Experimental activities based on ill-structured problems improve Brazilian school students' understanding of the nature of scientific knowledge

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Summary: Science education can help people to understand the nature and utility of science, and contribute to developing informed and active citizen. Hence, the purpose of this study was to see if problem-based learning (PBL) in experimental vacation' courses, with emphasis on the historical and epistemological foundations, could increase students' understanding regarding nature of scientific knowledge. After initial strangeness, our study has shown that students usually rated high the opportunities that they had to plan and execute experiments of their own, instead of following cookbook recipes as usually happens in laboratory classes at school. Also, post-test scores were significantly higher than pre-test scores on the total Nature of Scientific Knowledge Scale (NSKS), and on creative, testable, and unified NSKS subscales, indicating an improvement in the understanding of nature of scientific knowledge among school students. Of particular interest, the execution of practical activities in PBL form with ill-structured problems led a significant part of students to feel that they were creating and doing science. Therefore, the activities here proposed could be expanded as a form for improving the science education and to stimulate the formation of a new generation of creative scientists in Brazil.

Keywords: Science education, problem solving, nature of science, nature of scientific knowledge, Brazil.

Introduction

The potential beneficial and harmful effects of science have created in society a latent eager to demand for more information about science and a greater role in decisions related to science practices and goals (Rodrigues & de Meis, 1996). Given these facts and the pervasiveness of science in all of our lives, meaningful science education should help students become science literate and increase the level of science literacy in the population.

However, the vast majority of population has no knowledge of most of scientific basic terms or concepts (Alonso et al., 2007). For instance, data of the National Science Foundation show that, in United States of America, about 43% of population has no idea about terms such as molecule, light or sound relative velocity and only 27% know the notions of hypothesis and experiment. Likewise, Brazilian students have obtained very low grades in the evaluations of mathematic and scientific knowledge carried out by Program for International Student Assessment (PISA, 2000, 2003, 2006). The reasons for this short-coming are many, but prominent among them are deficient texts, unprepared teachers, and college and university scientists who divorce themselves from the problem (Malvin, 1990). Some suggested interventions include production of better texts, grounding science education teachers in their fields, and the involvement of scientists in the processes of education of science education teachers.

Science education can help people to understand the nature and utility of science and contribute for developing informed and active citizen. In Brazil, there is increasing awareness of the need to develop science, and to train new scientists as a way to deal with social and economic constraints of its society (Rodrigues & de Meis, 1996). Importantly, in countries like Brazil the small scientific communities can be considered an important resource for accessing the international pool of knowledge and a key link among science, technology and education. Thus, scientists could help to turn scientific knowledge more available and intelligible to young people who have to be educated scientifically.

Purpose and significance of study

Understanding the nature of scientific knowledge

A number of researches have shown that students do not develop desired understandings of the Nature of Science (NOS) from typical classroom instruction (Duschl, 1990; Lederman, 1992; Ryan & Aikenhead, 1992; Reis et al., 2006; Alonso et al., 2007). Consequently, over the past decade, NOS has enjoyed renewed attention among science educators as a principal component of scientific literacy (NRC, 1996). These documents specify that science teachers should not only teach in a manner consistent with current views of the scientific enterprise, but should purposively instruct students in specific aspects of the NOS.

To improve this situation, many researchers have recommended initiatives such as the use of history of science to help students develop more accurate views about the NOS (Duschl, 1990; Matthews, 1994; Hsu & Lee, 1995; Monk & Osborne, 1997). However, since most science education teachers today are already required to "cover" more material than time allows, they usually have no choice to focus on teaching the required science content while leaving the development of student understanding of the NOS to chance (Lemke, 1990).

Problematization and problem-based learning in Science Education

Considering the processes of change in science education and the demand for new ways of working with the knowledge, Problematization and Problem-Based Learning (PBL) can be considered as two new paths for methodological innovation. They provide the students with new opportunities to learn, and contribute to change teaching-learning processes. Though these two proposals are distinct, both apply teaching and learning developed from problems. According to Methodology of Problematization, the students are led to identify the problems from a certain reality, while according to PBL the problems are formulated by specialists (Berbel, 1998).

In relation to Problematization, a number of terminologies are found in literature. Importantly, Freire has proposed it as the Problematizing Pedagogy (Freire, 1996), and Diaz Bordenave as the Problematizing Education and / or Problematizing Pedagogy (Diaz Bordenave & Pereira, 1989). Berbel has suggested, alternatively, an association of these two proposals resulting in the entry/proposal Methodology of the Problematization as a way of teaching or research (Berbel, 1998, 1999).

The methodology of Problematization starts from the criticism to traditional education and proposes a kind of education that is based on the problematization of reality and the search for solutions to these problems, thus enabling the development of reflective and critical reasoning of the student (Berbel, 1999). In the methodology of Problematization (Bordenave, 1983), five phases develop from reality: observation, key points, formulation of theory, putting forward of solution and application to reality. This is an alternative methodology that is appropriate to higher education, and it differs from Problme Based Learning (PBL) in some points. Of particular importance, the cognitive objectives are all previously established in PBL, while in Problematization, total control over the resultant knowledge does not exist.

The pedagogy of Problematization assumes that in a world that is changing fast, the knowledge or the easy and expected behaviors are not important, but what is fundamental is an increase in the ability of the student-participant and agent of social change to detect the real problems and to propose original and creative solutions for them (Freire, 1996). Teacher/tutor in this process acts as the motivator for students to participate actively at the difficult stages of learning process and even more when they do not have the habit of doing so. Faced with theorizing of their reality, the student is naturally moved to formulate hypotheses of a solution to the problem under study. Therefore, students use the reality for learning from it, while they are preparing to transform it (Freire, 1996).

PBL is an innovative curricular approach that was originally developed in medical school programs (Barrows & Tamblyn, 1980), and later adapted for use in elementary and high school settings. Although new in some aspects, PBL is generally based on ideas that originated earlier and have been nurtured by different researchers, including Ausubel, Bruner, Dewey, Piaget, and Rogers (reviewed by Dochy et al., 2003). In accordance with the core model described by Barrows (1996), six cores are characteristics of PBL: 1) learning needs to be student-centered; 2) learning has to occur in small student groups under the guidance of a tutor; 3) the tutor is a facilitator or a guide; 4) authentic problems are primarily encountered in the learning sequence, before any preparation or study has occurred; 5). the problems encountered are used as a tool to achieve the required knowledge and the problem-solving skills necessary to eventually solve the problem; and 6) new information needs to be acquired through self-directed learning.

In PBL, problems act as the stimulus and focus for student activity and learning (Boud & Feletti, 1991). Unlike traditional teaching approaches, which introduce problems only after students had acquired the relevant content knowledge and skills, problems are introduced at the beginning of a unit of instruction. This reverse “problem-first” approach in PBL helps students to understand why they are learning and what they are learning (Gallagher et al., 1995).

Characteristics of PBL include using an ill-structured problem to guide the learning agenda, having the teacher to act as a metacognitive coach, and students working in collaborative groups. Ill-structured problems are those where the initial situations do not provide all the necessary information to develop a solution, and there is not a single correct way to solve the problem. As facilitators of learning, teachers acquaint learners with new ideas or cultural tools, to support and guide students as they make sense of these (Driver et al., 1994), and to scaffold students’ ideas in the zone of proximal development (Vygotsky, 1978). Students identify learning issues pertinent to the problems and ask questions related to these issues. They make their own decisions about what directions to take in their investigations, what information to gather, and how to analyze and evaluate this information.

PBL in collaborative group contexts is consistent with the theory of social constructivism which views learning as being mediated by the use of language, knowledge as being socially co-constructed, and problem solving as a process that is not internal to the individual but instead grounded in social practice (Vygotsky, 1986; O’Loughlin, 1992; Hennessy, 1993; Howe, 1996; Hodson and Hodson, 1998). This approach to learning is also consistent with the ideas of distributed cognition (Pea, 1993) as well as situated cognition (Brown et al., 1989; Hennessy, 1993).

Purpose

The idea of this work arose from some questions merged of our own accord and is based mainly in our concern about science education in Brazil, and they be summarized as follow: a) Are our students well prepared to meet the challenges of the future? and b) How can we improve science education in Brazil and in the World (including here NOS as an important part of science education)? These are questions that parents, students, the public and those who run education systems should be expected to continually ask. Thus, the purpose of this study was to see if a combinantion of Problematization and PBL experimental courses, with emphasis on the historical and epistemological foundations, could increase student understanding of NOS concepts.

This study attempts to show that small realistic changes can positively influence students’ perceptions of NOS concepts. Encouraging results could help reluctant teachers, those currently unmotivated by overly generalized and/or academic justifications, feel not confident enough to design and incorporate meaningful Problematization and/or PBL approaches into their own instruction. Also, the study tries to show the Problematization-based or PBL experimental courses’ potential to help students develop a more sophisticated understanding of the NOS.

Design and methods

Vacation courses design

Under the guidance of scientists who are members of the Post-graduate Program of Biological Sciences-Biochemical Toxicology of the Federal University of Santa Maria, graduating and undergraduating students prepared the Vacation Courses (VCs). Most of these students, in addition to their research projects in biochemistry also dedicate a part of their working time to educational projects in the Program. They were the course instructors playing the role of tutors. Before the first class, instructors met 5-7 times (~4 hours) to plan the course with respect to: a) theme and content expected to be covered; b) questions and ideas usually brought up by students; and, c) experiments that students might propose. This can be better understood by describing the assembly of course centered on the theme of Digestion (or “What do we eat and what do we drink?).

Content ranged from the composition of common foods to the chemical reactions involved in their digestion. An historical account of ideas about digestion was presented as a formal talk, or as theatre play, in the courses’ first day. In this phase, the students are stimulated to discuss/problematize the reality throughout questions encompassed by a general contextual question: “What do you want to know about nutrition, digestion, foods, etc?” In fact, this question is the starting point for any subject. Discussion of this initial question helps instructors to predict different alternatives for approaching the covered subject, starting from the abstraction level (question, ideas, hypothesis), and then moving towards the challenging direction of proposing specific experiments. Students’ initial questions and answers about digestion and food composition lead to more specific questions: “What kinds of technique we should use to discover the composition of foods we eat?” “What is the time a food stay in our stomach?” “We can digest a food outside our body?” The questions branching lead to new questions and new hypotheses, planning and executing new experiments, which encompass concepts from biology, physics and chemistry, transforming discussion and experimentation into an interdisciplinary enterprise. Such approach is not intended to reproduce how actual scientists proceed in their investigations. It is a planning exercise that allows instructors to develop a framework to orient discussion with the students, and also to have on hand a “tool kit” of materials and equipment that can be used to execute experiments usually proposed by the students.

The structure originally proposed and designed by the professor Leopoldo de Meis of the Institute of Medical Biochemistry in the Federal University of Rio de Janeiro School was adopted in the VCs. During the courses the whole group was approximately composed of about 40 school students. They arrived on Monday morning, and the theme proposed for the week work was introduced with a brief historical account or theater play. In the afternoon, the whole group was broken into laboratory groups and they were separated for the rest of the week. A laboratory group could be composed by up to 20 students and 5-6 tutors. There were no printed experimental protocols.

In the laboratory the students were encouraged to raise their own questions related to the course theme (problematization) and guess about the possible answers (hypotheses). After initial discussion section, the students choose which questions they want to investigate. They were told to work in small groups, but the group formation was fortuitous. The students only have to agree about the question, or a small number of related questions, to star with. Then, each laboratory group becomes organized into smaller groups (usually 2-6 students) and 1-2 tutors. However, there was no pre-determined organization structure, and eventually a student may decide work alone. They were also allowed to move from one small group to others. Materials for carrying out the experiments proposed by the students were assemble beforehand, or rounded up on the spot when unexpected proposal arise.

During the week, each laboratory group has usually daily discussion sections when students compared the ongoing results and decided what to do next. These discussion sections occurred in the lab either at the beginning (9 a.m.) and/or the end (4 p.m.) of the working day, or before and after the lunch time break. It is advisable that such sections do not exceed two hours/day. The discussions and the experiments were closely supervised by the tutors, which could thus decide when it is appropriate to advise the students about experimental decisions and procedures, and also proposing to start or finish a discussion section. Students were recommended to observe the experiments carefully and keep written notes of questions and related experiments. At the end of the week students from each laboratory, without tutor´ss assistance, weave one common story about the course theme based on what they have learned to all that worked in different laboratories. At this moment, the students present their conclusions about the original problems and hypotheses tested.

As plans for investigation and experimentations evolve, the research questions were sharpened and modified to meet the practical constrains of time and resources available. Therefore, the experiments proposed have to be adapted to the available resources. Time constraints are usually clearly realized by the students during the second day of laboratory work. The whole process is guided by discussion and collaborative work among instructors and students, directed toward reaching an agreement about worthwhile question and the experimental rationale for investigating them. It is important to emphasize that students are not discouraged from choosing experimental pathways that instructors perceive as likely to lead to negative results.

The main goal of the VCs is to involve students in actually doing experiments to answer their own questions. By the end of the course students should realize that producing scientific knowledge, which they have previously encountered only in books, involves an enjoyable and continuous process of creating, testing and discussing ideas about natural phenomena (including here a good portion of “frustrating” experimentation, i.e., those that reached to any conclusion or gave “wrong” results).

Data collection and quantitative analysis

Substantial researches directed at measuring the understanding of the nature of scientific knowledge are available in the educational literature (reviewed by Lederman, 1992). A reliable instrument for measuring the understanding of the nature of scientific knowledge is the “Nature of Scientific Knowledge Scale” (NSKS) developed by Rubba and Andersen (1978). This is divided into a six factor model, stating that scientific knowledge is: (1) *amoral (AMO)*, scientific knowledge provides man with many capabilities, but does not instruct him on how to use them. Moral judgment can be passed only on man’s application of scientific knowledge, not the knowledge itself.; (2) *creative (CRE),* scientific knowledge is a product of the human intellect. Its invention requires as much Creative imagination as does the work of an artist, a poet or a composer. Scientific knowledge embodies the creative essence of the scientific inquiry process.; (3) *developmental (DEV)*, scientific knowledge is never “proven” in an absolute and final sense. It changes over time. The justification process limits scientific knowledge as probable. Beliefs which appear to be good ones at one time may be appraised differently when more evidence is at hand. Previously accepted beliefs should be judged in their historical context.; (4) *parsimonious (PAR)*, scientific knowledge tends toward simplicity, but not to the disdain of complexity. It is comprehensive as opposed to specific. There is a continuous effort in science to develop minimum number of concepts to explain the greatest possible number of observations.; (5) *testable (TES)*, scientific knowledge is capable of public empirical test. Its validity is established through repeated testing against accepted observations. Consistency among test results is a necessary, but not a sufficient condition for the validity of scientific knowledge.; and (6) *unified (UNI)* scientific knowledge is born out of an effort to understand the unity of nature. The knowledge produced by the various specialized sciences contributes to a network of laws, theories and concepts. This systematized body gives science its explanatory and predictive power. The influence of VCs on the students’ conceptions of the nature of scientific knowledge was thus assessed using the NSKS.

The instrument was previously translated from English to Portuguese. It consists of 48 items (they are provided in the legends of figure 1-6) grouped into 6 conceptual subscales and each subscale is composed of 4 positive and 4 negative statements, randomly arranged, and associated with a 5 point Likert scale, ranging from “strongly disagree” to “strongly agree”. The total NSKS score was calculated by summing the subscale scores. A maximum score of 40 points for each subscale and 240 points for the entire NSKS is possible.

For facilitate the analysis and visualization in terms of agreement or disagreement, the 5 point Likert scale was adapted to represent the partial subscales’ scores in the Figures 1-6. In this adaptation, we used “strongly disagree” = -2, “disagree” = -1, “neutral” = 0, “agree” = 1, and “strongly agree” = 2.

In Brazil, the education system is organized in 12 grades. Until the 9th grade (~14–15 years old) physics, chemistry, and biology are taught as one discipline, called "sciences". From 10th to 12th grade (~15–18 years old), physics, chemistry, and biology are taught as separated disciplines. The population analyzed in this study consisted of 273 students enrolled in at least one science class, grades nine through twelve. Among this population, 67.8% (n = 185) were female, 28.2% (n = 77) were male, and 4% (n = 11) do not declared sex. In terms of grade level, 12.1% (n = 33) are enrolled in 9th grade, 22% (n = 60) in 10th grade, 27.8% (n = 76) in 11th grade, 14.3% (n = 39) in 12th grade, and 23.8% (n = 65) do not stated grade; however, in view of the schools they came, they were mainly (80%) from 10th to 12th grades.

The students were free to employ various forms of identification in the questionnaires, such as real names, imaginary names, or symbolic names, but they were asked to use the second name (post-test) equal to the first (pre-test). For this reason, some students did not declare their real names nor stated their grades or sex. Uncompleted or unpaired questionnaires were excluded of analysis. In order to determine the influence of a second exposition (reading) to the questionnaire, a control group composed by 80 students (20 – 9th grade, 20 – 10th grade, 20 – 11th grade, and 20 – 12th grade) was included in the study. These students were subjected to the questionnaire in their school and one week after the first reading (pre-test) they were asked to respond to the questionnaire again (post-test).

The data were analyzed using the SPSS (Statistics Package for Social Sciences) program. A MANOVA (2 control-vacation course x 6 Subscales x 2 pre-post-test) was performed. MANOVA indicated a significant interaction between vacation course x subscales x pre and post test scores. However, for sake of clarity, we will only present the results of the dependent T test statistical procedure comparing pre-test vs. post-test scores. An alpha value of 0.05 was admitted for all statistical tests.

Results

Initial resistance to work without "normal classroom lessons"

Some students showed resistance to the problem-first approach because they had difficulty in raise their own questions and to choose which questions they want to investigate. Such students were uncomfortable with the move from teacher-centered lessons to a student-centered approach and felt that a course of this nature was "a waste of time and effort." In fact, a portion of participants (10-20%) left off on the first or second VCs days.

A frequent response given by the students for their initial struggles in identifying a problem was that they "don't know how" to think the problems. However, when the students brought their initial problem in take initiatives, principally in second day of course, and used the time during the week to generate questions, they returned with several interesting ideas and new lists of questions. Some students even attempted to suggest answers to their peers' questions.

The students also revealed during the VCs' development that interactive discussions with the instructors in their work groups or their friends in contiguous groups also helped to generate ideas. During this process, the students discovered problems set in real-life situations which were embedded in personal contexts. For example, some students mentioned during the courses that their initially blank problem log progressively evolved into a new list of questions because they had become more aware of the theme's issues related to their daily life during the course of the week. Others, read science's books daily with greater interest, and paid special attention to matter concerning on the theme worked on the course (in fact, some students try to find the response to specific question in school text book, which was seldom found). Some students even asked their family members or school teachers if they had any problems or questions about that theme that perturbed them. This saw the transformation of a disinterested and apathetic student into one who was motivated by problems and who would continue to search for answers.

The requirement of having to generate their individual questions provided students with an opportunity to revisit past experiences. This process activated their latent puzzlement and curiosity about various issues which some of them had dismissed on earlier occasions. This was the first step which led students to pursue their subsequent inquiry. After brainstorming questions individually and negotiating among themselves, the students decided on a group topic in which to frame their problems, generally one that most of them could identify with and were interested in pursuing. The problem that finally became an object of study for the students was the result of a constructive interplay between the students' prior experiences, personal dilemmas, curiosity about a phenomenon or issue, input from others outside school, and social negotiation among group members.

Several students expressed a liking for the ill-structured nature of their problems. A student indicated that she enjoyed the freedom to "come up with own questions and answers" and found the process of inquiry fun. She also noted that "we never knew where the research would lead to and what our next steps would be". Other students liked "having to learn new things on their own" and "learning things outside the classroom."

The ill-structured nature of the problems compelled the students to approach their investigations from a broad perspective, consider multiple and varied stances to the problem, and ask a variety of questions since there was no fixed way of approaching the problem. This led the students to cross the boundaries typically encountered in school science, tread into novel areas that were usually unrelated to science, and discover new realms of knowledge. Thus, there was a multidisciplinary element to students' work.

Presentation and discussion of the final results

On Friday each laboratory group presented the results of the experiments they did during the week, to an audience of students from other laboratories groups, school teachers and instructors. The students usually chose informal presentation strategies for their report about the VCs, including talk-show format, theatre play, musical show, etc. However, about 30% of the students presented their results in a formal way.

After the presentation and discussion of the week's work, the students were asked to comment on the VCs. One of the aspects of their comments it worthwhile to emphasize, which distinguish the VCs from regular school laboratory classes, is present in the following students statements that emphasize the freedom they enjoyed during the course:

"The most impressive and unique aspect of this course, which distinguishes it from regular school laboratory activities, is the freedom we have to do our own experiments… the freedom to test our ideas…."

Measuring the Understanding of the Nature of Scientific Knowledge

NSKS was administered to each student at the beginning (pre-test) and at the end (post-test) of the courses. The NSKS' reliability was established previously by accompanying the coefficient Alfa reliability functions obtained from the translated version applied to Brazilian students (Rodrigues et al., 1994; Rocha et al., 2000). In attempt to evaluate the effect of a second questionnaire's reading in our quantitative evaluation, we included a control group to compare with the students that participated of VCs. In this group, the NSKS was administered to each student at the first reading (pre-test) and at a week after (post-test) to simulate the interval time of VCs. In control group, there was a significant difference between pre-test and post-test mean scores in DEV and PAR subscales (Table 1). However, post-test total NSKS mean scores were identical to that presented in pre-test (Table 1). In DEV subscale, there was a significant decrease in post-test scores in control group and in experimental group there was no change in scores. Although it has been observed a significant increase in post-test PAR scores for control students, the post-test's mean scores in this subscale were identical to that observed for pre- and post-test mean scores obtained by student participants of VCs (table 1).

The mean scores obtained in AMO and PAR subscales by both control and experimental groups were lower when compared to others subscales (table 1). In vacation course group, post-test mean scores were significantly higher on the CRE, TES, and UNI subscales and total NSKS when compared with pre-test mean scores (table 1).

	Control **N = 80**		**Vacation course** **N = 273**	
Sub-scales	***Pre-test***	***Post-test***	***Pre-test***	***Post-test***
AMO	25.60±0.42	25.38±0.45	24.83 ± 0.22	24.93±0.24
CRE	25.79± 0.59	26.05±0.78	26.95 ± 0.28	28.07±0.27*
DEV	28.29± 0.48	26.84±0.45*	28.04 ± 0.23	28.41 ± 0.25
PAR	22.90± 0.39	23.96±0.40*	23.89 ± 0.24	24.16 ± 0.25
TES	27.58± 0.38	27.93 ± 0.70	28.67 ± 0.21	29.30±0.21*
UNI	28.85± 0.55	28.69 ± 0.61	29.52 ± 0.29	30.51±0.29*
Total	158.85±1.41	158.70 ± 1.91	161.90±0.76	165.39±0.85*

Table 1.- NSKS subscales and total scores. Data are presented as means ± SEM.* $p<0.05$ vs. pre-test scores. Amoral (AMO), creative (CRE), developmental (DEV), parsimonious (PAR), testable (TES), and (6) unified (UNI).

A detailed analysis of VC students on AMO subscale (figure 1) demonstrate that students were in disagreement with the items 7 (Certain pieces of scientific knowledge are good and others are bad), 18 (Moral judgment can be passed on scientific knowledge), and 21 (It is meaningful to pass moral judgement on both the applications of scientific knowledge and the knowledge itself), even so there was a significant increase of item number 7 in post-test.

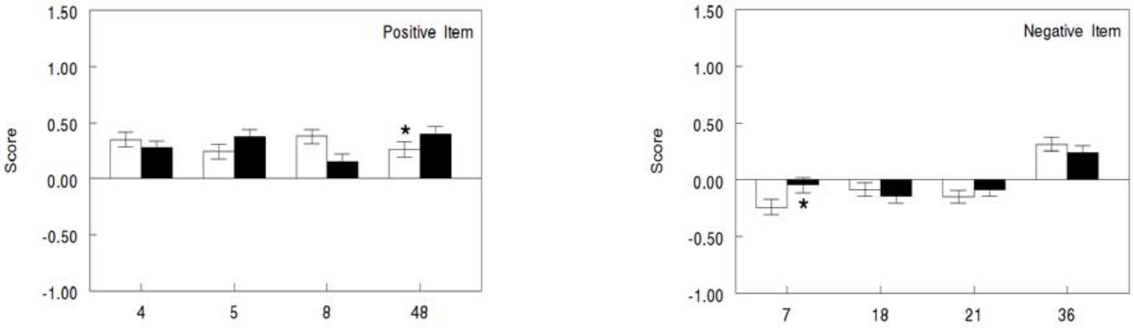

Figure 1.- Amoral subscale: White bars indicate the pre-test scores and the black bars the pos-test scores. Data are presented as means ± SEM. *****P<0.05 vs. pre-test scores.

Positive items

(4) The applications of scientific knowledge can be judged good or bad; but the knowledge itself cannot.

(5) It is incorrect to judge a piece of scientific knowledge as being good or bad

(8) Even if the applications of a scientific theory are judged to be good, we should not judge the theory itself.

(48) A piece of scientific knowledge should not be judged good or bad.

Negative items

(7) Certain pieces of scientific knowledge are good and others are bad.

(18) Moral judgment can be passed on scientific knowledge.

(21) It is meaningful to pass moral judgement on both the applications of scientific knowledge and the knowledge itself.

(36) If the applications of a piece of scientific knowledge are generally considered bad, then the piece of knowledge is also considered to be bad.

The scores obtained in CRE subscale increased with the participation in the VCs (figure 2). However, an increase did not occur in questions 23, 32, and 41 and, interestingly, the mean scores reached in the item 41 were opposite to the others in this subscale, demonstrating a significant disagreement (figure 2).

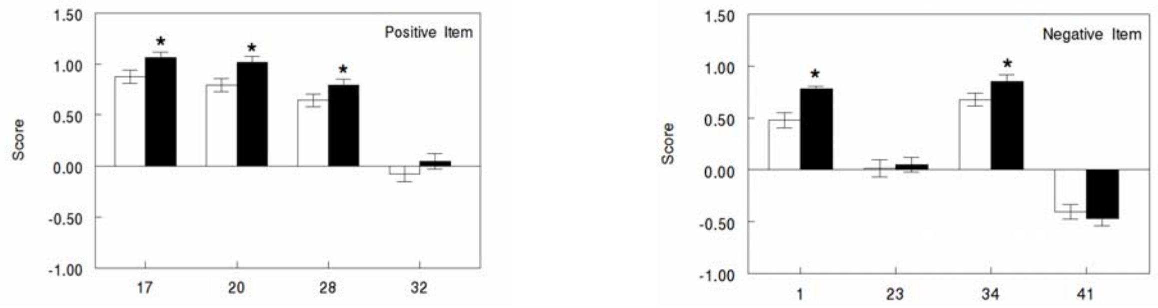

Figure 2.- Creative subscale: White bars indicate the pre-test scores and the black the pos-test scores. Data are presented as means ± SEM. *****P<0.05 vs. pre-test scores.

In the DEV subscale, the students were in agreement with the greater number of the items (figure 3). They were in disagreement only with the item 16 and the mean scores reached in the item 43 augmented in post-test NSKS for this subscale (figure 3)

Positive items
(17) Scientific knowledge expresses creativity of scientists.
(20) Scientific laws, theories, and concepts express creativity.
(28) A scientific theory is similar to a work of art in that they both express creativity.
(32) Scientific knowledge is a product of human imagination.

Negative items
(1) Scientific laws, theories, and concepts do not express creativity.
(23) Scientific knowledge is not a product of human imagination.
(34) Scientific knowledge does not express the creativity of scientists.
(41) Scientific theories are discovered, not created by man.

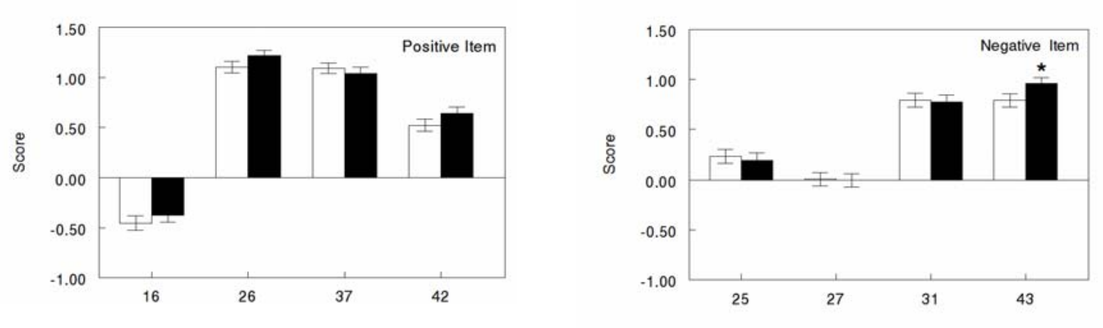

Figure 3.- Developmental subscale: White bars indicate the pre-test scores and the black the pos-test scores. Data are presented as means ± SEM. *P<0.05 vs. pre-test scores.

Positive items
(16) We accept scientific knowledge even though it may contain errors.
(26) Today's scientific laws, theories, and concepts may have to be changed in the face of new evidence.
(37) Scientific knowledge is subject to review and change.
(42) Those scientific beliefs which were accepted in the past, and since have been discarded, should be judged in their historical contest.

Negative items
(25) The truth of scientific knowledge is beyond doubt.
(27) We do not accept a piece of scientific knowledge unless it is free of error.
(31) Scientific beliefs do not change over time.
(43) Scientific knowledge is unchanging.

The mean scores obtained in PAR subscale were considerably low and did not augment in post-test NSKS and there was an impairment in mean scores reached in the item 6 (figure 4).

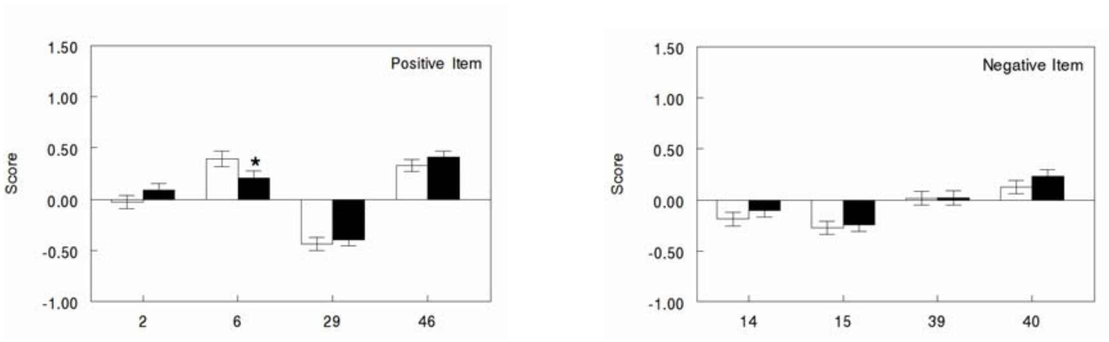

Figure 4.- Parsimonious subscale: (a) Positive items, (b) Negative items. White bars indicate the pre-test scores and the black bars the pos-test scores. Data are presented as means ± SEM. *P<0.05 vs. pre-test scores.

Positive items

(2) Scientific knowledge is stated as simply as possible.

(6) If two scientific theories explain a scientist's observations equally well, the simpler theory is chosen.

(29) There is an effort in science to keep the number of laws, theories, and concepts at a minimum.

(46) Scientific knowledge is comprehensive as opposed to specific.

Negative items

(14) Scientific laws, theories, and concepts are not stated as simply as possible.

(15) There is an effort in science to build as great a number of laws, theories, and concepts as possible.

(39) If two scientific theories explain a scientist's observations equally well, the more complex theory is chosen.

(40) Scientific knowledge is specific as opposed to comprehensive.

The students achieved the highest mean scores in TES and UNI subscales when compared to others (table 1, figures 5 and 6). Interestingly, in average the students were in agreement with all the items pertaining to these subscales (table 1, figures 5 and 6). Furthermore, the mean scores obtained in the 33, 38, and 45 items of the TES subscale augmented significantly after participation in the VCs (figure 5). Similarly, the scores obtained in the 3, 30, 44, and 47 items of the UNI subscale increased significantly in post-test NSKS (figure 6).

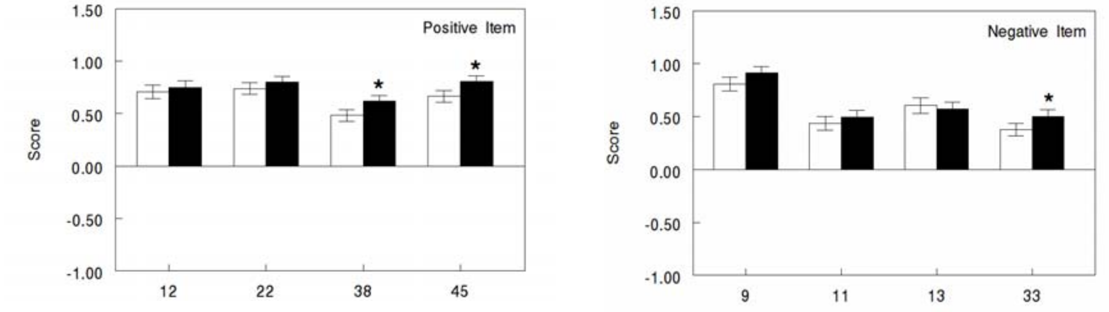

Figure 5.- Testable subscale: (a) Positive items, (b) Negative items. White bars indicate the pre-test scores and the black bars the pos-test scores. Data are presented as means ± SEM. *P<0.05 vs. pre-test scores.

Positive items

(12) A piece of scientific knowledge will be accepted if the evidence can be obtained by other investigators working under similar conditions.

(22) The evidence for scientific knowledge must be repeatable.

(38) Scientific laws, theories, and concepts are tested against reliable observations.

(45) Consistency among tests results is a requirement for the acceptance of scientific knowledge.

Negative items

(9) Scientific knowledge need not be capable of experimental test.

(11) Consistency among test results is not a requirement for the acceptance of scientific knowledge.

(13) The evidence for scientific knowledge need not be open to public examination.

(33) The evidence for a piece of scientific knowledge does not have to be repeatable.

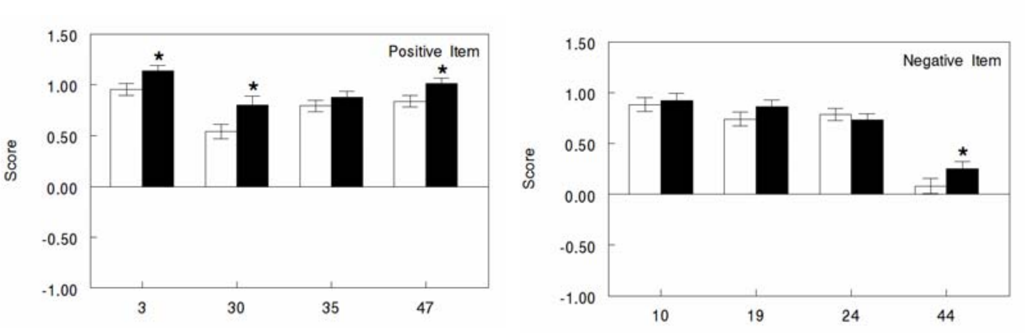

Figure 6.- Unified subscale: (a) Positive items, (b) Negative items. White bars indicate the pre-test scores and the black bars the pos-test scores. Data are presented as means ± SEM. *$P<0.05$ vs. pre-test scores.

Positive items

(3) The laws, theories, and concepts of biology, chemistry, and physics are related.

(30) The various sciences contribute to a single organized body of knowledge.

(35) Biology, chemistry, and physics are similar kinds of knowledge.

(47) The laws, theories, and concepts of biology, chemistry, and physics are interwoven

Negative items

(10) The laws, theories, and concepts of biology, chemistry, and physics are not linked.

(19) The laws, theories, and concepts of biology, chemistry, and physics are not related.

(24) Relationships among the laws, theories, and concepts of science do not contribute to the explanatory and predictive power of science.

(44) Biology, chemistry, and physics are different kinds of knowledge.

Discussion

Resistance to the Problem-First Approach in PBL

In the traditional approach to science teaching, the teacher is mainly concerned with the transmission of established knowledge and algorithms to students. Understanding of scientific principles and their relationships will occur after students have memorized a critical mass of facts (Tobin & Gallagher, 1987; Lemberger et al, 1999). This approach to classroom instruction does not lead to an effective and meaningful learning. Fatally, knowledge thus acquired is fragmentary and easily forgotten, and cannot be readily transferable to realistic or novel situations. Furthermore, in this scenery, there is no opportunity for the necessary confrontation between student and teacher thoughts that will require the student to demonstrate that understanding really has occurred.

Accordingly, a major criticism on the practical work in school science is that it is usually dominated by recipe-type, highly structured activities designed to lead unambiguously to the right answer. Teachers and students tend to accept experimental results at their face value without questioning the validity of the process of measurement. This illusion of certainty (Bencze, 1996) presents a false view of the process of scientific inquiry and the NOS. The heart of the problem is in students' poor understanding of the concept of assumptions which is essential for devising appropriate methods of measurement and drawing valid conclusions from experimental results. This established approach to classroom instruction in science matter could explain the opening resistance in work without following a cookbook recipe as a guide, observed in young students from VCs.

The teachers of biology, chemistry, and physics have a real opportunity to help correct these science education deficiencies. However, the school teachers admitted that they charge their pupils with tasks not easily executable and that their lessons do not have freedom for reflection and participation of the students. In fact, it may be emphasized that to successfully implement PBL or a problematization-based approach of science teaching, well motivated and trained staff is required to create the environment needed for effective and efficient student learning. Thus, there is a need for the provision of teacher training programs and workshops that aim at equipping science teachers with such knowledge and skills, and the development of relevant resource materials for use in school teaching.

Teaching science via PBL or problematization demands a diverse range of teacher roles beyond that of "teachers-knowledge transmitter." In her model of "collaborative inquiry," Crawford (2000) discussed a myriad of roles for a teacher to be a "facilitator" or "metacognitive guide" (Chin & Chia, 2006). These roles include a motivator, diagnostician, guide, innovator, experimenter, researcher, modeler, mentor, collaborator, and learner. Chin and Chia (2006) suggest the additional roles of provocateur and facilitator of opportunities. The teacher needs to encourage students to take responsibility for their own learning and to provide cognitive, social, and moral support so that they would persist in working on their problems (Chin & Chia, 2006). In addition, the teacher also has to challenge students to question their own assumptions and reconsider their original ideas or points of view, where necessary, as well as provide the necessary conditions to maximize students' use of conceptual, social, and material resources (Chin & Chia, 2006).

Ill structured problematic situations provide favorable conditions for learning

After initial strangeness, our study has shown that students usually rated high the opportunities that they have to plan and execute experiments of their own during the VCs, instead of following cookbook recipes as usually happens in laboratory classes at school (that indeed are almost absence in public Brazilian high-schools). Scientists usually agree that freedom to follow their ideas and intuition is an important characteristic of the scientific activity (Lederman & O'Malley, 1990). Therefore, it can be supposed that the VCs are being effective in eliciting an equivalent motivation among the students, and as a consequence contributing to improving their understanding about the NOS.

The school laboratory is supposed to be the place for developing an understanding of the process of scientific inquiry and mastery of investigative skills. However, many of the practical activities carried out in the school laboratory are highly structured where the students have to follow detailed instructions (Hodson, 1993; Germann et al., 1996). There is little opportunity for them to undergo an integrated process of posing a question, formulating a hypothesis, designing an experiment, and evaluating the empirical evidence accordingly. Such an approach in practical work may fail to promote a proper understanding and attitude toward the methods of scientific inquiry.

Moreover, the kinds of problems that students encounter in school have little to do with the problems that they need to solve in everyday settings (Lave, 1988; Roth and McGinn, 1997). Whereas school problems posed by textbooks and teachers are typically well-structured, the kinds of problems that students face in real-world situations are mostly open and ill-structured. Unlike well-structured problems that have convergent solutions, and engage the application of a limited number of rules and principles within well-defined parameters, ill-structured problems possess multiple solutions, solution paths, and fewer parameters which are less susceptible to manipulation. They also contain uncertainty about which concepts, rules, and principles are necessary for the solution, or how they are organized and which solution is the best (Jonassen, 1997).

The model for solving well-structured problems is based on information-processing theories of learning, while the model for solving ill-structured problems relies on (a) the theory of ill-structured problem solving as described above (Jonassen, 1997), (b) cognitive flexibility theory which conveys problem complexity by presenting multiple perspectives and opinions (Spiro et al., 1988), and on (c) constructivist and situated cognition approaches to learning (Brown et al., 1989). As Roth (1994) commented, "From a constructivist view, such [ill-structured] problematic situations provide favorable conditions for learning, because the problem solver is facing conditions for which no known procedures are available" (p. 216). The VCs activities, here described, put the instructors and students in contact with genuine situations of experience that generates real problems and "cases" to be discussed. During the week they had many opportunities to discuss, and learning occurs while stimulating students developing their ability to inquire and execute experiments they designed to answer their own questions.

When learning from ill-structured problems, students engage in a reflective conversation with the elements of the problem situation, which is a dialectic process. They are required to define the problem, recognize the divergent perspectives and multiple representations of the problem, determine what information and skills are needed to solve the problem, and synthesize their understanding of the problem. In doing this, they have to (a) articulate the problem space and contextual constraints, (b) identify and clarify alternative opinions, positions, and perspectives of stakeholders, (c) generate possible solutions, (d) assess the viability of alternative solutions by constructing arguments and articulating personal beliefs, (e) monitor the problem space and solution options, (f) implement and monitor the solution, and (g) adapt the solution (reviewed by Chin & Chia, 2006). Furthermore, solving ill-structured problems is largely an iterative and cyclical process (Jonassen, 1997).

Ill-structured problems are also inherently interdisciplinary (Gallagher et al., 1995), requiring the integration of several content domains. Students identify problems that are not defined by disciplines but by interest. The task environments and problem spaces of well-structured and ill-structured problems from a cognitive science perspective can be also very different (Goel, 1992; Chin and Chia, 2006).

The VCs laboratory classes are not intended to stimulate a research laboratory setting. However, like in a research laboratory, the students have the opportunity of learning by pursuing personally meaningful goals, internally elicited, and through a process of discovering meaning from experience, their perception and thoughts. The experiments proposed during the courses, when performed by the students, create an empirical situation – a case to discuss – giving the pupils the opportunity of connecting their ideas with genuine problems and facts. Naturally observable phenomena have a great impact on human beings and are planned to be the motif-cases of courses activities. They arouse complex behaviors like attention, curiosity, emotion, and motivate individuals in general, as well as scientists, to look understanding them. The courses is thus planned to encompass matters ranging from individuals' perceptual experience to the more abstract concepts of molecular mechanisms proposed by scientists to explain biological phenomena.

Improvement of the understanding of the nature of scientific knowledge

In this study, post-test scores were significantly higher than pre-test scores on the total NSKS, and on CRE, TES, and UNI NSKS subscales, indicating an improved understanding of nature of scientific knowledge among school students attending the VCs. Therefore, the VCs as previously described are intended to be a science teaching alternative which could improve science education achievements. Our data, however, cannot distinguish whether the elevation in scores on the post-test were due to an improvement in student analytical skills or simply acquisition of relevant background information. In any course, one expects that students will know more information at the end of the term than they did at the outset.

The ability to inquire scientific understanding of the natural world and understanding of the nature and utility of science has been considered to encompass all aspects of science achievement. According to the NRC (1996), “an understanding of science makes it possible to discuss scientific issues that affect society, to use scientific knowledge and processes in making personal decisions, and to share in the excitement of scientific discovery and comprehension” (p. ix). Besides, it has been stated that to neglect the science education of students is to deprive them of a basic education, handicap them for life, and deprive the nation of talented workers and informed citizens. These recommendations, directed to guide science instruction, are the result of the efforts of scientists and educators to face the challenges of education represented by the large number of reports decrying science, mathematics, engineering, and technological education (Beardsley, 1992).

Our study had also demonstrated an important diagnostic of the NOS’ understanding in Brazilian students. Firstly, the scores obtained in CRE subscale were intermediate in relation to the others subscales. In fact, CRE scores were higher than that of AMO and PAR, but lower than that of DEV, TES and UNI. However, CRE scores increased after the participation in the VCs. Understanding science as a creative human enterprise is an important component of science literacy and could helps to combat many absolutist and mechanist misconceptions that the majority of people harbor regarding science. Secondly, the mean scores obtained in AMO and PAR subscales by both control and experimental groups were significantly lower when compared to others subscales. The students were in disagreement with the items that deny the moral judgment of scientific knowledge. This appoints that, unfortunately, scientific knowledge provides men with many capabilities, but does not instruct him on how to use them. In fact, they were in disagreement that moral judgment can be passed only on man’s application of scientific knowledge, not the knowledge itself. For PAR subscale, they also were in disagreement principally with the statement that “There is an effort in science to keep the number of laws, theories, and concepts at a minimum”. For our students, scientific knowledge tends toward complexity, it is little comprehensive and do not appear there be a continuous effort in science to develop minimum number of concepts to explain the greatest possible number of observations. Noteworthy is also the fact that students do not accept “error” in science and this probably is related to the “absolute and certain” way science is taught in school. Thus, these results indicate that, although students had a good score in DEV and TES (that inherently accept errors in), we can suppose that science is taught as being correctly hermetic, which turns science topics difficult to be assimilated and incorporated in the cognitive structure of the majority of the students in school.

Rubba and Andersen’s NSKS (Rubba & Andersen, 1978) was used here to assess students’ acquisition of NOS concepts. The use of the instruments such as NSKS to measure understanding of NOS can be criticized in several grounds. However, its use does not imply any absolute acceptance of their views and the model was not introduced to students as the nature of scientific knowledge. In spite of this, NSKS does include many of the aspects of the NOS mentioned above, specifically the importance of creativity, the tentative and contextual nature of scientific understanding, parsimony, and the importance of testing understanding against empirical observations. Furthermore, research showing that such instruments were efficient to detect differences on NOS' understanding among students should not be ignored (Lederman, 1992).

Conclusions and perspectives

PBL or problematized approaches, which embodies values such as self-directed learning, active engagement, generativity, multiplicity of ideas, reflectivity, personal relevance, and collaboration, are important exemplars of a constructivist-learning environment. They emphasize concepts and methods that are designed to promote skills like critical analysis, self-directed learning and problem solving attitudes. As here observed, active involvement of students in this process induces attitudinal changes and initiates enthusiasm, curiosity, motivation and development of interest in the topic. Of particular interest, independently of the objective pedagogical contemplated, the execution of practical activities with ill-structured problems led a significant part of students to feel that they were creating and doing science.

Accordingly, during the VCs the students were actually involved in doing experiments to answer their own questions. When students drew conclusions based on their experimental results, and design experiments to test their own ideas, they followed one of the paths for the scientific understanding of the phenomena they are studying. Also, presentation and discussion of the final results, allow verify that the students were capable to weave, and report, a whole description of what they have learned during their working week. The way the students choose to present their ideas and experimental results is an expression of the collaborative work emphasis prevailing during the courses' activities, and reinforces the idea that science could be stimulating, exciting, and fun.

The use of ill-structured problems can engage students in ways that elicits desirable cognitive processes for a successful science education. Some desirable cognitive processes thus awaked include brainstorming to identify problems for investigation, generating questions to direct their own learning, considering multiple and varied stances to a problem, figuring out how to solve a problem via different types of inquiry, and thinking independently. In fact, most of the authentic problems in our lives are ill-structured. Thus, if students are given the experience of working on ill-structured problems in school science, they would be better prepared and equipped to face real-world challenges in their future.

We realize that kind of activities here proposed could be expanded as a form of improving science education and to stimulate the formation of a new generation of creative scientists. Without this Brazil can be considered as a nation at risk and without perspective of participating in the international decisions about fates of the world. Today, we are attempting implement this model course in scholar environment with the participation of the science teachers as monitors, jointly with undergraduate and graduate students. Fortunately, in scholar environment a good portion of students have been spontaneously participators in the experimental activities of the courses. Besides, a portion of science teachers have demonstrated a good receptivity to these kinds of activities in scholar environment. However, the times devoted to these activities are still very limited and intermittent.

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