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Changes in Students' Nature of Science Conceptions upon a HOS and NOS-Enriched PBL Intervention

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Abstract

History of Science (HOS) can be used as a successful strategy to discuss Nature of Science (NOS) themes in Natural Sciences classes [1]. The present study focused on improving students' views about the Nature of Science upon a short time length Problem-Based Learning intervention about the origin of life, using History of Science relevant episodes. The NOS learning objectives of the intervention were limited to the role of imagination and creativity in scientific investigations, the changing and provisional characteristics of scientific knowledge, and the understanding that the following conceptions are inadequate: unlike theories, scientific laws do not change, and research in Biology around the world is carried out the same way, because Biology is universal and independent of society and culture. Participants were 8th grade students, 13 to 16 years old (Mean = 13.26 and SD = 0.79), at a Portuguese state-funded school (N=34). The educational intervention occurred during the academic year 2017/2018 and its outcomes were evaluated using a pre-/post-test questionnaire and structured observations. The null hypothesis that there are no significant differences on students' epistemological conceptions was statistically rejected considering the results of a Likert scale questionnaire ministered before and after the intervention. The non-parametric Wilcoxon Signed Ranks Test of significance revealed that pre- to post-intervention gains were significant for the targeted objectives supporting the effectiveness of the intervention improving students' NOS understandings. Such results are in accordance with other studies (e. g. [2]) showing that shorter interventions may influence students' NOS understanding. Results also suggest that HOS and NOS-enriched PBL instructional units such as the one in the present study constitute a useful and valuable pedagogical method for Middle School students' learning curriculum contents and aspects of NOS.

Keywords: *Nature of Science, NOS conceptions questionnaire, Origin of life, History of Science;*

1. Introduction

The promotion of scientific literacy faces several obstacles today, namely, the lack of informed insight about what one classifies as Nature of Science ([3]; [4]).

Nature of Science (NOS) refers to the epistemology of science, science as a way of knowing or the values and beliefs inherent to scientific knowledge and its development [5]. In this study we considered NOS including also the aspects of scientific inquiry, according to [6].

The present study focused on improving students' conceptions of NOS, through an instructional intervention that takes an explicit and reflective approach to promote NOS as a cognitive outcome; a strategy described as more effective ([2], [3]) and an integrative approach in which NOS aspects are embedded within the Biology contents [3]. We consider that methods that enhance questioning, communication, argumentation and collaboration are adequate, and we have chosen Problem-Based Learning (PBL) was chosen since we hypothesized that students' analysis of the designed resources, including the problem situation, can induce the cognitive conflict [7] between their prior conceptions and the more informed conceptions of NOS and because PBL is also described as developing skills such as questioning, communication, argumentation, collaboration, decision making, problem solving, critical thinking and autonomous learning [8].

The understanding of NOS is referred as views of the Nature of Science by some authors [9], scientific epistemological views or scientific epistemological beliefs [10], conceptions of the Nature of Science [11] and understanding of science and scientific inquiry [12]. In our study we use the term NOS conceptions, in accordance to [11].

In the present, the most used NOS assessment tool about views of NOS are, probably, the Views of Nature of Science, VNOS questionnaire [9], and the Views About Scientific Inquiry, VASI questionnaire [13]. These questionnaires are constituted by open-ended questions. However, in this study, due to time constrains to complete the questionnaires and the limited knowledge of NOS and writing skills of the students we decided to use a questionnaire for assessment of students' NOS views

with Likert scale items and no open-ended items. We constructed some items, based in literature about the theme and used other items that were suggested and tested before by other authors ([12];[10]; [14]).

We chose to focus this study on some general NOS aspects [6], using History of Science relevant episodes about the origin of life, that constitute the learning objectives of the intervention unit: the necessity of the human imagination and creativity in the development of scientific knowledge [5], the tentative feature of scientific knowledge [5], the relationship between law and theory [5] and the use of different methods by scientists [15].

The following research question was addressed: what are the effects of the Origin of Life learning unit in students' NOS conceptions?

The following null hypothesis was considered: There are no significant differences on students' NOS conceptions, in a Likert scale questionnaire, before and after the Origin of Life learning unit.

2. Research Design

2.1. Outline of the intervention

The intervention consisted of 3 PBL sessions (50 min each). Students were provided with a problem-situation and a learning scaffold related to several theories about the origin of life enriched with an historical perspective, and with NOS aspects. Considering that students have access to considerable amounts of information and the short length of time available for the PBL unit, selected information about each theory was provided. This intervention occurred during the academic year 2017/2018 and was previously authorized by the National General Direction of Education.

2.2. Participants and settings

Participants in this study (N=34) were 8th grade students in two different classes of a Portuguese state-funded school (Oporto region, Portugal). Ages 13 to 16 years old (Mean = 13.26 and SD = 0.79), 18 females and 16 males willing to participate in the study after the corresponding informed consent signed by the parent/person responsible for education. The first author was responsible for the intervention and taught the intervention unit to all the students. The Natural Science teachers of the two classes, as voluntary participants, observed all the lessons.

2.3. Data Collection and Analysis

The impact of the intervention was assessed using a mixed-methods approach using a pre-/post-questionnaire (with items in a Likert scale) and qualitative analysis about the observation of the classes.

The NOS conceptions questionnaire is under development, in which some items were adapted from other authors ([11], [12], [14]] that were contacted and authorized their use while others were constructed based on literature about the theme (e. g. [16]). Previously, a panel of 4 experts (educational scientists, faculty professors and a middle school teacher) validated the content of the questionnaire. The adequate time for students to complete it was assessed and provided, and an adjustment to the vocabulary was performed. The quantitative responses were analyzed, using the software Statistical Package for the Social Sciences (SPSS), the Wilcoxon Signed Ranks Test (Z and p are presented in Table 1), and the effect size (r) was calculated according to [17].

We also designed an observation instrument regarding PBL facilitation, with a 1 (never) to 5 (always) Likert scale. Some items were of our own authorship and some were based on instruments designed by other authors [18] and [19] that were contacted and authorized their use; one instrument was applied for participatory observation (including observation of each group of students) and another one was applied to the teachers who observed the classes.

3. Results

3.1. Testing the null hypothesis: There are no significant differences on the students' NOS conceptions, in a Likert scale questionnaire, before and after the Origin of Life learning unit.

A comparison of students' responses from the pre- and post-test showed improvement of student's NOS understandings regarding some NOS aspects.

Students showed the most change (r = 0.41) in the item 2 - Scientists do not use their imagination and creativity because this is contrary to their logical reasoning (Table 1).

Table 1. Changes in students' epistemological conceptions of each NOS item, using the Wilcoxon signed ranks statistical test results (Z) and effect size (r) for items with statistical significance.

Items	Z	r
1 - Scientists do not use their imagination and creativity because they can interfere with objectivity [12].	-3.178**	0.39
2 - Scientists do not use their imagination and creativity because this is contrary to their logical reasoning [12].	-3.340**	0.41
3 - Scientists use their imagination and creativity to collect data[12]..	-3.229**	0.39
4 - Scientists use their imagination and creativity to analyze and interpret data [12].	-2.110*	0.26
5 - Unlike theories, scientific laws do not change [12].	-2.003*	0.24
6 - Current scientific knowledge can be changed or totally rejected in the future [14].	-2.302*	0.28
7 - Scientists, at different times, can use different theories and methods to interpret the same natural phenomenon [10].	-0.559	-
8 - Science is a form of knowledge that provides evidence-based explanations.	-0.384	-
9 - Science is a way of looking for answers to questions about natural phenomena (adapted [16]).	-0.500	-
10 - Scientists use different methods to conduct scientific investigations [12].	-0.465	-
11 – Scientific research around the world is carried out in the same way, because science is universal and independent of society and culture [12].	-0.179	-

Note: *Statistical significance at $p \leq 0.05$; **Statistical significance at $p \leq 0.001$

The difference between pretest and posttest was significant for several items (items 1, 2, 3, 4, 5 and 6, in Table 1) and in the overall mean classification of the total questionnaire, including some NOS aspects not explicit addressed in this unit, ($Z = -2.099$, $p = 0.036$ and $r = 0.25$); hence, the null hypothesis is statistically rejected. However, no statistical significance was found in other items that we would expect to find (e. g. item 7).

3.2. Analyzing the promotion of adequate PBL environment

Positive results were shown from the observation instrument for PBL facilitation. Responses 4 (frequently) or 5 (always) for the majority of groups of students and 2 (rarely) or 3 (sometimes) for 2 out of 13 groups (in the participatory observation instrument) and responses 3 to 5 (in the instrument observation instrument filled by the other two teachers) about teacher support including encouraging students to apply prior knowledge, student responsibility, student interaction and collaboration, quality of problem and of resources provided and promoting self-directed learning (such as formulating and answering their own questions). Therefore, this Origin of Life unit was an effective PBL unit.

4. Discussion

The NOS aspect that students struggled the most are the distinction between scientific laws and theories, according to authors [2], and in our study showed an improvement on the post-test after the intervention. The NOS aspect about the role of imagination and creativity in science, in which students showed a naive view, had a significant change after our intervention.

Our claim is that the intervention was useful for improving certain aspects of students' NOS understandings, however this intervention may not be effective for all types of students. This study has certain limitations, such as the small size of the sample that was a sample of convenience, and the choice of the school was based on its proximity and collaboration to the university. And also, due to the timing of the authorization of the study and the school schedule, the fact that the teachers of the classes of this study provided a previous non-PBL unit (3 sessions), about part of the contents of this intervention, and a previous NOS-enriched PBL unit (3 sessions) (Sousa & Chagas, in preparation), which may explain not finding statistical significance in items we would expect to find (e. g. item 7) and in the overall questionnaire.

Another potential limitation of the study is the short length of this intervention; however, previous studies have shown that shorter interventions have positive effects on NOS views ([2]; [20]). The short length of time of the intervention can be seen as strength, as it is a cost-effective method for increasing student achievement [20].

NOS aspects are not found in the curricular objectives of the Portuguese curriculum for middle school students, so our PBL unit was intentionally designed to align with current content standards defined for 8th grade students - learning goal "to argue about some theories of the origin of life on Earth" [21] - that was achieved by using an ill-structured problem, which leads students to the contents required in the curriculum.

5. Conclusions and Future Work

The intervention unit used in the current study was designed to address the role of imagination and creativity in scientific investigations, the understandings about theories and scientific laws, understandings of the changing and provisional characteristics of scientific knowledge and role of culture and society in Biology. This exploratory study using this Origin of Life unit seems to be useful for improving these NOS understandings planned.

The current study also provides support for the ability of shorter interventions to influence students' NOS understanding from immediately before to after the unit.

Presently, the questionnaire used in this study is under development and this study may contribute with useful information to achieve its improvement.

Taken together, the results suggest that this HOS and NOS-enriched PBL unit is a useful and valuable pedagogical method for teaching the Middle School curriculum contents and aspects of NOS. Given the lack of guidance documents with concrete proposals for NOS inclusion, our research is also relevant from the applied point of view since it includes the production of innovative educational resources to facilitate the integration of aspects of NOS in the curriculum, through PBL. More research is needed to provide a comprehensive picture of the role of PBL in student learning outcomes.

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