IMPROVING CHEMISTRY AND GEOLOGY TEACHING: THE DEVELOPMENT AND IMPLEMENTATION OF A SCIENCE TEACHER EDUCATION MODEL BASED ON THE HISTORY AND PHILOSOPHY OF SCIENCE

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ABSTRACT: Actual perspectives of the History and Philosophy of Science (HPS) abandon positivists views and bring into relief a more humanised idea of science which is socially and culturally involved. The main difficulty when transposing the post-positivist ideas from the scope of HPS to science education, centres on the lack of a proper education of the teachers (Matthews, 1994). The hypothesis of this study was that it is possible to design a teacher education program (TEP) based on HPS in order to improve the teaching of scientific topics. A TEP was developed following three interrelated phases: a naturalistic study was conducted throughout the teaching of a selected scientific topic by each of the participating teachers (two Geology teachers and two Chemistry teachers with the topics Continental Drift and Mass Conservation); a structured TEP based on each of the scientific topics which were considered to be epistemologically relevant and, in the third phase, teaching practices were implemented and evaluated which resulted from the education in HPS, acquired by the teachers as they carried out the necessary didactics transpositions on the selected topic. The instrument of teaching practices analysis considered the following categories: Scientific Methodology, Dynamics of Scientific Knowledge Construction, Human and Social Face of Science. Globally, the results suggests that the proposed model of teacher education is more in line with science education goals. After the TEP the images transmitted by the teachers can be considered closer to the framework of HPS.

INTRODUCTION

Current perspectives of science abandoned positivists' views and bring into relief a more humanised idea of science as socially and culturally centred. This perspective identified with the New Philosophy of Science (Abimbola, 1983), can be summarised as follows:

- Scientific knowledge cannot be equated as an absolute truth, it has temporary status and errors must be the object of reflection;
- Scientific discoveries have a context and structure and the history of science helps us to understand those aspects;

- Scientists are part of the very world they investigate and they must constantly submit their results to the certification of a scientific community;

- There does not exist a unique and singular method of producing scientific knowledge but a context dependent methodological pluralism;

- Observation does not exist apart from a theory that guides and gives meaning to it.

- Scientific theories interpret and explain the world tentatively;

- Science is not objective (in the positivist sense), impersonal and problem-free, but it is closely related to society and technology.

Relevant implications of this new perspective of science were pointed out during the 80´s and 90´s by researchers in science education (Cleminson 1990; Duschl & Guitomer 1991; Gil Perez 1996, Hodson 1985, 1986; Matthews 1989; Níaz 1994; among others). A possible way of transferring these new post-positivist perspectives to science teaching is to explore adequately the history of science in order to get a more global understanding of the nature of science, the construction of scientific knowledge and the way scientists work in their communities. Such an approach to science teaching means that the context of discovery and not only the context of justification should be considered, as well as historical controversies and tensions within the scientific community in their own time.

The main difficulty when transposing these new ideas from the scope of the History and Philosophy of Science (HPS) to science education, centres on the lack of a proper education of the teachers in HPS (Brickhouse, 1990; Matthews, 1994; Duschl, 1994; Praia & Cachapuz, 1998). In fact, although there are many studies defending the inclusion of the HPS in science teaching strategies (Dana 1990; Bybee et al 1991) studies exploring the HPS perspective as a teacher education strategy are rare (Paixão & Cachapuz, 2000).

In our view this is a matter of concern and justifies further research. The main hypothesis of this study is that it is possible to develop an adequate in - service teacher education program (TEP) based on the HPS to improve the teaching of chemistry and geology topics (low secondary school).

The purpose of the study is to present theoretical and methodological considerations that lie behind the design and development of a teacher education program exploring the HPS aiming to improve the teaching of the selected Chemistry and Geology topics – mass conservation in chemical reactions and continental drift, two key topics in Portuguese low secondary school curriculum.

THE SELECTED TOPICS

Mass conservation is a central theme for the subsequent understanding of the whole of chemistry, although the proposals in syllabuses and textbooks are rather restricted. From the viewpoint of the philosophy of science, the passage from the theory of phlogiston to the theory of oxygen occurred at a specific time of political and social turmoil while at the same time it represented a controversy that animated the scientific community. To change the paradigm demanded, at the time, an enormous effort of imagination from a conceptual and methodological viewpoint and at the same time much experimental and technological development.

In the case of continental drift, this is a topic, generally approached with a strong empiricist view in school textbooks and syllabuses. Furthermore, continental drift is usually considered to be a mere step to some aspects of global tectonics. However, the establishing of the theory of continental drift historically marked a turning point in geology, especially because of the paradigmatic confrontation that was being engaged in the scientific community between defenders of the two main rival theories, fixists and mobilists

METHODOLOGY

The general methodology adopted followed a case study research orientation. The proposed model for teacher education was structured in three interrelated steps (Fig.1): a naturalistic phase and two subsequent phases involving participating teachers and researchers working together in an action-research program. The design of TEP was based on three articulated phases. The first phase, aimed to characterise teacher's epistemologies as revealed by their teaching practices, and to identify problem areas. A naturalistic study was conducted throughout the teaching of a scientific topic by each of the participating teachers (three geology teachers and two chemistry teachers).The teachers were volunteers, they came from different Portuguese schools and they and had different academic training and professional experience. The analysis of the teaching practices was carried out after the transcription of the video-recordings obtained (12 hours per teacher). These protocols were later analysed and explored with teachers as an element for reflection in the two subsequent steps of the program. The instrument used for that analysis (Paixão, 1998; Praia, 1995) is summarised in Figure 2.

The second phase (nearly six months for each group of teachers), aimed to properly educate the teachers by the design of adequate teaching strategies and activities. More specifically it involved the preparation and selection of new teaching materials exploring the history of chemistry (chemistry teachers) or the history of geology (geology teachers), discussing relevant epistemological episodes identified in step 1, planning the new objectives, the reading and analysis of texts (adapted or translated from the originals of the time, biographical texts...), the construction and discussion of questions about the texts, the selection of adequate bibliography about that time and, in the case of chemistry, the preparation of laboratory experiments and of experimental protocols based on the experiments carried out by Lavoisier and his collaborators.

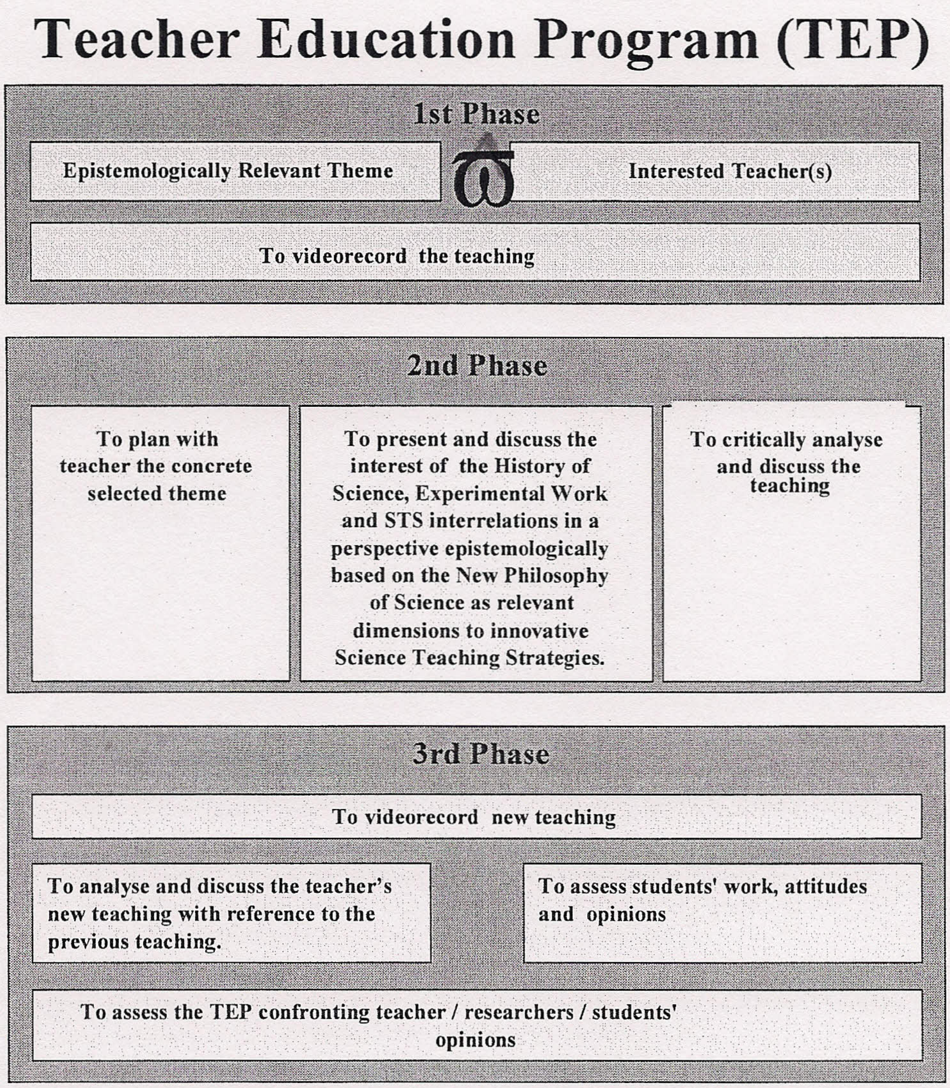

Figure 1: Teacher Education Model (TEP)

There was no previous formal theoretical training of the teachers centred on the study of contemporary philosophical authors. Theoretical discussions were always integrated in the context of the analysis of relevant epistemological episodes identified in phase 1 or in the planning of the new teaching strategies.

Epistemological Categories	Analysis Dimensions	Teaching Practice Indicators (examples)
I – Scientific Methodology	A – Methodological pluralism	Explicit references to some episodes of the HS and/or current aspects of scientific investigation with relevance to different scientists' working methods. Discussion of students' ways of working with clarification of the means of selecting experimental proceedings and their adequacy and/or limitation (not recipes).
	B – Theory / Observation / Experiment relations	Theoretical considerations before observation and experiments. Initial problematic questions and predictions. Critical report of the Experimental Work orientated by problematic questions and including critical assessment of the results
II – The dynamics of Scientific knowledge construction	C – Scientific discovery Context and structure	Activities exploring historical controversies in the establishment of a respected scientific theory (i.e. texts and related questions)
	D – Error /Truth Dynamics	Intentional valuation and exploration of students' errors. Identification of misconceptions. Discussion of discrepant Experimental Work results.
III – The human and social side of science	E – Images of scientists and the scientific community	Explicit references to the human side of scientists. Opportunities for the students to express their own ideas and confront them with their colleagues' ideas and/or with the current scientific version.
	F – STS interrelations	To begin with a social or a technological problem. To promote intentional discussions (debate) about science related questions, showing the relation between science and technology, and ethical or environmental questions... with the opportunity for students to express their established ideas.

Figure 2 - Instrument of teaching practices analysis

In the case of the chemistry topic, the new strategy explored a conceptual change approach by confronting the relative explanatory power and coherence between the phlogiston theory and Lavoisier theory to interpret the experimental results of the combustions of three domestic materials, iron, cotton (open system) and ethanol (open system). The assumption was that most of the students would defend Stahl's phlogiston theory (details of the strategy followed are described in Paixão & Cachapuz, 2000).

In the case of the geology topic, the new strategy explored a role-play approach. The pupils were grouped into two work groups "representing" the two rival theories (fixists and mobilists). In this way, helped the students to have a better understanding of the confrontation experienced within the scientific community (details of the strategy followed are described in Praia, 1995).

The third phase involved applying in the following year the new planning to different classes. The researchers were always available and guided the application of the new planning (collaborative action research). As in the first phase the lessons were video-recorded, transcribed and analysed using the same instrument (Fig. 2) by researchers and by teachers in order to identify whether innovation took place.

RESULTS AND DISCUSSION

In this section we present relevant aspects of the teaching before and after the TEP, one episode by a chemistry teacher and one episode by a geology teacher.

A. Chemistry teacher

First Phase

The topic was "to study the mass conservation law". The strategy followed was centred on the transmission by the teacher of central concepts followed by the demonstration of the classical reaction between potassium iodide and lead nitrate. Such confirmatory approach is clearly shown, for example, in the following discourse:

> *Teacher- And now? What am I going to tell Tiago to do? There are some weighing scales over there and now we are going to do a test – to see whether there is any change in the mass during the chemical change. And to do that... We have to measure the mass of the reagents, we can... to see whether there is any alteration or not. In order to measure... weighing scales are used.*
>
> *But then what we have to do is produce the reaction in a closed system because imagine one of the reagents leaked out... if it were open, what would happen is that the gas would leak out and therefore you wouldn't be measuring the mass of the gas...*

Although the teacher planed "to do a test" the strategy followed reinforces a non problematic perspective of observation which goes in linear form from the facts to the theory. It is a situation in which the role of the pupils are simple spectators. There is no problem-posing nor active participation of the pupils. There were no predictions nor guiding hypotheses. What could have been a problem situation (with regard to the open or closed system) to be properly explored was simply transmitted by the teacher.

Finally, and repeating the idea throughout the lesson that observation produces knowledge, she states: "As you saw, the mass of the products is equal to the mass of the reagents", followed by the pupils' writing down the chemical equation which expresses the reaction and which then becomes the central part of the lesson and a key aspect to be retained about the topic. The consideration of the participation of gaseous substances in the reaction is neither posed nor questioned, although this is known to be a problematical aspect in the understanding of the concept of mass conservation in chemical reactions.

After the analysis centred on phenomenological and descriptive aspects of the experiment carried out, the algorithmic treatment of the Lavoisier law was explored and the question of mass conservation in chemical reactions appears to have been reduced to this aspect alone.

The history of science, which in this matter of mass conservation in chemical reactions is full of episodes that give an account of countless aspects of scientific work in the human, social and technical aspects, which show evidence of controversy and non-linearity in the construction of scientific knowledge, was completely absent.

Third Phase

The set of nine planned and video-recorded lessons constitutes now a coherent whole.
In order to introduce the theme, the teacher began the lesson by conveying the idea of the need to acknowledge the importance of the work of scientists in the building of scientific knowledge.

> *Teacher – ... And I don't know whether you have thought about the following: your teacher teaches you laws, laws that take a minute to say, often less than that, and your attention is not drawn to the fact that it often took years of work for a scientist to arrive at those conclusions, to arrive at those same conclusions and today we put them in a corner, and use them in a moment, so quickly... It's only fair that we should acknowledge all the work that was done by them so that we might use them today.*

She also introduced a motivating context for the study of such reactions by means of the importance they have gained throughout the history of mankind and up to the present day: "Let's see then why we should talk about combustion reactions, why we should give such special importance to combustion reactions".

After some lessons the teacher comes back to the question that is still pending and which represents a "conducting wire", whether the value of the mass increases decreases or remains the same in combustion reactions. Before the three planned experiments the teacher gave the opportunity for students to predict the results and to confront them with their colleagues' ideas. As expected most of the students defended phlogiston perspectives to interpret the experimental results of the combustion of iron, ethanol and cotton. This was explored by the teacher to challenge pupils' ideas and of giving sense to the search for a new theory that might be more comprehensive than that of the phlogiston. The main difficulty of the students was how to conciliate the experimental results of the iron reaction with the results of the ethanol and cotton reactions in the light of the phlogiston theory). Some conflict was established between students.

The teacher continues, without giving the answer, but by going on to establish parallelism with the history of science. "For example, you certainly, didn't dedicate as much attention or as many hours to it as a chemist... that you took home that day to read about, right?" and then they are captivated by some biographical notes on Lavoisier. The teacher illustrates this with some materials, including the picture of David' s painting of the Lavoisier couple, about which she shares some thoughts in a cultural dimension. (...) Some of the pupils contribute with aspects that they read about at home such as a variety of some biographical aspects, mainly social, political, economical and ethical, situating the scientist in a period of time, aspects which confer a context for all that is to follow. Now the opportunity has come to start turning things round and to situate Lavoisier's proposals in opposition to those of the phlogiston' s theory by confronting their relative explanatory power and choerence to interpret the results of the three experimental situations studied. The image transmitted was that of the dynamics of scientific knowledge and that some theories gaining new ground while others lose it and each new conquest of a given theory is a sign of the losing of the status of a rival theory. The pupils had taken a text home to read: "The way for interpreting the combustion reactions". And that is how a new discussion began about the new explanations for combustions. The new explanation of mass conservation in chemical reactions was then applied to the interpretation of different kind of chemical reactions (eg copper with nitric acid, magnesium with sulphuric acid or potassium iodide with lead nitrate).

B. Geology teacher

First Phase

The teacher considers that "it was observation and data that enabled Wagner to set down hypotheses for the claim that around a hundred and fifty millions years ago there was only one continent surrounded by only one ocean". To refer to the almost perfect "fit" between the continents, together with an absence of other arguments and the lack of reference to the controversy that existed in the scientific community at that time, denotes a naive perspective of the building of science. It reveals many gaps in information since there is never any posing of problems or questions, nor are for and against arguments evoked, which is in fact the element of conflict in the building of the theory. In the end, everything seems simple and logical or, in other words, it would be sufficient to look at the figures in the book.

The scientific discourse of the teacher appears as an absolute truth which is outside of time as well as free from contingencies. The presentation of the scientific content is independent of the process for obtaining it, the reporting of the events being made in a linear way or, in other words, there are no controversial theoretical elements. The teacher makes no reference to the social and political contexts which conditioned the scientific work of the time.

The social building of knowledge, coming from an active and intervening scientific community is ignored. An appeal is made to what is obvious to common sense. The arguments in favour of the continental drift referred by the teacher are based on the simple examination of the facts that seem to have sprung from neutral observation (like the chemistry teacher referred to above). Moreover "the researcher's perspicacity" of which the teacher speaks, seems to be linked to the occasional observations that generate the discovery, which portrays conceptions of an empiricist tendency.

Here is a teacher who shows no concern whatsoever for the epistemological component. The difficulties which derive from the lack of an adequate structural view of the scientific content are apparent. The scientific content does not comply with the specificity of its building and the scientific processes, even the cognitively more simple ones, are ignored. The image of science which is passed on to the pupils is strongly dogmatic and of naif realism. There is total absence of problem-posing, as well as the formulation of provisional explanations for the contents. The teacher reveals that the building of scientific knowledge is marked by a strong and uniquely empiricist tendency, which puts emphasis on a scientific discourse which appears as an absolute truth and free of any contingency. The relationships between science and society do not exist during the lessons. On the other hand, scientific knowledge emerges unmistakably as a representation of the real world, just as it presents itself to observation. Scientific development comes about by accumulation, by the cumulative addition of parts, where the dividing into portions is stressed and substitutes the vision and the global coherence of the theory that is being explained.

Third Phase

The beginning of the lesson was organised around a quite personalised dialog with the pupils and constituted what we could call the phase of the motivation for the theme to be treated. There then arose a problematical situation posed by the teacher: "what should we look for, what should we do, what should we concern ourselves with, in order to get to know and study the history of earth?" A question which is afterwards reformulated and better defined. "... in order to be able to find out whether the continents were always joined?" The pupils work in groups with the teacher stimulating the discussion and at the end, he writes up on the board some of the ideas which emerge – the study of rocks, earthquakes, volcanoes, fossils, marine surfaces, glaciers and variations in sea levels, the study of other planets, ... During the time of open discussion, the teacher appeals to the pupils to listen to each other and to only refer to what the others have not yet mentioned.

After this, the pupils went on to read a text "History of the continents: some aspects", as the pupils were seen to have difficulty with that reading, at the same time the teacher made an effort to explain and help them to understand it. At a certain point in the lesson, the aim being to produce a synthesis, the pupils work in groups with a view to discussing and making clear what the scientific community of the time (nineteenth century) from the text, which has already been discussed and the centred question is asked: "could it be that the continents have always been continents and the oceans have always been oceans?" The pupils were grouped into two work groups "representing" the two rival theories (fixists and mobilists). In this way, HPS helped the students to have a better understanding of the confrontation experienced within the scientific community.

This was a rather prolonged and interesting discussion and the pupils were seen to be greatly involved. From the epistemological point of view, the fact that scientific knowledge is controversial and generates polemics in the scientific community was an argument clearly present. Although certain scientists carry a lot of weight, as in the present case of H. Jeffreys' opinion, which has influenced pupils so much that knowledge has been challenged. Scientific knowledge is not final and conclusive but dynamic and tentative. The history of science was clearly present, in this phase, when the teacher directs attention to the necessary exchange of opinions which showed themselves to be contrary in the debate that took place. The difficulties and hesitations concerning the opinion of Linth were overlooked, since he did not believe in his own ideas because they were very far from those in force. The method was flexible and above all, it obliged the pupils to think, to discuss with each other, to make suggestions, recreating the atmosphere of the time in terms of the conflict that existed in the scientific community. We believe that the problematical situation was clearly exposed and that the controversial elements – the mobilist or fixist perspectives – were considered and felt by the pupils to be the central idea to be "discovered". The prevalent ideas of the time became the hypothetical elements which needed to be put to the test which would come to happen during the development of the strategy.

CONCLUSIONS

The analysis of the results obtained in the first phase suggests a strong empiricist discourse about the nature of science and of scientific knowledge, hidden behind an idea of the apparent neutrality, objectivity and naive realism of science, by both chemistry and geology teachers. After the participation in the Teacher Education Programme, the teaching practice developed by the teachers was meaningfully different. In fact, the analysis of the teaching practices in phase three clearly shows that the images transmitted by the teachers can, on the whole, be considered closer to the framework of HPS:

(i) - The chemistry teachers (topic of mass conservation in chemical reactions) were able to develop much historical parallelism centred on the controversy generated, between supporters of the two rival theories (phlogiston and Lavoisier). The carrying out of experimental situations similar to those that Lavoisier and his collaborators carried out and also the presentation and group discussion of the results and their theoretical implications were at the centre of a debate in the class. At the same time the use of contextualized biographical texts and episodes helped to transmit images of science more in line with the desired framework.

(ii) - The geology teachers (continental drift topic), clearly stimulated the debate about the problem area discussed. Both presented clear problem situations: "mobility or non-mobility of the continents" and "what makes the continents move"? Contemporary rationalist perspectives were present in the classes although at times the popperian falsificationist views emerged. The new epistemological perspective of the teachers after the TEP reveals a more rationalistic tendency, a valorization of the process of construction of scientific knowledge as well the recognition of importance to the history of science and to the STS interdependence.

The teachers who participated were unanimous in emphasising the educational value of the TEP. Students' opinions were equally positive: "I really want to change.....I will at least change the way I teach this theme"; "It was very useful...all teachers should have access to some video-recorded teaching practices and reflect on them... I am going to improve, no doubt about it"; "The documents were interesting, it was a very good proposal...but what I considered the best during the training was the dialogue between us".

Globally, we can conclude that the proposed model of teacher education is more in line with science education goals which stress the importance of an education in science as well as an education about science. The study points out the relevance of HPS for in-service teacher education, structured on the use of particular epistemologies of concrete scientific topics. This implies the designing of teaching strategies in historical contexts which requires a sound scientific background and a strong historical and epistemological preparation. The main conclusion is that the proposed Teacher Education Model may be applied to different scientific areas but it implies the consideration of the specific epistemologies of scientific topics.

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