowledge. By serving this purpose, mental models are promoting a meaningful learning (Palmero, 2008).

Despite the potential of Model-Based Learning, this methodology will only succeed when based on a specific knowledge and training and applied in an appropriate educational context. The role of teachers remains essential throughout the entire learning process (Libarkin & Brick, 2002), since they are the ones [actors] asked to develop strategies that will enable restructuring students' mental models (Moutinho & Vasconcelos, 2017).

To be a science teacher is not an easy task. Among many other requirements, it is necessary to have the ability to develop numerous relevant activities, such as: i) to evaluate students' prior knowledge, i.e., their outset mental models about the phenomena; this means that teachers "must be aware of the most frequent alternative conceptions developed by students on the topic under study" (Mendonça & Justi, 2011, p. 482); ii) to analyse if these mental models are scientifically consistent, and, if not so, to decide the best way to help students to restructure them; iii) to confront students with problematic situations that will lead them to question their mental models and, iv) to assess if their mental models have indeed changed and became more congruent with scientific models (Moutinho, Moura & Vasconcelos, 2014a).

As such, teachers have a very important role in the understanding of students' mental models and in helping to restructure them, so as to promote a meaningful learning and to develop scientific literacy. It is necessary that teachers understand how students construct their own mental models; that they recognize the nature of those models; that they know how to introduce them to students; and, primarily, that they have the ability to develop models that can be fit into classroom activities (Lin, 2014; Justi & Gilbert, 2002).

RESEARCH PROBLEM AND AIMS

Using models as heuristic resources, and Model-Based Learning as a possible methodology, helps to promote the (re)construction of students' mental models, making them more congruent to curricular models. In the attempt to establish comparisons to reality, it is necessary to reflect on the phenomena under analysis, as well as on the materials that are to be used in its representation, and their behavioural characteristics. According to Harrison and Treagust (2000) models are simulations that should enrich scientific research, understanding and communication.

Having this in mind, this study intends to ascertain what type of models (computational model, physical model and mixed model) has a bigger influence in the restructuring of graduation students' mental models about the *seismic effects on soils and buildings*.

To address this problem, the following objectives were set, in relation to the above mentioned topic: i) To diagnose the existing mental models of students attending the course of Geological Hazards, in a public university in northern Portugal, under guarantees of anonymity and confidentiality of data; ii) To implement three different models, integrated in an intervention program (IP) using Model-Based Learning as the main methodology, and to assess the strengths and limitations of each of the models applied; iii) To understand the importance and the potential of the three different types of models (computational model, physical model and mixed model) in restructuring students' mental models, as well as in the development of meaningful learning in graduation students.

METHODOLOGY

The study was developed using a methodological triangulation, combining the use of quantitative and qualitative methods simultaneously, during both data collection and data analysis. In this study, quantitative and qualitative data were collected simultaneously, without giving any greater significance to any of them. Note that, today, a greater importance is given to methodological triangulation (since it allows the combination of the use of quantitative and qualitative methods), especially in social and educational research that involves variables (such as behaviours and attitudes) that cannot be captured by resorting to traditional methods used in exact sciences.

Study sample

A convenience sample was selected (n=20), comprising all graduate students attending the curricular unit of Geological Hazards, administered in a northern Portuguese public university. The selection of this sample is explained by the availability of those students to participate in the study. Nonetheless, the sample equal constituted the universe of study, since it included all the students present in the IP classes. These students constituted the target group, and all data collection instruments were applied to them. The sample integrated 10 females and 10 males, with an average age of 21.6 years old, ranging from 20 to 24. The curricular unit gathered students from 2nd or 3rd academic year of the graduation in Geology, Biology and Landscape Architecture. Students held some previous knowledge on this subject, since seismology issues are part of the Geology program in 10th and 11th grades, in Portuguese secondary school. Although some subjects were now discussed in more detail and depth, students were already familiarized with them, which facilitated the initial approach to the contents. However, it was necessary to diagnose students' prior knowledge (mental models), in order to ascertain whether or not their mental models were consistent with the scientific model that was going to be addressed.

Intervention Program

The IP that was developed included either the construction or the adaptation of three types of models: computational model, physical model, and a mixed model. All models had the purpose of simulating the seismic effects on soils and buildings. The IP was applied during three consecutive lessons (that took place in non-consecutive days), each one lasting four hours. Thus, the IP totalled twelve hours. In each lesson, each one of the three types of models was presented and manipulated by students. At the same time, several other resources were developed and used in the classroom, so as to guide students during the models' manipulation. For example, students looked at PowerPoint® presentations and documentation related to modelling. During the application of the IP, students' were given enough time to express their ideas and to discuss them with their classmates and the entire class.

Lessons were taught in Portuguese (by the first author of this study), under the guidance of the teacher responsible for the curricular unit. The author (a professionalized teacher) was present in all classes in an attempt to reduce the constraints of students. Finally, it was guaranteed anonymity and confidentiality to the participants, so as to ensure a more ease, confident and natural participation.

Instruments for data collection

To achieve the objectives of the study, the collection of data resorted to different instruments, which were specifically designed:

Pre and post-test (**Appendix 1**) were prepared with the purpose of analysing the development of students' mental models regarding "seismic effects on soils and buildings" – objective iii). They consisted of a questionnaire with 15 items, applied before (pre-test) and after (post-test) the application of the IP. Pre-test was also used to diagnose the existing mental models of students – objective i). Each item of the questionnaire had two tiers. The first tier had a sentence relating the seismic effects on soils and in buildings, and students were asked to classify each one as *True, False* or *Don't know*. The second tier had four sentences, attempting to justify the previous answer, and students were asked to choose the correct one. The questionnaire was validated and the results of its validation are presented in the work of the Moutinho, Moura & Vasconcelos (2016a).

A *Seismological Models' Evaluation Scale (SMES)* was used to analyse the opinion of students about each one of the models used in teaching "seismic effects on soils and buildings" – objective iii). The scale was applied after the IP and the analysis took into account some important aspects of its features and applications (Moutinho, Moura & Vasconcelos, 2016b). The scale included ten items that evaluated each one of the three models that were manipulated during classes. Each item was classified according to a five-point Likert scale, from 1- *Totally disagree* to 5 - *Totally agree*. The content validity of the scale was ensured by resorting to the literature and by applying it to two experts in geoscience education, who suggested some terminology changes and improvements to its final structure. Cronbach

Table 1. Questions and answers options of the questionnaire about Models and Modelling in Science (MMS)

Questions	Answer options
1. Models and modeling are important in the understanding of science. Models are:	**a)** Representations of ideas on how the phenomena occur. **b)** Precise duplications of the reality.
2. Scientific ideas can be explained by:	**a)** Only one model - each phenomenon can only be explained by a single model. **b)** A model - but there may be other models to explain the same ideas.
3. When scientists use models and modeling in science to investigate a phenomenon, they can:	**a)** Use only a model to explain scientific phenomena. **b)** Using several models to explain scientific phenomena.
4. When a model is proposed to support a new scientific theory, scientists must decide whether to accept or not. Their decision is:	**a)** Based on the facts those support the model and theory. **b)** Influenced by their feelings or personal reasons.
5. The acceptance of a new scientific model:	**a)** Requires support of the majority of scientists. **b)** Occurs when it can be successfully used to explain results.
6. The scientific models are constructed for a long period of time by many scientists working in an attempt to realize the scientific phenomena. Thanks to this, scientific models:	**a)** Cannot be changed in future years. **b)** May be changed in future years.

Note: Each answer should be justified.

Alpha showed a high internal consistency, which assured the fidelity of the scale, which is presented and analysed in the work of (Moutinho, Moura & Vasconcelos, 2014b).

A *Questionnaire about Models and Modelling in Science (MMS)* was designed so as to assess the opinion of students about the importance of models and modelling in science. It also allowed the analysis of students' knowledge on some aspects of the Nature of Science and the importance of the role of scientists – objective iii). This instrument was a plain questionnaire constituted by 6 multiple-choice questions, each question having two answer possibilities (**Table 1**). In addition, each open question referred to one topic, and students were asked to justify the choice they had made. The aim of this questionnaire was to understand the opinions of students regarding the methodology that was being applied and the use of models in general. MMS was adapted from a study previously conducted by Treagust and collaborators (2004), and which was validated for this particular study sample. Three experts in science education analysed the relevance and objectivity of the questions, taking into account the study sample and the type of data collection, ensuring the validation of this instrument.

Finally, interviews were carried out with the participants whose pre and post-test results needed clarification because they were confusing or vague – objective iii). For the

accomplishment of the interviews, a script was developed with questions related with the aspects that it was intended to clarify. However, these interviews were semi-structured, since during the interviews other issues were raised, whenever considered relevant. In this case, the data were collected through audio record and properly transcribed, in order to facilitate the subsequent data analysis.

Validity *refers to the extent to which a measure adequately represents the underlying construct that it is supposed to measure*. Reliability is the *degree to which the measure of a construct is consistent* (Bhattacherjee, 2012, pp. 56-58). The determination of the validity or the reliability of the instruments used to collect data gave more confidence to the study, even though a small sample was being used.

RESULTS AND DISCUSSION

The methodological approach (methodological triangulation) led to the collection of different types of data – quantitative data (through the pre and post-test and the SMES), and qualitative data (through the MMS questionnaire and the audio records interviews). Data collection followed different purposes, concerning the objectives of the study, and aimed a more accurate and deep analysis. Accordingly, the analysis and discussion of data is organized in three different subsections: development of students' Mental Models; assessment of the typologies of models; and the importance of Models and Modelling in Science. For each one of these subsections, which contribute to the achievement of the objective iii), the data were collected through different instrument, described previously in methodology section: pre-test, post-test and the semis-structured interviews for the analysis of the development of students' Mental models; SMES scale, for the assessment of the typologies of models; and MMS questionnaire to analyse the importance of Models and Modelling in Science.

Development of students' Mental Models

A pre and post-test were applied in order to analyse the development of students' mental models. Answers were examined by applying different quantitative and qualitative methods.

First of all, a descriptive analysis was undertaken in order to determine if there was an improvement of students' knowledge — in other words, to determine if the process of restructuring student's mental models had succeeded. All answers were classified into a scale of four values. The frequencies of the answers are presented in **Table 2**.

According to the analysis of **Table 2**, students improved their outcomes in almost all questions. The number of students who obtained the classification 4 in post-test is higher than in pre-test.

On most issues, when comparing answers to pre and post-test, there was an increase in the number of students who answered correctly; for example: PQ2, PQ3, PQ4, PQ5, PQ7, PQ9, PQ10, PQ13, PQ14 and PQ15. However, there also are questions in which the number of students who answered correctly decreased, for example: PQ1, PQ8, PQ11 and PQ12. Only in

Table 2. Classification of students' answers in Pre and Post-test (n=20)

| | Correct | | | | Incorrect | | | | Don't know | |
| | **4** | | **3** | | **2** | | **1** | | **0** | |
	Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre	Post
PQ1	8	3	9	15	1	0	0	0	2	2
PQ2	14	16	1	0	1	3	3	1	1	0
PQ3	4	15	4	3	1	0	0	0	11	2
PQ4	3	4	3	3	9	8	3	4	2	1
PQ5	4	12	3	2	1	1	0	0	12	5
PQ6	9	9	1	8	9	3	1	0	0	0
PQ7	6	18	1	0	10	1	0	0	3	1
PQ8	10	9	3	7	5	3	2	1	0	0
PQ9	1	11	3	3	4	0	4	2	8	4
PQ10	13	19	1	1	0	0	0	0	6	0
PQ11	17	16	1	2	2	2	0	0	0	0
PQ12	20	19	0	1	0	0	0	0	0	0
PQ13	13	17	2	3	4	0	0	0	1	0
PQ14	7	9	1	6	2	1	3	4	7	0
PQ15	11	14	4	5	0	0	0	0	5	1

Note: Pre and Post-test values correspond of frequency (f). 4 – both tiers correct; 3 – first tier correct, second tier incorrect; 2 – both tiers incorrect; 1 - first tier incorrect, second tier correct (contradiction).

PQ1 were the results high (Pre-test = 8; Post-test = 3). In the case of question 1 it appears that most of the answers were rated 3, confirming a high increase from the pre-test to post-test (Pre = 9; Post = 15). This means that some of the students who answered correctly in pre-test, failed to properly justify their answer in the post-test (second part of the question).

Furthermore, the number of students who answered incorrectly decreased from pre-test to post-test in almost all questions. The number of students who answered *Don't know* in pre-test also decreased in post-test. Moreover, through the analysis of **Table 2** it is possible to ascertain that, for the majority of the questions, the students' answers in post-test are centred in ratings 3 or 4. This means that the majority of students correctly classified the first tier of each question of the test, although in some situations they did not answer properly to the second tier. However, these data also show the development of mental models of students.

Building up on this analysis, the profile of the answers given to the pre and post tests was graphically drawn, so as to compare them more easily. As such, a profile-based comparative analysis was used, following the works of Moutinho and collaborators (2016a) to analyse similar type of data. This analysis consists in a multivariate statistical method, from which quantitative results are obtained based in the evaluation of the students' profiles (Serafini, 1988), and it observes the averages of the answers given to each of the items. Each evaluation refers to an existing relationship between the expected and the attained results, based on the distance/proximity between profiles. According to this coefficient, higher distances mean that the profiles are far from the ideal.
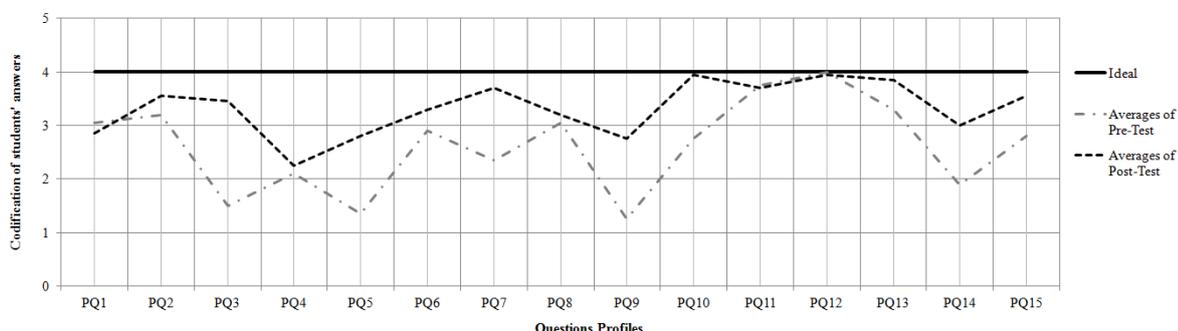
Figure 1. The ideal profile and its comparison with profiles from pre and post-test

Configurational similarity coefficient (appendix 2) is a complementary coefficient that measures the grade of correspondence of the high and low values between different profiles in each dimension (Cernuzzi & Zambonelli, 2008). In both coefficients, values range from 0 to 1, and if the coefficient range is from 0.90 to 1.00, the congruency is virtually perfect (1 being the perfect match in the evaluation of profiles); when the values of coefficient range between 0.70 and 0.89, there is a high congruency; a range between 0.40 and 0.69 indicates a moderate congruency; a range between 0.20 and 0.39 means that there is a low congruency, and if the coefficient ranges between 0.00 and 0.19, the congruency is virtually non-existent (Cernuzzi & Zambonelli, 2008; Serafini, 1981).

In this study, each profile question was analysed by comparing the simple congruency coefficient of the profile from pre-test and post-test with the congruency coefficient of the ideal profile. The ideal profile had a value that corresponded to a score of 4.

Figure 1 shows the ideal profile and its comparison with profiles from pre and post-test. Profiles result from the averages of the answers of pre and post-test, for all the 15 questions that constitute the profiles. The simple congruency coefficient for pre-test (Cpre) was Cpre = 0.50 and for post-test (Cpost) was Cpost = 0.70.

According to the data, pre-test results demonstrated a moderate congruency with the ideal profile, but the post-test results showed a high congruency. These results led us to ascertain that the results of post-test were better than those of pre-test, as the result of congruency coefficient with the ideal profile was higher in post-test.

The configurational similarity coefficient (CS) obtained was CS = 0.56, which meant that there was a moderate similarity in some of the high and low points of the two groups that answered the tests.

By observing **Figure 1** we can see that, in general, the profile of post-test questions is closer to the ideal profile than the profile of pre-test questions. However, there are situations in which the opposite occurs, such as in question 1 (PQ1), in which pre-test results are closer to the ideal profile. Additionally, a few situations are unclear. In order to clarify these dubious results, some interviews were conducted.

Amid the sample of 20 students, interviews were conducted to the following: i) Students who correctly answered question 1 in pre-test but, although correctly classifying the statement in question 1 in post-test, did not know how to justify it (classification 3) – students S3, S5, S6, S10, S17 and S19; ii) One student who achieved better results in pre-test than in post-test (student S20), thus suggesting that no change had been produced in his mental model; iii) One student whose results showed significant improvement between pre-test and post-test (student S2); iv) One student who improved his results, and yet it remained unclear whether there had been a development of his mental model.

The interviews were recorded and later on transcribed so as to ensure objectivity and facilitate data analysis. One of the objectives of these interviews was to understand whether or not changes in answers were due to contents addressed during the IP´s lessons, and if so, whether or not the use of some type of models had had any influence.

Having this in mind, the students were asked the following questions: i) Did the contents addressed in classes influence any change in your answer? Which contents?; ii) Did any of the models used in class allow you to better understand the question and guided you to change your answer?; iii) In your opinion, which one of the three models is the best to teach contents related to the seismic effects on soils and buildings? Why?

In relation to the first question, all students felt that the contents taught in classes led them to change their answers, and the majority (f=3) stated that the contents related to the characteristics of seismic waves guided them into changing their answers. Other students also referred to other contents that they considered relevant to help them revise their answers. These other contents included: the behaviour or buildings during an earthquake (f=1), contents related to seismology, as taught during classes (f=2), the liquefaction effect (f=2) and the effects of earthquakes and their possible damage to buildings (f=1).

The students' opinions were different as to which model had better helped them to revise their answers. Some students (f=3) felt that the computational model had helped them to understand the question better because of its practicality, simplicity and objectiveness.

If we have any question, we can answer it straightaway, and I think it is quite practical. (S2)

It is easy to see the movement and the behaviour [of buildings]. (S5)

It led us to better understand the effects that an earthquake could cause in buildings. (S3)

Two students (f=2) considered the physical model to be better because it allowed them to *simulate what happens in an earthquake in a direct and entertaining way* (S10); another student (f=1) also mentioned that the physical model helped students to test variables.

To be able to test several differences, such as more or less intensity, with taller buildings, with marbles, with sand, water, makes it easier to understand… (S20)

However, there was one student who felt that no model had helped him to better understand the question, since *they only allowed me to understand how to minimize the risks and damage to buildings* (S17).

These answers were relevant to the understanding of the students' views on the three models used to teach contents related to the seismic effects on soils and buildings. The results also showed that: i) Two students considered the physical model to be the best to teach these subjects (although they had previously designated the computational model as the best one – question 2), and gave similar justifications for their choice – *the model is practical, simple and objective*; ii) The majority of students (f=5) stated that the best model was the physical model because it is objective, easy to observe, and its results are easy to analyse:

Because it helps us to understand how the height of buildings, their structural reinforcement, or the type of soil influence how buildings behave during an earthquake. (S3)

It was easy to understand and it allowed us to change many variables related to the soil and buildings… (S5)

Nonetheless, since these justifications were also used to designate the mixed model as the best model to promote meaningful learning, it was not possible to ascertain the students' preference for the physical model; iii) Only one student unequivocally claimed that *the mixed model is better to understand what happens when an earthquake occurs, because the junction between the table and the simulator makes a better and a perfect understanding of earthquakes* (S19)

The interviews also meant to clarify the reason for discrepancies in the results of pre and post-test, increase or decrease in classifications (S2 and S20), or even confused and inconclusive answers (S16). Those three students under these circumstances were asked to answer four more questions: i) Which model helps more the development of scientific reasoning?; ii) What is the best model for assisting the elaboration of scientific processes?; iii) What is the best model for understanding the characteristics of Nature of Science?; iv) What are the advantages and disadvantages of each of these types of model?

When asked about which is the best model to help the development of scientific reasoning, two students elected the physical model, because *it is more instructive* (S2). *It really helps us to understand what we are trying to explain.* (S20). Only S16 considered the mixed model to be better because *we could see scientific data as we performed the experience.*

Regarding the elaboration of scientific processes, all three students considered the mixed model to be the best, because it allowed them to observe the phenomena in "real time".

It led us to understand better since, through the seismograph, we can observe when there are changes… (S2)

We moved the seismic table and we were able to see (maybe) the seismograph at work in real time. (S16)

Regarding the understanding of the characteristics of the Nature of Science, two students felt that the physical model allowed them *to make more changes as they occur in nature, and add more variables to be studied* (S2).

S20 stated that the mixed model allowed students *to make many variations, using many materials, different intensities… In this model we can always introduce change: Oh, let's experiment with this, we will experiment with that soil, we will experiment with that stuff with wood (…).*

Concerning the advantages and disadvantages of the three types of models, the main aspects that were pointed out are as follows: i) The computational model is more practical to use in everyday classes, because students *don't need to mess up the class, and we could use it comfortably at home, without having to go to the field.* (S20) However, this model is also the most limited, because *we cannot add others variables to test, it must be used as stipulated.* (S2, S20); ii) The physical model is the one closer to reality, it allows students to manipulate several variables, and it is also the most attractive model.

Very close to reality, we can imagine much better what happens… (S2)

We can define which variables to study, and we can create different type of variables. (S16)

It is more attractive to teach and to explain to students. (S20)

Despite the aforementioned advantages, students also felt that this model is difficult to carry and to operate because it is big and too sensitive.

It was not very easy to transport. (S2)

It was difficult to control the intensity [of the mechanical motor]. (S16)

Finally, students considered that the mixed model was instructive, realistic and gave students more leeway.

We can see [the phenomenon] *happening in real time.* (S16)

The use of a seismograph helps us, because it allows us to better understand and to manipulate and to simulate what we want it to do. (S20)

But students also claimed that this model is too sensitive and difficult to operate.

It is very sensitive and the slightest touch can change the register. (S20)

Following the pre and post-test data analysis, we could verify that students recognized many advantages in the use of models in class, and they understood that the major purpose was to teach contents related to the seismic effects on soils and buildings.

However, we needed to deeply analyse data so as to understand if the differences registered in students' pre and post-test results were indeed significant under the context of this study. For this purpose, we began with a simple statistical analysis of the average ratings and standard deviations in both tests. Data were analysed through the 23rd version of a statistical program SPSS. The results are presented in **Table 3**.

Table 3. Students' results in Pre and Post-Test. (n=20)

	Average	Standard Deviation	Minimum	Maximum
Pre-Test*	32.8	8.24	17	41
Post-Test*	49.9	5.55	41	58

* Pre and post-tests' maximum score (15 items): 60 points

According to the data presented in **Table 3**, the average of results in post-test (49.9) is higher than in pre-test (32.8). The minimum and maximum values obtained in the questionnaire are also higher in post-test (min = 41; max = 58) than in pre-test (min = 17; max = 41). All these results allow us to confirm an increase in students' scientific knowledge on the seismic effects on soils and buildings.

Considering this information, it was deemed relevant to perform a deeper analysis so as to determine if the results were significant. The Wilcoxon Test was used.

Wilcoxon Test

Wilcoxon Test is a non-parametric test used to compare two paired samples when the study sample is small and does not show a normal distribution. The application of this statistical test demands for the definition of a hypothesis, as follows:

H0: The average of students' results in post-test is equal to the average of the students' results in pre-test.

HA: The average of students' results in post-test is higher than the average of students' results in pre-test.

In this case, a unilateral test was used since the data signalled what was the trend of this difference – an increase in the students' results.

The results of the Wilcoxon test rejected H0 for a confidence level of 99% (Z = -3.921; p = 0.000), thus indicating that post-test data showed a significant increase in students' results. This meant that indeed students developed their knowledge and improved their mental models on seismic effects on soils.

Assessment of the typologies of models

Through the results collected with SMES (the students' opinion about the three types of models - **Table 4**) it was possible to assess which was the model that better promoted meaningful learning.

As already stated, since the study sample was small and did not follow a normal distribution it was decided to use the same nonparametric test used in the analysis of the pre and post-test results – the Wilcoxon test. Three hypotheses were defined (HA, HB and HC):

Table 4. Statistical information about computational, physical and mixed model (n=20)

	Computational model	Physical model	Mixed model
Average	36.2	33.9	36.4
Standard Deviation	6.70	5.15	5.92
Minimum	21	24	26
Maximum	48	45	50

H0: The average of the importance of the computational model in the learning process is equal to the average of importance attributed to the physical model in the learning process.

HA: The average of the computational model importance in the learning process is different from the average of importance attributed to the physical model in the learning process.

H0: The average of the importance attributed to the computational model in the learning process is equal to the average of the importance attributed to the mixed model in the learning process.

HB: The average of the importance attributed to the computational model in the learning process is different from the average of the importance attributed to the mixed model in the learning process.

H0: The average of the importance attributed to the physical model in the learning process is equal to the average of the importance attributed to the mixed model in the learning process.

HC: The average of the importance attributed to the physical model in the learning process is different to the average of the importance attributed to the mixed model in the learning process.

According to these hypotheses, the Wilcoxon nonparametric test for paired samples was applied. In this case bilateral tests were used since data would only indicate whether the hypotheses were or not different.

The results presented in **Table 5** led to the acceptance of HC at a confidence level of 95% (Z = - 2.094; p<0.05). As such, only the difference between the physical model and the mixed model was qualified as significant. It was not found any significant improvement in learning when the other two types of intervention were used. Thus, mixed models are

Table 5. Results of Wilcoxon test for the three tested hypotheses (n=20)

	HA Computational – Physical	HB Computational – Mixed	HC Physical – Mixed
Z	-1.674	-0.379	-2.094
Significance (bilateral)	0.097	0.723	0.035

considered to be the best type of model for promoting the construction of knowledge, which includes restructuring mental models and making them more congruent with curricular models (Moutinho & Vasconcelos, 2017).

The importance of Models and Modelling in Science

Students also answered a questionnaire regarding Models and Modelling in Science, which integrated six multiple-choice questions. Students were asked to explain each of the answers.

Following data collection and analysis, results were divided into two sections: one relating to the views of students on the characteristics of different models, and another referring to the process of scientists acknowledging models (Moutinho, Moura & Vasconcelos, 2014a).

Characteristics of models

Questions 1, 2 and 6 (**Table 1**) addressed the conceptions of students on models and modelling in science. Results showed that all students perceived models as representations of ideas on how phenomena occur, and the majority related this characteristic to the unpredictability of natural phenomena. Some participants also stated that although models are not completely faithful to reality, they still contribute to a better understanding of natural phenomena (question 1).

It is impossible to make a model that fully corresponds to reality since natural phenomena are always associated to unpredictability and/or variables that cannot be tested. (S1)

Models are representations that help to understand how [the phenomenon] is manifested in real life. (S4)

As for explaining scientific ideas (question 2), all students considered that the use of a model could be helpful, but other resources could also be used. The majority of students recognized that there existed several models directed to the explanation of the same phenomenon.

Different models lead to the same conclusions, as we have seen in class. (S6)

The earthquake simulator and the seismic table, for example. (S12)

There are many variables and different models to represent them all. (S16)

Finally, the majority of students believed that models were liable to change in the coming years (question 6) since science is constantly evolving.

With the evolution of knowledge about the phenomenon, models will evolve as well, and will eventually change. (S18)

Models can always be changed, because science is always evolving. (S14)

The role of scientists in the validation and acceptance of models

The conceptions of students on the role of scientists in the validation and acknowledgement of models were analysed through questions 3, 4 and 5 (**Table 1**).

The majority of students recognized that models could be used to explain many scientific phenomena, and that different models could be used to explain the same phenomenon (question 3).

We can use several models to explain the same idea, and this idea can be framed in various situations. (S13)

If they succeed to represent the same phenomenon in various models, they can do it. (S18)

Only one student stated that scientists resort to only one model so as to explain phenomena, since that one model helps studying that phenomenon.

(...) A model may allow us to study the various phenomena involved. (S9)

In relation to the criteria used by scientists to accept (or not) a given model, students stated that that decision should be based on evidence that backed both the model and the theory (question 4). As such, the majority of students underlined the need for scientists to base their decisions on observations that corroborate the theory.

Their decision is based on observations that prove the theory. (S3)

(...) Facts prove theories, even if our beliefs do not agree. (S9)

You must check whether the model fits the study/new theory. (S20)

Finally, students voiced different opinions when asked about the process of accepting a new model (question 5). The majority of students (12 of 20) considered that the acceptance of a scientific model requires support from the vast majority of scientists. If a consensus could not be reached, the model should not be accepted.

If only one scientist concurs then the majority does not accept the theory as correct. (S2)

If no one agrees with a given scientific model, it will not be accepted. (vg: Galileo). (S6)

Finally, students revealed consistent views regarding the importance of models and modelling in science. These concepts had already been indirectly addressed during the IP lessons, as it is demonstrated by some of the answers that resorted to examples used in class. Overall, results showed that Model-Based Learning Methodology contributed to the construction of more realistic views on this topic.

CONCLUSIONS

At this point, an appraisal of the conclusions of this study comes in order, bearing in mind each of the objectives outlined at the beginning of this article.

i)   Prior to the application of the IP, a pre-test was used to ascertain the mental models held by those students that integrated the study sample. As it was observed, we can´t say that their mental models regarding seismic effects on soils and buildings were inconsistent with the scientific model, and this may be related to previous concepts acquired during high school. Answers to pre-test made it possible to list those concepts in which inconsistences were perceived, so as to guide an intervention that would promote the restructuring of mental models.

ii)   The second goal of the study was to develop and to apply an IP through a Model-Based Learning Methodology. This included the application and the use of three types of models (a computational model, a physical model and a mixed model), and the assessment of their strengths and limitations. All models were developed and adapted to the study sample, and all of them were applied during the IP classes. Throughout the IP students actively participated in the activities, they arose questions and debated the contents that were taught. The analysis of the interviews led to the conclusion that the IP succeeded, since students positively referred to both the classes and the models.

According to Mendonça and Justi (2011), and as corroborated by this study, the application of Model-Based Learning is important to support the process of students' knowledge construction, including the seismic effects on soils and buildings. The authors consider it fundamental to further analyse the impacts/benefits of this methodology when applied to students of other age groups. This effort will make it possible to understand how different groups of students react to the application of Model-Based Learning, and which adjustments should be made so as to enhance its advantages in different contexts.

At this point, we can list the advantages and limitations of models according to the opinions of students, but also according to the visions of the researchers. First of all, students recognized some advantages linked to the use of models, for instance: computational models are practical, objective, simple, and easy to manipulate. They are practical since processes can be repeated over and over again, in only a few minutes and in any place, including at home. Nonetheless, students felt that computational models are also limited since they do not allow the manipulation of all variables that need to be studied, since the software is programmed for a specific purpose.

Researchers point out some other limitations, such as the fact that these types of models are only available in the English language, making it difficult for non-native students to use them. Moreover, since the majority of these models are available in the Internet, the access to these models requires a Wi-Fi connection that is not available to all.

Students consider that physical models brought them closer to reality, since they could observe the simulation in real time, they could select which variables to test, and they could even change these variables during manipulation. All these aspects make this model more visual and more attractive to students. Nonetheless, students pointed out limitations such as

its size, weight and manipulation difficulties (the mechanical engine was too sensitive and required soft movements or else it wouldn't work correctly).

The authors consider that this type of model is indeed more interesting than the computational model, and it is more capable of motivating students during class. Furthermore, it gives more freedom to the teacher, since he may decide which variables to explore, or even delegate that decision to students. But this advantage is equally a limitation since this model requires that teachers hold a consistent knowledge of both the model and all its characteristics and applications. According to Model-Based Learning, students should also think about the model they will need to develop and how to build it. This study did not address these difficulties since it was not possible to build a wooden model and the mechanic motor during classes, which lasted for four hours. This is probably the biggest limitation of this type of model – building the model. Considering that the length of the majority of science classes in Portugal, including secondary school, is approximately of (and at the most) two hours, a rather limited time, it is very difficult for students to reflect upon, plan and build the model. Moreover, to build a model that has been carefully thought, or even to develop other resources, requires the involvement of teachers, who also have quite restrictive timetables.

Finally, students found the advantages and limitations of the mixed model to be very similar to those of physical models, a point of view with which the authors agree. But the mixed model is also the clearest of all, and it is the only one that allows simulation and observation simultaneously – the simulation of the phenomenon and the registration of seismic waves. This is very important since mixed models have allowed students to observe the occurrence of the entire phenomenon, including the reception of the signal in a seismograph, in a way similar to what happens in Nature.

Categorizing models is relevant since it helps to organize them according to their characteristics and purposes, but especially because it helps students to understand that many different models can represent the same given phenomenon. Moreover, by helping to perceive the importance of models, model categories also help students to construct robust and coherent mental models about the phenomenon (Boulter and Buckley, 2000). This study showed that the application of different types of models to teach a scientific subject helps students to recognize the potential and limitations of models, as well as to better understand the phenomenon, since they can explore it through different approaches. Bearing this in mind, we believe that the use of different types of models, or the use of models that include many components, such as mixed models, can promote meaningful learning.

iii) Finally, one major purpose of the study was to understand the potential of different types of models in the process of restructuring mental models and developing meaningful learning in graduation students, with special focus given to computational, physical and mixed models. Data analysis of both pre and post-test showed that students improved their results, indicating that they developed knowledge on the subject. In addition, with the help of the Wilcoxon test, the hypothesis that the average of results in post-test was equal to the average of the

results in pre-test was rejected, at a high confidence level, thus proving the results to be significant.

Moreover, the results obtained through the analysis of SMES showed that mixed models are the best at promoting the construction of students' knowledge (including restructuring their mental models), and developing meaningful learning. These results were expected from the very beginning. Considering all the characteristics of computational models and physical models, the development of a model that integrated the characteristics of both was perceived as relevant. This mixed model minimized the limitations of both models and improved the process of knowledge construction.

The limitations of this study are also worth noting. Firstly, access to students' mental models was only indirectly possible, through what students expressed. Accordingly, there is no way to ensure that students' answers were not influenced by external factors. Nonetheless, in order to minimize this limitation, different data collection instruments were applied and different activities were undertaken during the intervention program, helping us to confirm that the models voiced by students indeed corresponded to their mental models.

Another limitation of this study relates to the difficulty in planning lessons according to this methodology. The implementation of Model-Based Learning requires time for activities and discussion with students. Both are essential to this methodology and both require much time in class. This was taken into account during the preparation of the IP. It is important to reflect on this issue, since it pertains to difficulties that teachers face in their daily routine at school/college, and which can discourage the implementation of this methodology.

ACKNOWLEDGEMENTS

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APPENDICES

Appendix 1

Pre and Post-Test

For each question, classify the sentence as True, False or Don't know, noted with a X in respective square. Next, please select only one option (a, b, c or d), which justify the previous sentence. If you choose option d, write an explanation that you consider more appropriate.

1. Rayleigh waves (R) are superficial waves. ☐ True ☐ False ☐ Don't know Because: a) They are extremely destructive waves. b) Their amplitude rapidly decreases with depth. c) S waves are surface waves. d) Other._____ _____	**4. Soil slope is responsible for the vulnerability of a region.** ☐ True ☐ False ☐ Don't know Because: a) Vulnerability corresponds to alterations caused by human actions which influence its behaviour. b) The only relevant factor is soil composition. c) Soil slope is responsible for the increase of seismic intensity. d) Other._____ _____
2. Modified Mercalli Scale measures the seismic magnitude. ☐ True ☐ False ☐ Don't know Because: a) Modified Mercalli Scale measures seismic intensity. b) Modified Mercalli Scale measures the energy release in the seismic focus. c) The maximum magnitude of an earthquake is 10. d) Other. _____ _____	**5. Artificially filled grounds which are created to construction levelling have high seismic effect.** ☐ True ☐ False ☐ Don't know Because: a) Artificially filled grounds are constituted by unconsolidated soils. b) Artificially filled grounds are constituted by different types of rocks. c) Seismic intensity effect is not considered in artificially filled ground. d) Other._____ _____
3. Regions located in granitic massifs have a null seismic amplification effect or even a mitigating effect. ☐ True ☐ False ☐ Don't know Because: a) Granite is an unconsolidated rock.	**6. Building construction influences the seismic risk in a region.** ☐ True ☐ False ☐ Don't know Because: a) Seismic risk depends on regions' vulnerability. b) Only the soil properties influence the seismic risk.

b) Seismic amplification effect is almost zero in soils constituted by firm rocks. c) Granite is always an earthquakes' resistant rock. d) Other. _____ _____	c) Some materials and techniques used in building construction give them a weak response to seismic waves. d) Other_____ _____
7. Earthquake is felt with more intensity in a region with sandy soil than a granite soil. ☐ True ☐ False ☐ Don't know Because: a) Sandy soils have a higher seismic intensity effect. b) Granitic soils have a higher seismic intensity effect. c) The intensity which people feel the earthquake depends on the structure of the buildings that are located in each region. d) Other._____ _____	**10. Seismic effect is very important on the evaluation of soil response to the effects of seismic waves.** ☐ True ☐ False ☐ Don't know Because: a) Soil response depends on its composition and the aggregation degree of its components. b) Soils from nearby regions have a similar seismic intensity effect. c) The human action on soil influences its response to an earthquake. d) Other._____ _____
8. People located in nearby regions feel the earthquake with same intensity. ☐ True ☐ False ☐ Don't know Because: a) People from regions located at the same distance to the epicentre, feel the earthquake with the same intensity. b) Soils where people are located during an earthquake may have different responses to the seismic waves. c) People have different sensitivity to feel the earthquake**.** d) Other. _____ _____	**11. Earthquakes could be predicted.** ☐ True ☐ False ☐ Don't know Because: a) Earthquakes' prediction is important to minimize damages on buildings and population. b) Nowadays there are many techniques and instruments used to predict the earthquakes. c) There are many instruments and techniques which allow us to study the seismic hazard in a region, however it is a non-deterministic natural phenomenon, and its prediction is most of the time impossible. d) Other. _____ _____
9. Hazard is a factor responsible for the existence of soils with high seismic risk. ☐ True ☐ False ☐ Don't know Because:	**12. Earthquake effects could be "controlled" if people are accordingly educated.** ☐ True ☐ False ☐ Don't know Because:

a) Hazard refers to natural factors which influence soils' seismic response.
b) Hazard includes peoples' behaviour, which influence soils properties.
c) The most significant factor is vulnerability.
d) Other. _____
    _____
	a) Population does not have any change to survive during an earthquake.
	b) People education includes learning some safety measures to adopt during an earthquake.
	c) During an earthquake, population turns vulnerable, and provokes unexpected results.
	d) Other. _____
	    _____

Appendix 2

Coefficient of Simple Congruency is used when all the variables or dimensions have the same weight in the evaluation. The formula is:

$$Cij = 1 - \left(\frac{D_{ij}}{D_{max}}\right)$$

Cij, means the Simple Congruency of the values
Dij, means the Euclidean Distance between profiles in a p - dimensional space, and its formula is:

$$Dij = \sqrt{\Sigma_{k=1}^{p}\left(X_{ik} - X_{jk}\right)^2}$$

D_{max}, means the Maximum Distance lied for the common scale of the p – dimensions, and its formula is:

$$D_{max}, = T\sqrt{p}$$

Where: $k \in \{1,2,...,p\}$
p, is the Number of dimensions of the profile
Xik, is the value of the profile i in the dimension k
X jk, is the value of the profile j in the dimension k
T, is the difference between the maximum and the minimum values of the scale.

The formula for the **Configurational Similarity coefficient** is:

$$CS = \frac{\Sigma_{k=1}^{p}|d_{1(k)} - d_{2(k)}|}{\Sigma_{k=1}^{p}|d_{1(k)} + d_{2(k)}| + \Sigma_{k=1}^{p}|d_{1(k)} - d_{2(k)}|}$$

Where: $k \in \{1,2,...,p\}$
p is the Number of dimensions of the profile
If $k = 1$ then $d_{i(k)} = d_{j(k)}$
If $2 \leq k \leq p$ then $d_{i(k)} = X_{i(k-1)} - X_{i(k)}$ and $d_{j(k)} = X_{j(k-1)} - X_{j(k)}$
$d_{i(k)}$ is The Difference between successive values of the *Xi*
$d_{j(k)}$ is The Difference between successive values of the *X j*

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