GEOLOGY IN THE LAB: PRELIMINAR STUDIES FOR VALIDATING A CHECKLIST FOR ANALYSING MODELLING ACTIVITIES IN TEXTBOOKS

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Abstract

Models and modelling activities play a central role in the making and understanding of science [1], making the learning of science more meaningful and helping students to build appropriate mental models [2, 3]. When students learn with models, they build mental ones that are more consistent with scientific models. This reconstruction process is generally complex and generates many cognitive conflicts. It was only in the early 19th century, when J. Hall (1761-1832) resorted to models to corroborate plutonism, that geology, an eminent field science, became a laboratory science. Throughout the years, these models became dimensioned with rules of proportionality, thus acquiring the status of representations of natural phenomena. In the last 30 years experimental modelling has been a subject of fruitful research, mainly using the classic tectonic *sandbox* models to control parameters for the structural evolution of mountain belts [4]. However, models were integrated in geoscience textbooks for educational purposes and, veiled behind them, many mandatory analogue properties, which are required for research purposes, where forgotten. In fact, many of those modelling activities didn't resort to analogue materials with similar geologic properties, nor did they respect the dynamics, kinematics and geometric similarities. Indeed, respecting the similarity rules is a difficult, time-consuming and an expensive process that may not be justified in some educational purposes. However it is necessary that teachers and textbooks have correct information regarding modelling activities and the kind of analogy they provide. The reduction of time and of space that underlays those geoscience lab activities, as well as the heuristic rule of the models used in geoscience classrooms, needs to be well explained to students. Thus, it is worthwhile to analyze the modelling activities in geoscience textbooks, in order to evaluate their nature and whether or not the syllabus purposes can be accomplished. To do so, an instrument designed to analyze model activities of geoscience textbooks was developed guarantying a reliable, comprehensive and systematic study. Bearing in mind some items and issues that arose from other instruments designed to analyze lab activities, and after reviewing the literature, a first version of the checklist was developed. It encompassed three main dimensions: type of lab activity; type of manipulation of variables; type of models. All three dimensions included a few sub-dimensions further specified. As in other studies [5], the sub-dimensions emerged from the literature as well as from our knowledge on how lab-modelling activities are dealt with in science textbooks. Four researchers carefully undertook the process of analyzing the 35 lab activities from three geoscience textbooks, in two rounds. The results of the first round were presented to all researchers in order to promote reflection and an improvement of the checklist. A consensus was established after the second round, which was applied one month after the end of the first analysis. Although developed by resorting to Portuguese textbooks, the checklist may be used as a referential for a more comprehensive and meaningful analysis of textbooks from other countries, a task that can be regarded as a follow up study, further increasing its validity.

Keywords: checklist, geoscience education, modelling, preliminary studies.

1 INTRODUCTION

Both in the field of neuroscience and of cognitive psychology, acknowledged studies value the role of mental models in the construction and understanding of knowledge [6]. Likewise, studies of educational nature reinforce the relevance of knowing the higher cognitive processes that are inherent to the individual construction of these structured representations, that accompany each subject in the understanding of the world, his experiences, knowledge and emotions [7] Although they are often scientifically inconsistent, these representations are developed by individuals so as to respond to the

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challenges of everyday life, helping them to face problems that require daily resolutions. However, once formed, these models are useful mechanisms for assigning meaning to what we observe [8].

The polysemy that is inherent to the concept of model and its many classification taxonomies, justifies a clarification of the meanings that we herein consider. By *mental model* we understand a personal model built by the individual to represent a part of the world, and that can expressed through action, speech, writing and drawing [9]. The *scientific model* corresponds to the model that results from the specific work of a scientist, and is meant to represent an idea, an object, an event, a process or a system. They correspond to conceptual models scientifically accepted, and reflect the ways of the reasoning of the scientist [10]. Nonetheless, these models are generally complex and require some simplification so as to be taught in the science classroom. Such simplification, used for teaching purposes, is designated by *curriculum model* and conveys science at school level [10]. However, it is necessary that the teacher resorts to *teaching models*, built with the specific objective of helping students to learn some aspects of a particular curriculum model. Thus, the *teaching model* corresponds to an approximate representation of a part of reality, that is designed with the purpose of promoting its understanding by the student. In its broadest sense, it is the teaching model that supports the teaching mediation responsible for the transformation processes of scientific knowledge (scientific model) into school knowledge (curriculum model) giving consistency to the students' personal representations (mental models).

To promote the restructuring of student's mental models, in an easy, spontaneous and autonomous way, is undoubtedly the path required by significant learning. Nevertheless, students often lack the ability to understand the conceptual models that the school tries to teach them (curriculum model). This failure is a result of the memorization of loose propositions and the inability to accept that the laws and definitions are articulated propositional representations that, to be understood, need to be integrated into mental models consistent with those scientifically accepted. They may also result in the development of hybrid models [11] that deviate from either the previous or the desired (scientifically accepted) mental models, integrating components of the two.

By considering the construction of models that recreate natural or physical phenomena and processes [12], modelling can promote the restructuring of student's mental models, increasing their consistency by allowing observation of a simulated reality. In this sense, modelling emerges as a strategy that needs to be developed in the training of science teachers and to be disseminated in primary and secondary schools, enhancing the development of student's scientific knowledge and scientific literacy [13]. Modelling aims at enabling students: (i) to learn *the* science (through the use of teaching models that act as learning facilitators of scientific models), (ii) to learn how *to do* science (through the development and testing of some teaching models) and (iii) to learn *about* science (by building proper views about the nature of models and their role in the development of scientific knowledge) [14, 2,15].

2 MODELS AS INSTRUMENTS FOR GEOSCIENCE RESEARCH

It was Sir James Hall (1761-1832), today considered the father of experimental geology, who designed and explored some experiences in the late eighteenth century, so as to test the vision of Hutton. However, his geochemical experiments failed, because of the difficulty in melting quartz and because sands did not agglutinate so as to form a rock, thus making it impossible to prove the plutonic origin of the sandstone by the action of both pressure and temperature. The literature states [16] that his attempts ended with the need to add crystallized salt to the water as a way of cementing the sands, a fact that, ironically, almost led him to corroborate the Wenerian perspective. On the other hand, Hutton, his master, radically opposed to the use of experimentation, arguing that it was impossible to infer from the results obtained in the laboratory, since the magnitude scale of reality and that of the models were not correlated [16].

Nevertheless, with Hutton's death, Hall (1815) re-emerges with experimental modelling and obtained amazing results with his device, that became, for one hundred years, the prototype of physical model in geological research. Despite the success that Hall had in demonstrating the importance of horizontal compression in the formation of folds, it took about 50 years before other researchers continued the path of experimental geology [4]. Experimental geology had an expected slow progress and studies related to scales in experimental models also evolved, particularly with the work of King Hubbert (1903-1989), who researched the physical realism of modelling experiments evaluating the scope and the significance of the results of this experimental technique [4]. It was this author who laid the foundations of scale representation in analogue modelling and the definition of conditions of similarity, which have become fundamental in experimental geology [17].

Building scale models, as proposed by Hubbert, revolutionized analogue modelling, by turning it into a quantitative technique that guaranteed physical similarity and therefore defined it as an efficient and reliable tool in the study of tectonic processes [17]. He was the first author to address in a fully quantitatively way the issue of the choice of the physical properties of analogue materials, to be used in models designed on a rather reduced scale and time. At the time, and still, the rheology and the mechanism of natural systems are modelled using physical materials such as clay, water, sand or silicone putty. [4] The principles of compressive forces used in the nineteenth century are still in existence, but instead of manually simulating forces with the help of pistons, today sophisticated electric engines are used, or else, speeds are programmed with computers [17]. *Sandboxes* (as known in the literature) are still used today, since it is relatively easy to make analogue (representative) comparisons with reality, using calculus that resorts to equations and the ratio of proportionality between nature and the model (the boxes) [4].

In the first half of the twentieth century the use of experimental models increased and the development of economic models began, a fact that helped to boost up the use of modelling in laboratories of experimental tectonics and in the classroom [4]. However, although designed with the same representativeness rules and resorting to analogue materials, these physical models can only control some of the parameters and properties involved.

From the second half of the twentieth century numerical models, emerged in geological research; in these models, equations mathematically describe several parameters and properties under study, and computational systems calculate the dynamics and the evolution of the model [4]. These models play a fundamental role in geological research, and their role is no less important in education in geosciences [18,3,19], since they allow the clarification of substantive knowledge, the experimental manipulation of variables, the development of reasoning by analogy and the reconstruction of the student's mental models.

3 MODELS AS RESOURCES FOR GEOSCIENCE TEACHING

Although an inquiry model-based learning approach has already presented evidences of its success, not many geoscience teachers apply this strategy in the classroom and usually show a limited knowledge about models and modelling [20]. The models that usually appear in science textbooks and are used in the classroom (lessons activities) do not make any reference to its role in the scientific knowledge elaboration process. The majority of them are not dynamic, and although meaning to aid the process of building the students' knowledge, they frequently do not help them to develop mental models similar to the scientific ones.

However, scientific models are considered to be crucial not only for the scientific practice, but also in science education. Indeed, models and modelling play a central role in the making and understanding of science [1], making science-learning more meaningful and favoring the development of appropriate mental models [2, 3]. Moreover, according to some authors [15], models and modelling help students (i) to learn *the* science, as students may learn significant scientific and historical models; (ii) to learn how *to do* science, as students may create and evaluate their own models and (iii) to learn *about* science, as students may develop an adequate view of the nature of models, as well as about the nature of science and thus become capable of appreciating the role of models in the accreditation and dissemination of the outputs of scientific enquiries. In fact, understanding scientific models becomes a crucial element of understanding how science works [21].

Models are powerful tools that scientists use for developing scientific knowledge. As a result, models and modelling activities in science classes may contribute to the understanding of several aspects regarding the nature of science, as they contribute to the understanding of the tentative nature of models, the role of creativity in their design and their multiplicity [22].

A model is a representation of a target, and it is considered to be a mediator connecting a theory and phenomenon [3]. Models can also represent a variety of targets, which are represented for some purpose [3]. In fact, a model does not copy reality; it consists of a representation of reality that varies with our purposes [23]. Although scientific models are undoubtedly important in science education they play an even greater role in geoscience education. In fact, geoscientists resort to comparisons and scientific models, as they deal with processes and forces that cannot be directly perceived [18]. However, although the Portuguese Geoscience Curriculum highlights the use of models in geoscience classes, some caution should prevail when resorting to models in the classroom, since many students may perceive them as replicas of the reality [24]. Thus, students should be made aware of the differences, as well as of the similarities between the target (the real system which is represented) and the model. Due to the characteristics of geological knowledge, it is also important to promote some discussion regarding the complexity of the target and the limitations of the model, as some problems may arise regarding scale issues, velocity of the processes and material representativeness.

Nevertheless, the use of school models to simulate geological phenomena contributes to the development of competencies that are deemed fundamental for the development of the students' geoscience learning and thinking. Modelling may contribute to a better understanding of deep time, as well as to the development of a spatial vision [25]. Additionally, the analysis of the historical evolution of scientific models is crucial for the student's understanding of the science endeavour and its nature.

Considering that teachers resort frequently to textbooks, it is important that they follow a clear and valid conceptualization of models of nature. Thus, it is worthwhile to analyze the modelling activities presented in geoscience textbooks, in order to evaluate their nature and to evaluate whether or not the syllabus aims can be achieved. In order to do so, an instrument designed to analyze model activities of geoscience textbooks was developed guarantying a reliable, comprehensive and systematic study.

4 METHODOLOGY

The previous section shows the relevance of a correct use of modelling in geoscience classes so as to improve science teaching and learning. Accordingly, it is worthwhile to analyze the modelling activities included in geoscience textbooks, so as to evaluate the kind of activities that are suggested and, through them, to infer about the teachers' and students' understanding on models and modelling. A first version of the checklist was developed (table 1) bearing in mind some items and issues that arose from other instruments designed to analyze lab activities, and after reviewing the literature. It focused in three main dimensions, which were considered relevant: *type of lab activity*; *type of manipulation of variables*; *type of models*. All these three dimensions included a few sub-dimensions further specified. As in other studies [5], the sub-dimensions emerged from the literature as well as from our knowledge on how lab-modelling activities are dealt with in science textbooks. They were helpful not only in terms of clarifying the main meaning of each dimension but also by offering guidelines for a more comprehensible analysis, as they better specified the specific aspects that researchers should pay attention to.

The aim of the activity (conceptual knowledge: to know science; epistemological knowledge: to know the nature of science; procedural knowledge: to know how to do science), as well as the thematic of the activity, where addressed by open questions to be answered by teachers after analyzing the syllabus.

Table 1. A checklist for analysing modelling activities in geoscience textbooks.

Dimensions and sub-dimensions (brief explanation)

Type of laboratory activity
- Practical (the student has an active role)
- Demonstrative (the teacher has the active role)
- Explicative (a description is presented in the textbook without any suggestion as how it can be performed)
Type of manipulation of variables
- Experimental work (if students manipulate variables)
- Not experimental (if students do not manipulate variables)
Type of models
- Activity resorting to a model
  - a digital model
  - a two dimension model (teachers make reference to the use of a scale model or not)
  - a three dimension model (a physical model is presented; teachers state whether students build the model or just prepare the activity):
    • replica of an historical geoscience model (dynamic or static)

- not a replica of a geoscience model (dynamic or static)
- teachers clarify if the model establishes analogies or if it uses analogue materials or if it holds any analogies similar to those used in scientific research.

4.1 Validation of the checklist

The selection of the textbooks was not random. In order to develop a checklist suitable for analyzing modelling activities in geoscience textbooks, we chose manuals that better showed the existing differences in respect to our aim of study. Accordingly, we chose textbooks that showed different kinds of geoscience modelling activities, their use and how they are performed. Three textbooks were chosen from the publisher that sold more books to secondary school geoscience classes in the last years. Since different authors wrote these books we considered that they embodied the diversity of the modelling geoscience activities in use. The three selected textbooks are presently in use in Portuguese schools (2014-2015 academic year).

One way to assure the reliability of a research instrument is to evaluate the instrument twice (two rounds), by different researchers. If a consistent analysis is found we can assure the reliably of the research instrument. Accordingly, four researchers carefully undertook the analysis of the 35 lab activities (included in the three geoscience textbooks), in two rounds, with a month in between. After the first round the results were discussed and the significance of the categories of the checklist was clarified. The results of the second round evaluation point to a good reliably of the checklist, since the four researchers that independently analysed the textbooks came to a very similar codification of the activities. A general consensus was obtained, but difficulties remain regarding some specific activities. As such, the four researchers will analyse the textbooks one last time, one year after the first application of the checklist, in an attempt to reach a final consensus.

5 RESULTS

A checklist was developed building up from the literature. The results of the first round application of the instrument where given to the four researchers so as to promote thinking and an improvement of the checklist. After the second round, which was applied one month after the end of the first analysis, a general consensus was reached. Since some difficulties related to some specific activities still persist a final analysis will be made one year after the first application. We believe that the checklist herein presented covers some significant aspects of geoscience modelling activities, as mentioned on the theoretical framework. Nonetheless, we also believe that a final study is required so as to obtain a final consensus.

Our major concern was the validation of the checklist, but some attention was also given to the results regarding the modelling activities. Many of the activities were not experimental and did not resort to a model. When a model was used, it was usually already made, and students only manipulated one or two variables. Some materials were authentic (vg.: rocks, mineral, water…) but no scaling was performed and students did not necessarily realize that a reduction of time and space took place in the classroom.

6 CONCLUSIONS

Although developed by resorting to Portuguese textbooks, the proposed checklist can serve as a referential for a more comprehensive and meaningful analysis of textbooks from other countries, a task that can be regarded as a follow up study, increasing its validity. We are confident that the checklist can be used to quantify and to stand as the basis of a more comprehensive qualitative analysis, especially if complemented with other ways of measuring this kind of modelling activities.

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