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History and Nature of Science enriched Problem-Based Learning on the origins of biodiversity and of continents and oceans

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Abstract
The episode of the History of Science (HOS) on the theory of continental drift proposed by Alfred Wegener has been considered an excellent example for teaching students aspects of Nature of Science (NOS) and the relation of Science with social and technological contexts. We implemented a NOS and HOS-enriched Problem-Based Learning environment at the middle (year 7 of the Portuguese National Curriculum) and secondary level (year 10) for teaching the origins of biodiversity and of continents and oceans (mobilism).
The main objective of this study was to provide implementation practices to address the lack of guidelines of how to use Problem-based learning (PBL) in classrooms for 12 to 16 year old students. This constitutes the first practical example of implementation using Wegener's episode of HOS for teaching geological mobilism integrated with evolution. Therefore, in this study, we provide specific suggestions for supporting teachers' classroom efforts in implementing PBL, such as the appropriate scaffolding.
The ill-problem presented to students was based on the phylogeny of extant and extinct ratite birds, described by Charles Darwin and the present geographical distribution. The evaluation of the students was focused on the chain of reasoning employed, and we performed a comparison analysis of the problem's solution presented by the students of both classes regarding the explanation of the phylogeny of ratites based on geological mobilism. We observed an overall improvement (25-77%) of the percentages of students pre- and post-instruction adequate answers; therefore our PBL strategy was efficient.

Keywords Problem-Based Learning; History of Science; Nature of Science; scaffolding; geological mobilism; biodiversity.

1. Introduction

Problem-based learning (PBL) is an instructional and curricular student-centered approach that requires that students apply knowledge and skills to propose a viable solution to a given problem (Savery 2006). While PBL can come in a variety of forms, it is generally characterized by using problems as triggers of learning and is usually associated to educational aids that support learning, including: the collaboration of the students in small groups, the metacognitive guidance of a tutor and the self-directed learning activities of the students (Sousa 2007). According to Ertmer and Simons (2006), PBL has a long history of successful use at college level, mainly in medical and pre-professional students, but has yet to be widely adopted by K–12 teachers, due to several challenges and constraints, such as, in case of portuguese schools, time available and mandatory number of students in the classroom.

The understanding of scientific epistemology is beneficial and encourages public engagement since knowledge about *how science is done* is useful because citizens need to make systematic, rational decisions about scientific projects, either about their ethical implications or about the public funding to be allocated for scientific projects, for example by voting in referendum. So, scientifically literate students should exit formal schooling (at the end of year 12 of the Portuguese National Curriculum) with knowledge about science core ideas and aspects of Nature of Science (NOS); this expression - nature of science - typically refers to the epistemology of science and to the science as a way of knowing (Abd-El-Khalick and Lederman 2000).

During part of an academic year we implemented a History of Science (HOS) and NOS enriched Problem-Based Learning environment at the middle (year 7 of the Portuguese National Curriculum) and secondary level (year 10) for teaching the origins of biodiversity and of continents and oceans (geological mobilism). At the level of middle school the discipline in the Portuguese curricula that includes Biology and Geology contents is named Natural Sciences, and according to the curriculum guidelines it is divided into four organizational themes: “Earth in Space”, “Earth in Transformation”, “Sustainability in the Earth” and “Living Better on Earth”. The study presented in this article focuses on the theme “Earth in Transformation”. Within the curricular organization, corresponding to the level of middle school, there are two main guiding texts, such as the Essential Competences (DEB 2001) and the Curriculum Guidelines (DEB 2002), that defines the competences to be developed across the various disciplines and defines the specific competences of each discipline, respectively. According to Ferreira and Morais (2013) the absence of guidance, in these texts, has led teachers to merely teaching science topics and the relation between science and technology. Therefore, in this study, we provide specific suggestions for PBL implementation and supporting teachers’ classroom efforts in scaffolding student learning including aspects of NOS.

The ill-problem that we presented to students, without a single correct answer, was based on episodes of HOS, including Charles Darwin’s work, mainly evolution mechanisms that explain the biodiversity, in his book *The Origin of Species: by means of natural selection*, and phylogeny of some ratite birds, as well as Alfred Wegener’s continental drift theory, in his book *Die Entstehung der Kontinente und Ozeane* (*The Origin of Continents and Oceans),* since both episodes have been considered excellent independent examples for teaching students central aspects of NOS (Jacoby 2012; Lederman *et al.* 2002). Khishfe and Lederman (2007) have considered that the aspects of NOS might be taught successfully if integrated in real-life controversial science issues, therefore we decided to choose the historical controversies, due to the socio-scientific context, around the acceptance of the idea of geological mobilism and of evolution, which both illustrate several aspects of NOS. Furthermore, this study constitutes the first practical example of implementation using this episode of HOS for teaching geological mobilism integrated with biodiversity and evolution.

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We used inquiry activities - also known as *hands-on and minds-on activities* - and promoted the discussion of aspects of NOS by the students that is a partial match of the discussions occurred throughout History, raising their dissatisfaction with some of their own misconceptions on aspects of NOS. This is the first step for conceptual change and it motivates students since it constitutes a challenge for further learning.

Several studies showed that middle school students in optional-scaffold conditions performed significantly better than students in a no-scaffold condition (Kirschner *et al.* 2006; Schmidt *et al.* 2011), so, in this study, we used hard scaffolds for the seventh graders, and in both classes, the author (in the role of PBL's tutor) used challenging and motivation questions - soft scaffolds - to generate cognitive conflicts and to guide students to establish linkages and relationships between concepts. PBL implementation in classrooms, of 12 to 14 year old students, is still relatively uncommon because of many challenges and barriers (Liu *et al.* 2012), however, we propose a modified PBL strategy that includes adequate scaffolding for each grade level in order to improve learning outcomes. We developed hard scaffolds, for seventh graders, based on expected learner difficulties associated with the task, such as: an inquiry activity based on a puzzle activity adapted from USGS (2008) that includes Wegener´s arguments, and an exploration worksheet for Google Earth (tectonics), including questions that the students should go through, and that constitute intermediate results, of the problem-solving learning process on the type of plate limits associated with each geological phenomenon. Some metacognitive tools were also used for both grade levels and can be considered learning scaffolds, such as: concept maps and heuristic V diagram. Recent issues related with these episodes of HOS were also included either in the problem or as a learning outcome, such as, the phylogeny of extant and extinct ratite birds and their present geographical distribution (Lieberman 2005) and the tectonics theory that integrates the continental drift theory.

In summary, the purpose of this educational action research was to propose an effective teaching-learning strategy that improves understanding of concepts, and their relationships, as well as students' views of nature of science, using episodes of History of Science. We tested whether there was an improvement on students' views of nature of science and selected scientific topics by a problem-based learning that highlights two relevant episodes of the History of Science.

2. Methodology

This study is the result of a one-academic year educational action research project (during a 7 months period) and constitutes an exploratory study containing a qualitative analysis of results.

2.1. Participants

Study participants were students from the same public school, at a portuguese public school (Oporto city, Portugal), and either of the seventh grade class (middle school, with age from 11 to 14 years, and 12 years as median age) or the tenth grade class (high school, with age from 14 to 16 years, and 15 years as median age) that willing to participate in the study had the corresponding informed consent signed by the parent/person responsible for education. The author participated in the instruction by teaching the corresponding curricular units to all the students of both classes.

2.2. Educational interventions

Our teaching strategy was mainly student-centered, and we used a PBL methodology that included an ill-structured problem, as well as appropriate learning scaffold activities for each level. And for the tenth grade students, we also included lectures, by scientists

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(principal investigators) with relevant expertise regarding each of the focus themes (Geodynamics, Paleontology and Biogeography), that included questioning and discussion (60min total, each).

All the themes are included in curricular units of Geology (continental drift theory and its role on in the development of tectonics theory) and Biology (biodiversity and evolutionary history of birds' species). The aspects of NOS were distributed throughout the units and taught as embedded within the curricular content by promoting discussion on these aspects, in small groups and with all students in class. We summarize the characterization of our learning environment for 7th grade level and for 10th grade level, that may constitute future guidelines for other teachers (Table 1).

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Table 1. Overview of PBL's learning environment for each science topic of 7th and 10th grade level.

Discipline	Science topic	PBL's learning environment
Natural Sciences (7th grade level)	- Continental drift theory - Plate tectonic theory - Biodiversity and species' geographic distribution	- NOS integrated-PBL in the lesson about HOS: alternative explanations to continental drift theory (before 1912 and 1912-1960), Wegener's evidences and inferences, social context and oppositors to the theory, technological advances and theory acceptance. - Problem-solving presented in an exploration worksheet for Google Earth (tectonics) on the type of plate limits associated with each geological phenomenon. - NOS integrated-PBL in the lesson about the historic episode of Darwin including explanation of geographic distribution of ostrich, rheas and their common ancestral (in Gondwana).
Biology and Geology (10th grade level)	- Continental drift theory - Plate tectonic theory - Biodiversity and phylogeny	- NOS integrated-PBL on the historic episode of Wegener: alternative explanations to continental drift theory (before 1912 and 1912-1960), Wegener's evidences and inferences, social context and those contrary to the theory, - PBL lesson on technological advances and integration of continental drift theory in plate tectonic theory and subsequent lectures by experts, - Problem-solving presented in an exploration worksheet for Google Earth (tectonics) on the type of plate limits associated with each geological phenomenon and predictable future geological events for each geographic area. - NOS integrated-PBL in the lesson about the historic episode about Darwin including description of geographic distribution and phylogeny of extinct and extant ratites species and common ancestral of ratites (ostrich, rheas and moa); and the role of geological mobilism on these.

We started with a small problem - a PBL subunit - that included the main question “Of all the arguments presented that support his theory, which one do you think is the most convincing argument? Why?”, since the students were unfamiliar with PBL. In the seventh grader level we provided, as handouts, the description of the arguments that one considered relevant for their age/level: morphological, paleontological, paleoclimatic and lithological arguments.

The handouts containing the description of the arguments constituted a hard scaffold that facilitated the research of relevant information by each student. For the tenth graders we provided, to each small-group of students, a handout containing additional, and more complex, arguments (geophysical and stratigraphical), and they were asked to propose an answer to the same problem ("Of all the arguments presented that support his theory, which one do you think is the most convincing argument? Why?"). On this first learning phase, we also proposed to the seventh grade students a concept map to be completed by each small-group, since the students were unfamiliar with this tool, based on the concepts about the continental drift theory, by Wegener in 1912, that proposes the existence of horizontal movement of continents responsible for the supercontinent Pangea fragmentation from 300Ma ago, and in his theory supported by scientific arguments.

Then, we proposed to the seventh graders, an inquiry activity, based on a puzzle activity adapted from USGS (2008), that includes four types of Wegener´s arguments and requires the use of all arguments to be successfully completed (Sousa 2013).

Subsequently each small-group explained to the author/tutor their proposed solution for the activity and to the question proposed before. This activity allowed students to understand the importance of considering all the evidences obtained by different sciences.

It was also provided an hard scaffold to all students - an exploration worksheet for Google Earth (tectonics) - that includes questions that the students should go through, and that constitute intermediate results of the problem-solving learning process on the type of plate limits associated with each geological phenomenon.

Biodiversity and non-flying birds (ratites) species' geographic distribution themes were introduced integrated with the theme geological mobilism and in a History of Science context, with the visualization and tutor-promoted discussion of selected parts of the film "Darwin's lost voyage", produced in 2008 by National Geographic, containing parts of Darwin's book. NOS integrated-PBL in the lesson about the historic episode of Darwin included a simple phylogenetic tree regarding the ratites group: the focus of seventh

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graders was oestrich and rheas, while the tenth graders studied the phylogeny of seven extinct and extant ratites species. Students were asked to characterize the geographic distribution of their common ancestral and explain the geographic distribution of the other species based on their knowledges on geological mobilism.

2.3 Instruments and data collection

The questionnaire for seventh grade students consisted of open-ended and multiple choices items, and the questionnaire for tenth grade students consisted of open-ended items. These questionnaires were composed of several types of questions: questions about single concepts, questions about the relationships between concepts and questions that assess alternative conceptions and prerequisite knowledge.

The items were developed and, next, a panel of experts examined these items to establish their validity (one university professor and a science educator), and then the items were modified according to the panel's comments and suggestions for improvement.

Data was collected using pre and post-test students' responses to the questionnaire (prior and by the end of the unit, respectively).

3. Results

The most common proposed answer to the small problem - "Of all the arguments presented that support his theory, which one do you think is the most convincing argument? Why?" - was different in each class, that is, the most frequent answer by tenth graders was paleontologic arguments (4 out of the total 6 groups), while morphological arguments was the most frequent answer by seventh graders (4 out of the total 7 groups).

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The overall improvement of the seventh grade student's views of NOS and knowledge of the science topics was evaluated by their responses to each aspect, corresponding to an item of the questionnaire (Fig. 1).

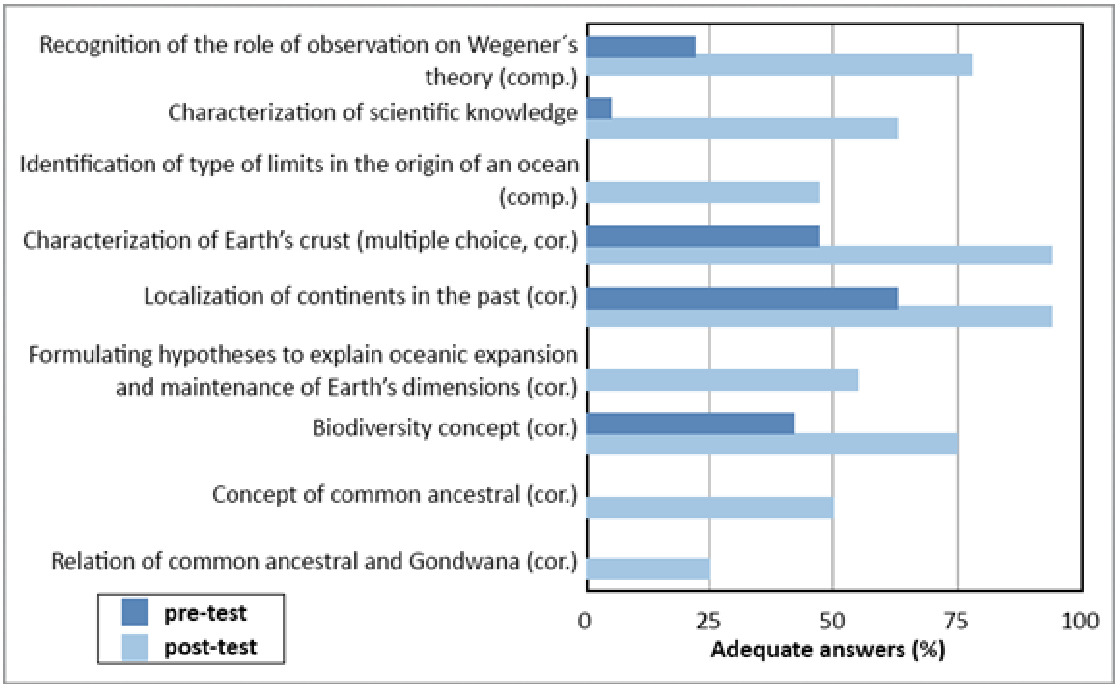

Figure 1. Comparison of pre and post-test results of middle-school students: pre-instruction and post-instruction adequate answers of seventh grade students for each question (as percentage). Note: n=16; adequate answers consists of either complete answer (comp.) or correct answer (cor.).

The overall interval of gain in the percentages of adequate answers (including complete and correct answers) is 25% to 58%.

All the groups were able to explain and justify their answer to the other students in the classroom, and by the end of this small PBL unit all the students understood the importance of all the types of arguments for Wegener's theory, as well as several consensus aspects of NOS, such as: empirical, creative and inferential. We observed an

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increase of percentage of adequate answers to items regarding aspects of NOS between 55% and 58% (Fig. 1).

The final product asked to the students, by the end of the instruction, was a power point presentation and a written mini-essay, elaborated in small-groups, on “What is the role of geological phenomena in the evolution and geographic distribution of species through Earth’s history?”, that was successful for all the groups evaluated with Good or Very Good.

We observed an overall improvement of the responses by the participants (tenth graders) for each aspect, corresponding to an item of the questionnaire (Fig. 2).

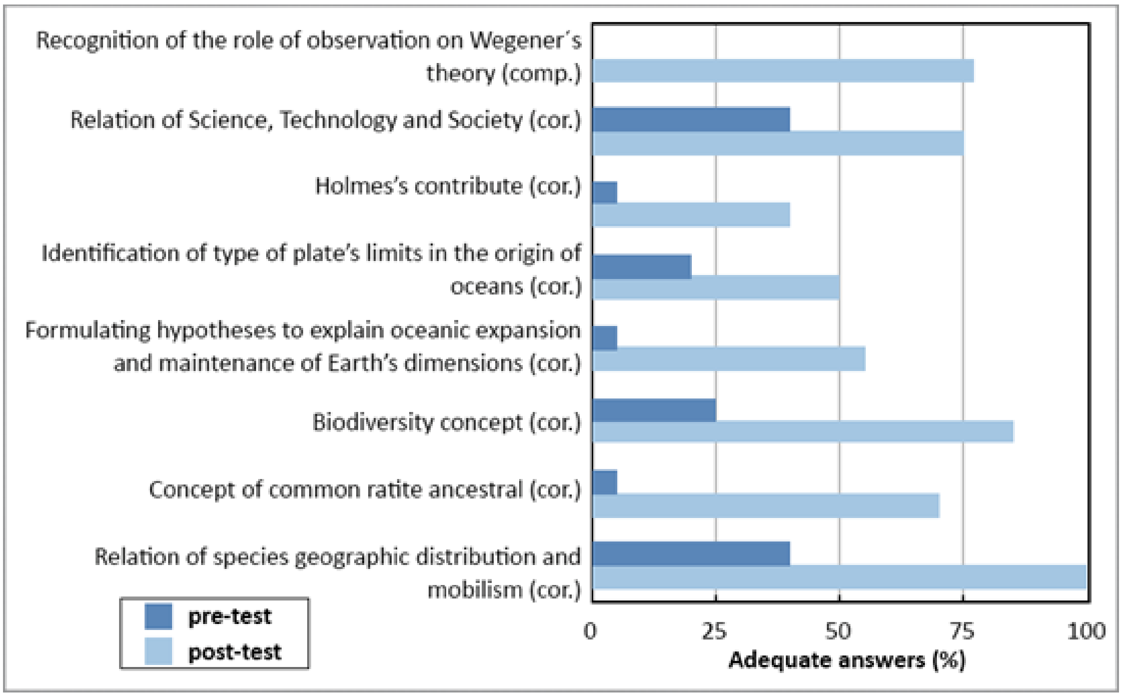

Figure 2. Comparison of pre and post-test results of high-school students: pre-instruction and post-instruction adequate answers of tenth grade students for each question (as percentage). Note: n=20; adequate answers consists of either complete answer (comp.) or correct answer (cor.).

At the end of the unit, 77% of the high-school students (Fig. 2) demonstrated an informed understanding of the importance of observations and inferences in Science, since Wegener's observations of the contours of the south-american and african continents contributed to the inference of the existence of a supercontinent, 300Ma years ago, he named Pangea, that also shows the importance of creativity.

The students' views on the subjective and dynamic nature of scientific knowledge at the end of the study were improved, since we observed an increase of 35% of high-school students (Fig. 2) with adequate answer/view, corresponding to an adequate understanding of the role of the technological and social contexts in the acceptance of the theories at any time point.

The understanding of central concepts on the new theory that explains the origins of continents and oceans - plate tectonic theory - was assessed by several items in the questionnaire, such as Holmes's contribute (corresponding to 35% increase of correct answers) and the type of lithospheric plate´s limits found at regions of origin of a new ocean (corresponding to 30% increase of correct answers).

The scaffolding used was adequate to each grade, for example we organized talks (mini-lectures) by experts for the tenth grade, and this activity was one of the activities that the students considered that have a higher contribute on their own learning.

4. Discussion and conclusions

In this article, we describe some specific guidelines for implementation of PBL in K-12 contexts integrating NOS and HOS aspects into Biology and Geology classes. We showed an improvement on students' views of nature of science and selected scientific topics by a problem-based learning that highlights two relevant episodes of the History of Science. In accordance, other authors have described the efficacy of inquiry activities, on

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different themes, with aspects of NOS embedded within the content (Khishfe and Lederman 2007).

Our PBL strategy was guided by hard scaffolds, that were provided as handouts, to the students, during various stages of the learning process that helped students perform a variety of inquiry-related tasks, such as more efficient search for relevant information. We also used soft scaffolding such as some questioning during the learning process by the teacher. The strategy described here was effective as shown in the results obtained in post-tests, however, future research should shed further light on the role of scaffolding to support student performance in PBL.

Results showed that the context of celebrating the centenary of the first public presentation by Wegener of his theory may constitute an excellent learning environment as previously described (San Román, 2012).

We consider that in order to be successful in the implementation of such a novel strategy it is important to start with small problems, mini-PBL subunits, to initiate and engage students, unfamiliar with PBL, as according to other studies (Ertmer and Simons 2006).

Our PBL strategy allowed students to experience multiple opportunities to establish the links between epistemological ideas and biological and geological concepts due to the integration of different views of aspects of NOS within the content from the curriculum. Therefore, the expected efficacy was observed as an increase of percentage of adequate answers to items regarding aspects of NOS between 55-58% (seventh graders) and 35-77% (tenth graders). Some consensus aspects of NOS (Abd-El-Khalick 2012) were the focus of this PBL strategy, such as: scientific theories as systems of explanation which includes results obtained in several fields of investigation; and the characterization of scientific knowledge as empirical, tentative, creative and inferential. Students were able to overcame some of their misconceptions, about oceanic expansion and maintenance of Earth's dimensions, since we observed an increase of 56% (seventh graders) and 50%

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(tenth graders) in the percentage of correct answers to the corresponding item (Figures 1 and 2).

By the end of the unit the students had a good idea of what is known about the relation of the common ancestral of some species of ratites, mainly ostrich, Rheas (*Rhea pennata* and *Rhea americana*) and moa and geological mobilism as it is hypothesized that it lived throughtout Gondwana 100 to 120 Millions years ago (100-200Ma) according to Lieberman (2005); however the phylogeny of their family of species is still quite controversal (Haddrath and Baker 2012).

Our PBL strategy allowed the improvement of attitudes, as described by other authors (Ferreira and Trudel 2012), such as collaboration and may, also, have contributed to the development of friendships among some students that we observed.

Some limitations of this study are recognized, that are mainly due to the number of participants and the specific context within the research project was conducted, however our results are consistent with other studies and allowed the author to contribute with suggestions to the new National Curriculum Guidelines, some of which were included in the final document that will be mandatory for the forthcoming academic years. We will pursue the research with other grades so we can generalize the results to wider contexts.

We recognize the necessity for the development of national and international collaborative structures and actions to support and encourage K-12 teachers in using a PBL approach successfully, since there is a lack of high quality instructional materials and courses for teachers, and an insufficient link between HOS and NOS and science topics in national curricula (Ferreira and Morais 2013) and in textbooks (Höttecke and Silva 2011). Hence, we hope this article will constitute a background that enables other teachers to take their first steps into PBL.

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