Revista Electrónica de Enseñanza de las Ciencias Vol. 1 Nº 3 (2002)
http://www.saum.uvigo.es/reec

Prospective physical sciences teachers' use of laboratory activities: An analysis of its evolution due to a science teaching methods course

Laurinda Leite and Ana Sofia Afonso

University of Minho, Institute of Education and Psychology, Braga, Portugal
E mail: lleite@iep.uminho.pt & aafonso@iep.uminho.pt

Abstract: Prospective teachers entering Science Teaching Methods Courses already bring ideas about how to teach Physical Sciences as well as how to use several teaching resources, namely the teaching laboratory. Research has shown that prospective teachers consider the teaching laboratory of great importance for science teaching and learning but they would be unable to use it properly. The Science Teaching Methods Course taught by the authors to Portuguese prospective Physical sciences teachers includes a module on using the laboratory for Physical Sciences teaching. The teaching of this module was organised according to a constructivist perspective that draws heavily on critical analysis and reflection. Thus, the objective of this paper is to analyse how the learning of the module referred to above affected prospective teachers' ideas on using the laboratory for teaching the concept of Chemical Reaction. Data were collected by means of a questionnaire, used both as a pre- and a post-test. Pre-/post-test comparisons showed that prospective teachers' ideas suffered meaningful changes due to treatment.

Key words: Science Teacher Education, Science Teaching Methods Course, Laboratory Activities, Physical Sciences Education, Chemical Reaction

Introduction

In Portugal, most prospective Physical Sciences teachers take five years long undergraduate programmes on Physical Sciences Education. Along with courses on Chemistry, Physics and Education, these programmes include courses on methods of teaching Physics and Chemistry (in the fourth year) and a full year of teaching practice in a school (fifth year).

The Science Teaching Methods Course does not aim at teaching Chemistry and Physics knowledge nor pedagogical knowledge, as there are other courses intending to deal with these subjects. Rather it aims at helping students to integrate all those types of knowledge together with specific knowledge from the domain of Science Education to be taught in the Science Teaching Methods Course itself. Its ultimate goal is to give prospective teachers some hints on how to find the best ways to deal with a given Physics or a Chemistry topic so that it becomes understandable for students of a certain age and academic level. In fact, this goal may lead us to think about Shulman's pedagogical content knowledge (Shulman, 1986). However, we are aware that teaching experience is the major source of pedagogical content knowledge (van Driel, Verloop & de Vos, 1998) and

that this type of knowledge is best developed in conjunction with practice rather than prior to any teaching experience (Bryan & Abbel, 1999).

As far as the Science Teaching Methods Course is concerned, the University of Minho undergraduate programme on Physical Sciences Education includes a five hours a week in a year long course on methods of teaching Physical Sciences (in the fourth year). Students are free to attend the two hours of theoretical classes but the attendance in the three hours of practical classes is compulsory. Nevertheless, most of the students regularly attend the theoretical classes.

In Portugal the academic year starts in late September but the number of students in a course may increase during the year, especially over the first three months. This is due to the fact that university students can take some exams in November or December, and also to the fact that few students may come from other programmes and/or universities, and therefore register later in new courses, in this case, in the Science Teaching Methods Course.

Nowadays, there is a large consensus on the idea that people construct knowledge before being formally taught and that previous knowledge influences future learning. This influence can play a positive role, when previous knowledge makes new learning easier. However, the previous knowledge can make the new learning become more difficult or even impair it from happening. This is likely to occur when previous knowledge differs from the one to be learnt and includes alternative conceptions. In this case, especially designed teaching strategies are needed in order to facilitate students' conceptual change (Driver & Oldham, 1986; Vecchi & Giordan, 1990).

Research (Jong *et al.*, 1999) indicates that prospective Science teachers construct ideas from their experience as learners about how to teach a school subject. Portuguese prospective teachers entering Science Teaching Methods Courses also bring ideas about how to teach Physical Sciences as well as about how to use several teaching resources, namely the teaching laboratory (Afonso & Leite, 2000). This knowledge differs, at least in part, from that to be taught in a Science Teaching Methods Course. Therefore, if a Science teaching methods teacher acknowledges a constructivist perspective of teaching and learning, prospective teachers' previous knowledge should be the starting point for the learning to occur in the Science Teaching Methods Course, in order to facilitate its development and/or reconstruction, whenever necessary.

Theoretical background

Three topics will be developed in this section. They are: Teaching methods courses in teacher education – A case for a constructivist approach, Laboratory activities in Science Education, and Teaching about chemical reactions.

Teaching methods courses in teacher education- A case for a constructivist approach

The ideas on alternative conceptions and conceptual change were settled within Science Education but they were soon transferred to teacher education (Stofflett, 1994; Bell & Gilbert, 1996; Hewson *et al.*, 1999). Together with the results of the research on teachers' conceptions on teaching and learning (Aguirre, Haggerty & Linder, 1990; Stofflett, 1994; Skamp, 1997; Flores *et al.*, 2000), these ideas lead us to expect prospective Physical Sciences teachers entering a Science Teaching Methods Course to have previous knowledge on how to teach Physics and Chemistry.

In secondary schools, students are used to be told about what to do and how to do it. Influenced by that previous experience, many prospective teachers hope to meet a Science teaching methods teacher who tells them exactly how to teach a subject (Loughran, 1994; van Zee, 1998). Of course no Science teaching methods teacher should do this not only because Didactics has for long rejected the prescriptive theories (Laursen, 1994), but also because there is not a unique way of teaching (Loughran, 1994; Wellington, 2000). Therefore, prospective teachers need to change their conception of passive learners to active learners, in order to develop their critical awareness (Watts, Jofili & Bezerra, 1997) which is also required in future to facilitate their own students' active learning.

Bearing in mind what is suggested for the case of students' alternative conceptions (Driver & Oldham, 1986; Vecchi & Giordan, 1991), a constructivist teacher of Science Teaching Methods would therefore expect prospective teachers to have ideas on how to teach a subject with which and against which he/she has to work in order to change them. Thus, the approach he/she would follow should take the prospective teachers' ideas as the starting point, include conceptual change teaching strategies, draw heavily on reflection upon previous ideas and experiences, acknowledge evaluation strategies able to monitor prospective teachers' conceptual and attitudinal development (Cachapuz & Martins, 1991; Stofflett, 1994; Tabachnick & Zeichner, 1999).

There is a lot of research on students' alternative conceptions on science concepts (Moreno & Moreno, 1989; Driver *et al.*, 1994) that enables teachers to anticipate their students' alternative conceptions and to design teaching strategies in order to promote their change. On the contrary, there is scarce research on the ideas held by prospective teachers about how to teach a given subject. Research carried out with German university students indicates that many of them acknowledge a reproductive approach to the teaching of Chemistry (Koballa *et al.*, 2000). However, it seems that conceptual change on teaching is much more complex than conceptual change on a science topic (Watts, Jofili & Bezerra, 1997). Nevertheless, it seems that it is possible to apply the conceptual change fundamentals to teacher education (Stofflett, 1994; Watts, Jofili & Bezerra, 1997; Tabachnick & Zeichner, 1999).

There is some evidence (Afonso & Leite, 2000) that Portuguese prospective teachers entering a course on methods of teaching Physics and Chemistry already hold conceptions on how to teach Physical Sciences. They also look at the laboratory as an outstanding resource for the teaching of

this subject. However, as they would use the laboratory mainly to confirm previously taught knowledge, a constructivist approach seems to be necessary to teach them about how to use the laboratory for teaching science without the recipes that would make them feel secure but that cannot be given to them.

Laboratory activities in science education

The Portuguese school curriculum reform implemented in the early nineties has stressed the importance of laboratory work and improved the conditions for it to be carried out in school science classes. It not only acknowledged the division of classes into two groups, making it easier to set up laboratory work, but it also led to Physical Sciences syllabi that make recommendations about the way laboratory work should be integrated in this subject. In fact, the eighth and ninth grade syllabi mention that "the experimental component cannot be separated from the theoretical component and it is present all over the syllabus" (DEB, 1995, p. 14) and that "all classes should be seen as potentially theoretical and practical in nature" (DEB, 1995, p. 24). This syllabus has even a section where several types of laboratory work are described and their powers and limitations are discussed. Amongst those types of activities one can find those which have been addressed by Gunstone (1991) as Preview-Observe-Explain. It should be pointed out that this type of laboratory activities seems to be able to promote students' conceptual change on science topics, namely on chemical reactions (Afonso, 1997).

A study carried out by Cachapuz *et al.* (1989) has shown that although laboratory work is often used in Physical Sciences classes, in-service Portuguese teachers nevertheless do it mainly as demonstrations to confirm previously taught knowledge. It should be noticed that this is the prevailing way of using laboratory activities by prospective teachers from several European countries (Jong, 1997; Jong *et al.*, 1999), including Portugal (Afonso & Leite, 2000), when they are asked to plan lessons on science topics. It is obvious that demonstrations do not engage the students from a psychomotor point of view. The point is that demonstrations performed with the objective referred to above together with the way that they are conducted prevent students from being mentally involved with the laboratory activity. Ten years later, and despite the implementation of the curriculum reform mentioned above, no meaningful changes occurred in the use of laboratory work in Portuguese schools, as revealed by data collected from teacher trainees (Freire, 2000), in-service teachers (Afonso, 2000) and textbook analysis (Leite, 1999; Leite, in press).

According to Corominas and Lozano (1994), well-conducted teacher's demonstrations can be better than other ways of performing a laboratory activity. The conceptual problems faced by the students when they are to learn a specific scientific concept from a demonstration are similar to those they face when learning from activities carried out by themselves (Roth *et al.*, 1997). Nevertheless, some types of procedural knowledge can only be developed if students carry out the activities themselves (Leite, 2001).

If it is true that science is a practical subject, it is also true that science is a theoretical area of knowledge (Millar, 1998). We learn and teach science at least in part because it helps us to understand the world around us

better. Laboratory work is often seen as a way of promoting concept learning but research results are not consistent in supporting this common belief (Hodson, 1993). On the other hand, despite the fact that laboratory work is not as popular in our schools as desirable, it is both over used and under used (Hodson, 1990). In other words, too much time is spent with it for the effect it has upon students' learning. Gunstone (1991) claims that for practical work to have any serious effect on student theory reconstruction and linking of concepts in different ways, "the students need to spend more time interacting with ideas and less time interacting with apparatus" (p. 74). This does not mean that procedural knowledge does not need to be taught. Rather, we agree with Woulnough and Allsop (1985) and De Pro (1998) when they argue that manipulative skills and other types of procedural knowledge can and need to be taught. The point is that it is not the amount of laboratory work but its quality that is at stake. To improve its quality several kinds of activities should be used, selected and carried out according to the objectives aimed at (Leite, 2001).

Thus, a Science Teaching Methods Course should be oriented in such a way as to help prospective teachers to learn that laboratory activities should not be used just "because science is a practical subject". Moreover, it should help them to acquire the theoretical foundations needed to use the laboratory without conjuring (Nott & Wellington, 1997) and in such a way as to promote the students' meaningful learning of Physical Sciences.

Teaching and learning chemical reactions

The concept of *chemical reaction* is approached for the first time in the 8th grade within the teaching unit *Chemical substances: what they are and what we do with them*. The syllabus refers that students are to "recognise that one substance can originate another one by the effect of heat, electricity, a mechanical action and light (..) by contact between two substances" (DEB, 1995, p. 17). It also adds that it is not enough to understand what a chemical reaction is at a macroscopic level and suggests the interpretation of chemical reactions in terms of rearrangement of atoms.

Several research studies carried out both in Portugal (Martins, 1989; Afonso, 1997) and in other countries (e.g. Chastrette & Franco, 1991; Hesse & Anderson, 1992; Pasdeloup & Lougier, 1994; Kwen, 1996; Barker & Millar, 1999), have shown that students hold several alternative conceptions on the concept of chemical reaction. Some of them seem relevant within the context of the present study. They are as follows:

- There is a main reactant in a chemical reaction;

- The reactants do no interact with each other in a chemical reaction;

- In a chemical reaction just the physical state of the substances changes;

- Chemical reactions produce a substance that is heat.

The existence of these conceptions emphasises the importance of both the syllabi recommendations focusing on the sub-microscopic level and Moreno and Moreno's (1989) argument for starting at the macroscopic level

and afterwards moving to the sub-microscopic level when teaching the concept of chemical reaction.

According to some researchers, the understanding of chemical reactions at a macroscopic level can be enhanced by laboratory activities (Solomonidou & Stravidou, 1994; Barker & Millar, 1999) which enable the student to use perceptual criteria in order to decide whether or not a chemical reaction took place (Solomonidou & Stravidou, 1994). However, it is worth noticing that this type of criterion may be fallacious, as it does not enable one to distinguish between cases were a chemical reaction occurs (e.g.: salt in water) and other cases in which no chemical reaction takes place (e.g.: sugar in water). To avoid this fallacy, properties like density, melting point and boiling points or tests to identify gases should be used as to complement perceptual data (Bar & Travis, 1991; Solomonidou & Stravidou, 1994). This procedure would prevent students not only from using the methodology of superficiality (Gil & Carrascosa, 1985), in order to decide whether or not a chemical reaction has taken place but also from reinforcing alternative conceptions on this concept. In fact, the tests of the burning wick and the cracking noise would prevent students from attributing the origin of the newly formed gases (oxygen and hydrogen) in the electrolysis of water to the evaporation of water, as they often do (Bar & Travis, 1991).

According to Murdoch (2000), Chemistry can be understood at three distinct levels: "a macroscopic (sensory) level; a sub-microscopic level (with explanations in terms of behaviour of particles); a symbolic level (involving formulas and equations)" (p. 47). The macroscopic analysis of what happens in a chemical reaction requires students to master the concept of substance and to know the properties that characterise the substances. As far as the sub-microscopic analysis is concerned, it requires students to hold some knowledge about the structure of matter. These are the reasons why some researchers (e.g. De Posada, 1993; Furió, Bullejos & Manuel, 1994) consider these topics as prerequisites for the learning of chemical reactions.

Objectives of the study

Prospective teachers entering Science Teaching Methods Courses already bring some ideas about how to teach Physical Sciences as well as about how to use several teaching resources, namely the teaching laboratory. Research previously carried out by the authors of this paper (Afonso & Leite, 2000) shows that the prospective Physical Sciences teachers consider the teaching laboratory to be a very important resource when they enter the Science Teaching Methods Course. Most of them would use the laboratory in order to confirm the previously presented content knowledge, within a teacher centred class framework.

The Science Teaching Methods Course taught by the authors includes a module on using the laboratory for the teaching of Physical Sciences. The teaching of this module was organised according to a constructivist perspective that heavily drew on critical analysis and reflection and included some theoretically grounded practical activities.

Thus, the objective of this paper is to analyse how the learning of the referred module affected prospective teachers' ideas on using the laboratory for teaching. To attain this objective, pre/post-test comparison will be performed, focusing on:

- The importance given to laboratory activities when compared with other teaching resources, that is whether prospective teachers plan to use laboratory activities or other teaching resources;

- The objectives of the laboratory activities that prospective teachers plan to use; this has to deal with the role of the class on-going activities;

- The responsibility for carrying out the laboratory procedure, that is, whether it is a students' activity or a teacher's demonstration;

- The levels of interpretation of the chemical reactions, focusing on sensory aspects, concentrating on the sub-microscopic level or dealing with physical and/or chemical tests of the new substances;

- The content of the laboratory activity, that is, whether or not the activity deals with a chemical reaction and the sort of reactants it includes.

Methodology

Overview of the study

This is a one-group quasi-experimental study (Schumacher & McMillan, 1993) that aims at comparing the evolution of a group of prospective teachers due to a treatment. In this kind of design, the effect of the treatment under trial cannot be compared with other types of intervention. Therefore, the non-existence of a control group is a limitation of the design as it makes it difficult to judge the value of the treatment. This limitation is justified by the existence of research results supporting the idea that a constructivist approach to teaching the module would lead to better results and by our will to avoid the ethical problems that would arise if one would have divided the class into two groups.

Thus, a pre-test was administered to prospective Physical Sciences teachers in October (first class of the Science Teaching Methods Course). Six months later, in April, they were taught the module on using the laboratory for the teaching of Physical Sciences (intervention). A post-test was administered to them a month after the teaching of the referred module had finished (that is, on the first week of June). The modules approached between the intervention and the pre-test and between the intervention and the post-test did not focus on the use of the laboratory for teaching. Hence, those time intervals cannot be seen as rivals of the module under question in this paper. They can rather be interpreted as enabling subjects to plan the lesson according to what they think is the best way to teach the topic and to avoid getting lesson plans based on the knowledge that they imagine their teacher wants them to use (because know he/she is going to or has just finished to teach it).

The prospective teachers

The prospective teachers participating in this study are fourth year university students that would become Physical Sciences teacher trainees the year after the research had taken place. For ethical reasons the academic year in which data were collected is not made explicit.

Forty-four prospective teachers answered to the pre-test. Fifty-one prospective teachers (that is, 75% of the students that registered for the course) answered to the post-test. The possibility to register for the course throughout the academic year explains, at least in part, the increase in the number of prospective teachers. It should also be added that a few students that registered for the course but never attended a class, did not took part in the study and are the main factor responsible for the magnitude of the percentage of prospective teachers that answered to the post-test.

Most of the prospective teachers were under 25 years old. Three older students had already taught Physical Sciences in schools despite the fact that they had never taken a Physical Sciences methods course or a teaching practice programme.

During the three previous years of university study these prospective teachers had taken several science courses on Physics and Chemistry and also a few courses on Education. The former focus on science and the latter on general educational issues. Thus, none of those courses had focused on how to teach Physics or Chemistry to school students. Hence, the only course in which prospective teachers deal with issues related to how to teach Physics and Chemistry is the Science Teaching Methods Course that is under question in this paper.

Data collection technique

Data were collected by means of a questionnaire, used both as a pre- and a post-test. The questionnaire includes a written task that asks each prospective teacher to do the following:

> Imagine that you were invited to go to a secondary school to teach a Physical Science lesson to an 8th grade class.
>
> In that lesson students are supposed to learn the concept of chemical reaction.
>
> Please describe that lesson in detail and mention all the things that you think are relevant from a scientific and a science teaching point of view.

This way of collecting data was adapted from the lesson planning method described in Valk and Broekman (1999) and also used by one of the authors in a research study (Frederik *et al.*, 1999) involving prospective Physical Sciences teachers from three European countries, including Portugal.

Prospective teachers carried out the task under examination conditions and did not have access to any science book or school Chemistry textbook. As far as school lesson planning is concerned, these conditions are not real, as when teachers are planning their lessons they rely heavily on the textbook (Sánchez & Valcárcel, 1999) and can use science books, journals, etc. Thus, the results of the analysis may show poorer lesson plans than those written in real conditions. However, lesson plans elaborated under

examination conditions may reveal prospective teachers' knowledge on the topic of the lesson as well as their knowledge and beliefs on how the topic should be taught to eighth graders. This knowledge and beliefs is what we were interested in.

The intervention

Assuming that prospective teachers bring to the Science Teaching Methods Course ideas about how to teach a subject, the main aim of the module on using the laboratory for teaching was settled to restructure and to develop prospective teachers' ideas on using the laboratory for teaching Physical Sciences. The module was organised according to a constructivist perspective of teaching and learning as research studies reported in section 2.2 indicate that it provides guidelines for a promising way of organising the module in order to foster the development of prospective teachers' knowledge and beliefs.

The constructivist perspective was already familiar to the prospective teachers, as in the Science Teaching Methods Course they had already studied topics like Epistemology of Science and Science Education, Psychology and Science Teaching and Learning, Alternative Conceptions and Teaching for Conceptual Change. The aim of the inclusion of these topics in the course was to lead prospective teachers to reflect upon the nature of science as well as upon the nature of the learning process and to develop some awareness of their future role as teachers of science. A constructivist perspective of both science development and teaching and learning of science was advocated and prospective teachers had the opportunity to become aware of the role of previous knowledge in both the development of science and the learning of science. The necessary conditions for the development of the students' previous ideas on science concepts were also addressed. These include dissatisfaction with the previous ideas, and intelligibility, plausibility and utility of the new ideas (Strike & Posner, 1982). These issues had never been explicitly related to the use of the laboratory for teaching but they were to be used to approach the module under question.

Thus, the intervention acknowledged the conditions for conceptual change (Strike & Posner, 1982) and was organised according to the main phases of a conceptual change teaching model (Driver & Oldham, 1986): elicitation of previous ideas, clarification and discussion of students' ideas, exposition to conflicting situations, construction of "new" ideas, application of the "new" ideas, and revision of the learning process. The objectives of each phase and the main activities carried out will be described bellow.

i) Elicitation of previous ideas

The objective of this phase is to make prospective teachers aware of their own ideas on how to use the laboratory for teaching and on the way they experienced the use of the laboratory as students.

From the pre-test it was known that prospective teachers would use the laboratory bearing in mind the traditional teaching approach, that is, to confirm previously taught conceptual knowledge. The pre-test was administered a long time before the beginning of the intervention and its

results could not be worked out in class because it was going to be used again as a post-test. Hence, an activity was devised in order to make prospective teachers aware of their own ideas about how the laboratory was used when they were in school and about what they would like to be different. Thus, students were asked to answer individually and in writing to the following questions:

- Did your physical sciences teachers use laboratory work in your classes?

- How were the laboratory activities carried out?

- What memories do you keep from your laboratory classes?

- Why do you think physical sciences teachers use laboratory work in their classes?

- What objectives were attained with the laboratory activities carried out in your physical sciences classes?

ii) Clarification and discussion of students' ideas

Prospective teachers were informed about the main results of the activity and were allowed to discuss their own answers as well as the class results with their peers, in small groups. Afterwards, a class discussion based on some questions raised by Hodson (1993, 1994) was conducted. They are as follows:

- Does lab work carried out in schools really motivates students? Are there other better ways to motivate students?

- Do students really learn skills and lab techniques from the activities carried out in schools. Do they have educational value?

- What image of science do students develop through lab work carried out? Is it an adequate image?

- Are scientific attitudes developed through the lab work undertaken in schools? Are they needed for a successful science practice?

- Take the following three dimensions of science education: learning science, learning about science and doing science. Does lab work give a contribution to all the three dimensions of science education? What characteristics should it have for each dimension?

Following Beeth's (1998) suggestions for conceptual change in science, these activities were planned to lower the status of the prospective teachers' experiences as learners that is, to make them feel unhappy with the way physical sciences have been taught in the school laboratory. Prospective teachers reported that they were expected either to passively observe the teacher performing a demonstration or to follow a recipe whose objective and procedure most of the times they did not understand. The same sort of comments was made with regard to the way laboratory classes are run in their university courses on Physics and Chemistry.

As it was expected, these discussions led prospective teachers to conclude that the way the laboratory was used in school (when it was) was not appropriate either to motivate students or to promote meaningful learning or to develop scientific attitudes. Besides, they showed strong

concern about their own preparation (from a scientific and a science teaching point of view) to use the laboratory for teaching Physical Sciences in other ways than to confirm and demonstrate Physics and Chemistry concepts and phenomena.

iii) Exposition to conflicting ideas

The main objective of this phase is to lead prospective teachers to feel a cognitive conflict relative to the use of the laboratory. It partly overlaps with the preceding one. In fact, the discussions held among students enabled them to become aware of different points of view on the efficacy of the traditional way of using the laboratory for teaching science as well as about the possibility of using it in rather different ways. The discussion in class reinforced this awareness as the teacher guided it according to the researchers' perspective, and helped them to recognise better the insufficiency and/or the inadequacy of the way the laboratory was used in schools.

iv) Construction of "new" ideas

The main objective of this phase is to help prospective teachers to reconstruct their knowledge and beliefs and to find better ways of using the laboratory for science teaching. The discussions aforementioned revealed the need to clarify some concepts, especially those related to laboratory activities, investigations, illustrative activities, teacher's demonstrations and students' laboratory activities. Ideas presented by researchers such as Gott and Duggan (1995), Hodson (1988, 1990, 1993, 1994), Leach (1999), Leite (2001) and Millar (1998) supported the discussions held in class to reconstruct these concepts.

Following Garcia, Martínez and Mondelo's (1998) suggestions, curriculum and teaching materials like syllabi, textbooks and worksheets were then analysed in order to find out the sort of laboratory activities they propose and whether or not they are in agreement with the experts' ideas. A point was made for the use of different types of laboratory activities and different ways of conducting them. It was also argued that laboratory activities should be selected and /or structured according to the main objective to be achieved.

Some ways of overcoming the constraints to the use of laboratory activities (namely the syllabus, the lack of laboratory technicians and materials and the insufficient number of laboratories per school) that are commonly mentioned by the teachers (Afonso, 2000) were discussed. Then, ways of minimising their effects on the use of laboratory activities were explored.

Finally, starting from prospective teachers' experience of being evaluated in the university laboratory, a discussion was also held on how to assess students' learning on the laboratory component. Severe criticisms were pointed out to the over use of laboratory reports, especially because the laboratory activities usually carried out are illustrative in nature that is, they aim at confirming a previously taught concept or law by following a receipe. Afterwards, alternative evaluation techniques were analysed. Based on Tamir (1990) and Leite (2000), a point was made for the use of several evaluation techniques in laboratory settings.

v) Application of the "new" ideas

This phase was an opportunity for the prospective teachers to use previously acquired knowledge to new situations. In order to avoid a theory overload, it was implemented concomitantly with the previous one. Thus, all prospective teachers were asked to criticise and reformulate teaching materials (namely laboratory worksheets taken from school textbooks), in order to find out about the correctness of their labels (investigation, experiment, etc), the adequacy of their structure and the sufficiency of their content. Available evaluation instruments (namely traditional lab reports) were analysed and the prospective teachers developed alternative instruments (like Gowin's Vee). Some of them had to prepare and present laboratory based lesson simulations (including low cost materials and worksheets, whenever necessary), focusing on a Physics or a Chemistry topic. These classes were observed by their counterparts and discussed by the whole class and the teacher. In order to avoid interference with the on-going research, the concept of chemical reaction was not selected for this purpose.

vi) Revision of the learning process

The objective of this phase is to help prospective teachers to "learn how to learn". Hence, they were asked to identify the main phases of the set of classes devoted to the module, to identify the objective of each phase. Afterwards, they were asked to relate the structure of the module to the constructivist perspective of teaching and learning and to reflect upon the trajectory that was followed from the first to the last class of the module and the way their conceptions and beliefs evolved.

The intervention lasted for 20 hours.

The topics "Problem-Solving in Science" and "Using the Computer for Science Education" were addressed during the time that elapsed between the intervention and the post-test. The former topic includes problem-based-learning and the latter includes datalogging. Although these two sub-topics may be related to the use of the laboratory, it is worth noticing that problem-based-learning was focused on other resources and that datalogging was approached from a technical perspective. Thus, after the module on using the laboratory for teaching science no teaching and learning activity that could interfere with it was performed.

About a month after the end of the module, prospective teachers were again given the lesson-planning task, in order to collect data to enable the analysis of the evolution of their ideas on using the laboratory for teaching.

Data analysis

To attain the objectives of the study the lesson plans were content analysed. The categories used for the analysis of the lesson plans were formed *a posteriori*. At first, the lesson plans were read by one of the authors in order to find out a first version of the sets of categories. Then, the categories were defined and discussed with the other author. Afterwards, the two authors classified a few randomly selected lesson plans separately and their classifications were compared and discussed. Hence, the final sets of categories were established. In order to obtain the final

data, the authors conducted the categorisation of all lesson plans separately and the results were compared and discussed in order to reach a consensus.

Quantitative as well as qualitative results will be presented. They will be illustrated with a few quotes from prospective teachers' lesson plans translated from Portuguese. A number was given to each prospective teacher. Quotes from the pre-test are identified by the prospective teacher's number followed by a *B*(before intervention). Quotes from the post-test are identified by the prospective teacher's number followed by an *A* (after intervention).

Results of the study

The presentation of the results will be organised in five sections, each one dealing with one of the aspects mentioned in the objectives section of this paper

Importance of the laboratory activities when compared with other teaching resources

The majority of the prospective teachers that answered to the pre- and the post-tests planned to use laboratory activities (Table 1) but the percentage increased markedly from the pre (52.3%) to the post-test (90.2%).

Teaching resources	Pre-test (n=44)		Post-test (n=51)	
	f	%	f	%
Laboratory activities	23	52.3	46	90.2
Verbal examples/discussion	19	43.2	3	5.9
Analogies	2	4.5	0	0.0
Concept presentation	0	0.0	2	3.9

Table 1.- Teaching resources mentioned in prospective teachers' lesson plans

Verbal discussions of chemical reactions presented by the students or the teacher are the second most frequent resource mentioned. However, the number of prospective teachers planning to use it decreased from 43.2%, in the pre-test, to 5.9%, in the post-test. In the pre-test, two prospective teachers (4.5%) planned to use analogies with people's behaviour. This resource did not appear in the post-test. In the post-test, two prospective teachers planned to do a concept presentation. One of them did not mention any special resource while the other stated that he/she would use a concept map to do so.

Objectives of the laboratory activities included in prospective teachers' lesson plans

The lesson plans that include laboratory activities were object of further analysis. Table 2 shows the results of the analysis of the objectives of the use of the laboratory activities that were planned by some of the prospective teachers, in the pre-test (n=23) and in the post-test (n=46).

Objective	Pre-test (n=23)		Post-test (n=46)	
	f	%	f	%
Confirmation/illustration	18	78.3	3	6.5
Exploration	0	0.0	9	19.6
Starting point	5	21.7	12	26.1
(Re)construction of knowledge	0	0.0	21	45.6
Problem solving	0	0.0	1	2.2

Table 2.- Objectives of the use of the laboratory activities

The diversity of objectives increased with teaching. Before teaching, prospective teachers planned to use laboratory activities to confirm previously taught concepts or as a starting point for subsequent teaching. In the post-test, the percentage of prospective teachers that planned to use laboratory activities to the above purposes decreased abruptly. Nevertheless, the use of laboratory activities as a starting point for further teaching persisted after the intervention. However, new ways of using the laboratory appeared after the intervention. In fact, a few prospective teachers planned to use laboratory activities for the exploration of concepts and a large percentage (45.6%) of prospective teachers planned to use laboratory activities with the aim of promoting the reconstruction of students' ideas.

The activities aiming at confirming/illustrating previously taught concepts are integrated within a deductive strategy. After introducing the concept, the teacher would carry out an experiment intended to illustrate/to confirm it and afterwards some examples of the concept would be given and discussed. Some illustrative quotes (taken from the lesson plans) are given bellow:

> First of all I would define chemical reaction as a process (..) afterwards I would illustrate with a laboratory experiment (..). I would finish the lesson with a formative worksheet in order to see whether or not students understood the concept (19B);

> I would start the lesson by introducing the concept of chemical reaction (..) would carry out an experiment (..) would lead students to infer whether or not chemical reactions occur in the natural world (25A).

Exploration activities are integrated in inductive strategies. Prospective teachers would divide the class into small groups and would ask students to freely manipulate the given materials and chemical substances. They would be able to come across with cases where a chemical transformation occurs

and can be observed and others where this is not possible or where a chemical reaction does not occur. Students would be expected to find out some regularity. Then, students and teacher would reach a conclusion leading to the introduction of the concept and afterwards an application of the concept could be done. This way of using laboratory activities is illustrated by the following quote:

> In order to introduce the concept of chemical reaction I would start by suggesting a laboratory activity to the students. For example, I would give them (organised in small groups) several bakers and other materials, not dangerous reactants and would let them to do their experiments. After that I would ask them about what they had observed (..), and afterwards would ask students to think about the causes of those results. Then, I would introduce the concept of chemical reaction (..) afterwards would ask students to apply the concept of chemical reaction (..) and would suggest another activity (8A).

When the laboratory is used as a starting point for further teaching, it is integrated in a strategy that may start with the teacher (28B) or the students (41A) undertaking one or more previously chosen laboratory activities in which chemical reactions occur. Along with motivational effects (28B), laboratory activities would enable students to observe what happens when certain chemical reactions occur and give them an opportunity to try to find out an explanation for the phenomena before the introduction of the concept. The following quotes illustrate this.

> At the beginning I would carry out some simple and quick chemical reactions. In doing so I would (at least I would like to) motivate students for learning the topic. Then, I would try to have students explaining the previously done observations. Afterwards, I would give them the correct concept of chemical reaction (28B);

> I would start the lesson by saying that I shall perform an experiment (..) afterwards, I would ask students whether they knew what had happened. After a short discussion, I would explain that a chemical reaction occurs when (..) (33A);

> I would prepare a chemical reaction in which the formation of a new substance was evident. This experiment would be carried out by the different groups of students. Afterwards, the new substance would be identified (..) and the concept of chemical reaction would be introduced' (41A).

Laboratory activities aiming at promoting the reconstruction of students' ideas are integrated in a conceptual change teaching strategy. Prospective teachers planning to use laboratory activities with this purpose would divide the class into groups and would ask students to make a prediction of a certain event. Afterwards, an activity would be suggested to the students so that they could collect data and confront them with their initial predictions. The activity may be chosen taking as reference a given alternative conception (7A) or it may happen that the reasons for the choice were not made explicit (6A). In any case, if inconsistencies were found amongst students' predictions and experimental results, they would be helped in restructuring their ideas and in learning the scientific accepted point of view. Sometimes, students are suggested to apply the newly acquired knowledge to other situations. Examples of this way of using laboratory activities are given bellow:

(..) I would put the question: 'predict what would happen if a zinc plate were placed inside a cooper sulphate solution. Justify your prevision.' After collecting and writing on the board students' answers, they would be asked to use the material that was in their tables and to observe what would happen. After students had registered what they had observed, one would try to explain, with their help, what had happened (6A);

I started my lesson by dividing students into groups and giving each group (..) sodium iodide solution and (..) lead nitrate (solution), being these solution colourless. Afterwards, one asks students to predict what would happen when the sodium iodide solution is mixed with the lead nitrate solution. After registering students' predictions, they would be asked to test them, observing what really happens (..), creating a cognitive conflict in students' minds, as they think that when two solutions are put together (..), 'there is a mixture of things', 'nothing is formed'. At this stage, with my help, students will try to explain what really happened (..). To finish the lesson students would be asked to explain what happens to an apple when we cut it into pieces and leave them on the table (7A).

The only problem solving oriented laboratory activity was integrated in a class where the teacher would face students with a problem and ask them to put forward hypothesis for its solution. Then students would be given several reactants in order to test their hypothesis. Afterwards, the teacher would introduce the concept of chemical reaction and the students would find out a solution for the initial problem.

(..) I would tell them that this summer I had had a nice vacation and had seen many monuments but I got upset because many of them seemed to be degraded and I asked myself about what would have happened then. What do you think that might have happened? After a while, after students think on the question, I would write down their answers on the board. Then I would hand them out a worksheet that asks them to use different reactants to test their hypothesis (..). I would give the definition of chemical reaction and ask them whether they were now able to solve the initial problem (51A).

Responsible for carrying out the laboratory procedure

In the pre-test all the prospective teachers planned to carry out the laboratory procedure themselves (Table 3), that is, they planned to use a teacher's demonstrations. In the post-test the percentage of prospective teachers that planned to do so is 23.9% while the largest percentage obtained relates to students undertaking the procedure (60.9%).

Responsibility of implementation	Pre-test (n=23)		Post-test (n=46)	
	f	%	f	%
Student	0	0.0	28	60.9
Teacher	23	100.0	11	23.9
Not specified	0	0.0	7	15.2

Table 3.- Implementation of the laboratory procedure

Thus, students' laboratory work increased with teaching and therefore students' manipulative involvement with the task would also increase. Still

in the post-test, seven prospective teachers, that is 15.2% of the participants, did not mention who would carry out the laboratory procedure.

Table 4 focuses on the school students' involvement in the laboratory activities that were planned to be undertaken by the prospective teachers. Although the teacher would be the one to carry out the laboratory procedure, the tasks students would have to do seem to depend on the objective of the activity, being more diverse and complex in the case of reconstruction activities. Thus, students' cognitive involvement seems to be higher in the activities aiming at the reconstruction of students' ideas and lower in the case of confirmatory activities (restricted to observation). Most of the prospective teachers did not specify how the students would be organised when analysing the activity carried out by the teacher (Table 4). While in the pre-test no prospective teacher planned to ask students to work in small groups, some of them, however, did it in the post-test when activities were planned to be used for theory reconstruction purposes or as a starting point for concept teaching.

Objective	Students' involvement		Pre-test (n=23)		Post-test (n=11)	
	Tasks	Organization	f	%	f	%
Confirmation	Observe	Not specified	17	73.9	0	0.0
Starting point	Observe and answer to teacher's questions	Not specified	6	26.1	4	36.4
		Small group	0	0.0	1	9.1
Reconstruction	Predict, observe, describe or register data and discuss the results	Not specified	0	0.0	3	27.3
		Small group	0	0.0	3	27.3

Table 4.- Students' involvement in activities carried out by the teacher

In the post-test prospective teachers planned activities to be performed by the students (Table 3). Most of these prospective teachers would have students working in small groups (Table 5). The cognitive involvement of the students in the task seems to depend again on the objective of the activity, being higher in the case of reconstruction and problem solving activities.

Objective			Post-test (n=28)	
	Tasks	Organization	f	%
Exploration	Perform, observe and look for regularities	Small group	9	32.1
Starting point	Perform, observe and answer to teacher's questions	Not specified	1	3.6
		Small group	5	17.9
Reconstruction	Predict, perform, observe, describe or	Not specified	3	10.7
	register data and discuss the results	Small group	9	32.1
Problem solving	Formulate hypothesis, perform activities and test hypotheses, solve problems	Not specified	1	3.6

Table 5.- Students' involvement in activities carried out by themselves

Level of analysis of the chemical reactions

In the pre-test, many prospective teachers did not specify the level at which the chemical reactions performed in class would be interpreted. The same occurred in the post-test. In this case some prospective teachers planned to use identifying tests (Table 6) to interpret what would happen in the activities which would be performed. Although the number of people using sensory criteria increased with treatment, the percentage of prospective teachers doing so, nevertheless, decreased a bit. The sensory criteria mentioned by the prospective teachers are changes in colour, temperature variations, gas formation, etc., as shown bellow:

> I would do a easily seen reaction (..) for example those reactions that produce gases or that lead to changes in colour, so that it was evident that a chemical reaction occurred (29B);
>
> I would do experiments that, for example, through changes in colour, or production of gases would enable students to realise that a chemical reaction occurred (38A).

As far as the identifying tests are concerned, they may be chemical criteria, like the pH value (16A), or the result of the flame test (12A) or physical criteria, such as the melting and boiling points (12A, 9A). The following quotes illustrate this.

> (..) I would carry out an experiment not producing any sensory evidence of the occurrence of a chemical reaction, burbles, effervescence or change in colour. But a chemical reaction should really occur. To assure this, we would need to find a way of verifying the occurrence of the chemical reaction (maybe to wet pH paper before and after the chemical reaction) (16A);

(..) I would prove through some tests (m.p., b.p., flame test, etc) that the reactants are different from the products (12A);

(..) in the case of the experiment that would produce a precipitate, one would filtrate, dry and measure the melting point and the boiling point. This would point out that a new substance had been formed (9A).

Type of criteria	Pre-test (n= 23)		Post-test (n=46)	
	f	%	f	%
Identifying tests	0	0.0	13	28.3
Sensory	8	34.8	12	26.1
Sensory plus sub-microscopic	0	0	2	4,3
Not specified	15	65.2	19	41.3

Table 6.-Type of criteria used to infer about the occurrence of a chemical reaction

About half of the prospective teachers planning to use identifying tests to conclude about the occurrence of a chemical reaction did it to attain the objectives related to the reconstruction of students' knowledge (Table 7). The following quote illustrates the use of laboratory activities with this objective.

I would start by asking students about what they think a "chemical reaction" is, what happens in a "chemical reaction". That is, I would try to discover what students already know (their alternative conceptions). (..). In order to change their conception that one of the substances has a main role in a chemical transformation, students, in small groups, would be given the substances A, B and C chosen in a way that A would react with B but not with C and that B would react with C. One way of showing that two substances were transformed into another substance different from the initial ones would be to measure their boiling and melting points (50A).

Few students (one in the pre-test and two in the post-test) planned to interpret a chemical reaction at the sub-microscopic level after doing it at the macroscopic (sensory) level. Illustrative examples are given bellow:

(..) Would tell students to imagine that they had especial glasses and ask them to describe what happens to the particles in every case that originated new substances' (9A).

Objective	Post-test (n=13)	
	f	%
Exploration	2	15.4
Reconstruction of knowledge	7	53.8
Starting point	4	30.8

Table 7.- Objectives of the laboratory activities analysed through identifying tests

Content of the activity

When answering to the pre-test, the majority (60.9%) of the prospective teachers that planned to use laboratory activities did not specify the substances to be used (Table 8). A similar result was obtained in the post-test.

Category	Pre-test (n= 23)		Post-test (n=46)	
	f	%	f	%
Specify	9	39.1	11	23.9
Do not specify	14	60.9	35	76.1

Table 8.- Specification of the reactants to be used in the activity

Some prospective teachers put forward some characteristics of the substances they would use in the laboratory activities and related them to the alternative conceptions they would like to change. The quote from prospective teacher 50A given above illustrates this.

When the reactants are specified, some prospective teachers also specified the substances that would be put into contact, while others left this decision to the students. In the former case (Table 9), some prospective teachers planned activities including examples of chemical reactions only (e.g. sodium and water, water electrolysis), others including examples of chemical changes along with examples of physical changes and no changes (e.g. sodium and water, heating water, transferring water from one vessel to the other) and others including only a non example of the change they want to illustrate (e.g. sugar and water). One student chose the reaction between iron and water that would take a long time (incompatible with the time of a lesson) to produce observable effects. In the pre-test, two students planned to use the electrolysis of water but they did not mention any further test. Some students planned to use the reaction between sodium and water that originates a flame, and others planned to dissolve sodium chloride in water which is apparently similar to the case of sugar and water.

Substances	Pre-test (n=9)	Post-test (n=11)
Glycerine, sodium chloride, water	-	1
Copper (II) sulphate, sugar, water	-	1
Water (electrolysis)	2	-
Water and olive-oil; Sodium and water; Heating water; Transferring water from one vessel to other	1	-
Copper (II) sulphate and zinc	-	1
Potassium iodide and lead (II) nitrate	-	2

Sodium, water, flour, lemon	-	1
Inks of different colours	1	-
Water and sugar	1	-
Iron and oxygen (combustion)	-	1
Sodium chloride and water	3	-
Sodium and water	1	-
Potassium dichromate and water	-	1
Sodium hydroxide and hydrogen chloride; Magnesium and oxygen (combustion); Water electrolysis; Sand and water	-	1
Iron and water	-	1
Sodium iodide, lead (II) nitrate, barium hydroxide, hexahydrated ammonium chloride	-	1

Table 9.- Combinations of substances to be used in the activities (f)

Discussion of results

The results of this study indicate that when entering the Science Teaching Methods Course the majority of the prospective teachers intend to use laboratory activities but they use them mainly for confirming the previously taught concepts. This result compares with the one obtained by Jong *et al.* (1999) with prospective teachers from four European countries. Contrary to what happened in the pre-test, very few prospective teachers used the laboratory activities for this purpose in the post-test and a considerable number of them rather planned to use activities to help students to restructure their ideas. This change may reflect a shift from a content centred planning to a student centred planning. It is a very important shift because chemical reactions is a topic in which students hold several alternative conceptions (Moreno & Moreno, 1989; Driver *et al.*, 1994), and students' active engagement in learning activities is a necessary condition for conceptual change to take place (Driver & Oldham, 1986; Vecchi & Giordan, 1990). However, some prospective teachers showed some difficulties in choosing laboratory activities able to create a cognitive conflict in students' minds, even in the post-test. This may be due to the fact that they are not familiar enough with students' alternative conceptions and/or to the fact that the examples of chemical reactions in their memory are reduced. The latter probably applies to those prospective teachers that put forwards the characteristics of the substances that should be selected as reactants but that did not give examples of specific reactants to be used.

An evolution occurred from the pre- to the post-test with regard to the implementation of the laboratory activities. The fact that in the post-test many more prospective teachers planned not only to use students' laboratory work (instead of teacher's demonstrations) but also to do it in small groups supports this statement. The latter aspect is an important issue as learning is not an individual enterprise but it also depends on and

can be facilitated by the social context in which the learner is placed (Hodson & Hodson, 1998). In fact, interaction with peers would help school students not only to make sense of the evidence collected from the laboratory activities planned and used by the prospective teachers but also and to restructure their alternative conceptions.

Our prospective teachers relied heavily on the first level (sensory level) mentioned by Murdoch (2000) to infer about the occurrence of a chemical reaction. Only after treatment did they suggest identifying tests to conclude about the occurrence of a chemical reaction. Identifying tests are needed, for example, in the case of the electrolysis of water to avoid reinforcing the idea held by some school students that the only thing that changes during a chemical reaction is the physical state of the reactant(s) (Bar & Travis, 1991). In fact, unless prospective teachers suggest the use of the flame test and the burning wick to identify hydrogen and oxygen, their hypothetical school students would probably use this chemical reaction to reinforce the alternative idea of chemical reaction as a mere change of state.

Contrary to the syllabus recommendation mentioned in section 2.3, the relationship between the macroscopic and the sub-microscopic levels is not established in most lesson plans. This may be due to the prospective teachers' non-sufficient understanding of the concept of chemical reaction, leading them to avoid going into depth on it. They may also not see the need for a microscopic explanation of the macroscopic observations or do not feel compelled to relate evidence (given by the laboratory activity) with the theory (accepted by the scientific community) to make sense of the evidence collected.

Before as well as after teaching, the majority of the prospective teachers do not make explicit the substances to be used in the activity(ies). In the pre-test this can be interpreted either through the low level of importance given by the prospective teachers to this aspect or by the lack of knowledge of specific reactants and/or the difficulty that prospective teachers have in recalling them. After teaching, lack of knowledge and/or difficulty in recalling is probably the main explanation, as it is clear that several prospective teachers worry about selecting reactants or mentioning their characteristics taking into account certain students' ideas (but did not give specific examples). However, when reactants were made explicit, they were not always adequate to the teaching of the concept, as they may:

- Reinforce students' alternative conceptions on the topic. In fact, the alternative conception "In a chemical reaction there is a main reactant" may be reinforced by the reaction between sodium and water, as no transformation of water can be seen. Also, the flame that can be observed during this chemical reaction can reinforce the idea that "Chemical reactions produce a substance that is heat";

- Include reactants in the gaseous state (as in the case of the combustion of magnesium) and therefore impair learning, as students cannot see the oxygen (Moreno & Moreno, 1989);

- Be very slow reactions (e.g. iron and water) that cannot be observed during the time of a lesson;

- Be intended to illustrate chemical reactions without reacting. This applies to the case of sugar and water, as the structure of the sugar is not modified when it is in contact with water (Pimentel, 1978);

- Involve dissolving (e.g. sodium chloride and water), a phenomena that is hard to explain even by expert chemists (Oversby, 2000).

Despite the limitations of the prospective teachers' lesson plans with regard to the use of the laboratory, it is important that they take into account students' alternative conceptions when planning their lessons (Jong *et al.*, 1999). Dealing appropriately with them requires very deep pedagogical content knowledge that prospective teachers should not be expected to show under examination conditions.

After dealing with the module on using the laboratory for teaching, prospective teachers learnt about problem-based-learning of science (Boud & Feletti, 1997). Despite the fact that problem-based-learning can use the teaching laboratory as a resource, only one prospective teacher planned a lesson based on a problem to be solved through a laboratory activity. The fact that prospective teachers did not use the laboratory according to a problem-based-learning perspective may mean that they found it inadequate for the purpose of this lesson or hard to plan such a lesson or did not integrate the two modules by themselves.

Despite the fact that language is not the focus of this paper, it is worth noticing that its use by prospective teachers when writing their lesson plans also reveals some of their difficulties at both the content knowledge and the pedagogical content knowledge levels. In fact, they often use words such as mix when they are dealing with chemical reactions (rather than with mixtures of substances). This is a serious fault, as it may lead to the reinforcement of the idea that "the reactants do not interact during a chemical reaction". It may indicate that the concepts of substance, mixture of substances and chemical reactions are not very clear in prospective teachers' minds. It may also point to prospective teachers' lack of attention to language when planning to teach the concept of chemical reaction to novice students.

Conclusions and implications

The results of this study lead us to conclude that the percentage of prospective teachers planning to use the laboratory for teaching the concept of chemical reaction increased markedly with the intervention and that the planned ways of using the laboratory became more consistent with what experts in Science Education argue for. This means that the way the module was taught was successful in restructuring prospective teachers' general ideas on using the teaching laboratory.

Nevertheless, the results could still be improved, namely with regard to the application of the theoretical perspectives to the use of the laboratory for the teaching of specific Physical Sciences topics. This would require an intervention at the scientific and the technical levels. In fact, and despite the large number of hours that prospective teachers spent in Chemistry classes and in the university Chemistry laboratories, they lack knowledge on some basic aspects of Chemistry as well as on some technical issues. This

means that university Chemistry classes need to be reorganised. That reorganisation should take into account that 'for optimum preparation pre-service teachers should be exposed to inquiry activities on as many topics as possible, especially on topics which they will be required to teach' (Marshall & Donward, 2000) rather than to the usual recipe like activities.

A good preparation in Science, in general, and in Chemistry, in particular, as well as in laboratory techniques would facilitate the Science teaching methods teacher's job, as his/her students would thus be equipped with a relevant pre-requisite for learning how to teach science. Moreover, it would lead to a better preparation of the prospective teachers from a Science teaching methods point of view, as Science Teaching Methods classes could then be used to deal just with Science Education issues and with the teaching of science topics, as they are supposed to be. In any case, the time allocated to the Science Teaching Methods Course is not sufficient to cover the diversity of issues that are relevant for a future science teacher. On the other hand, and due to the fact that pedagogical content knowledge is best developed in practice (Bryan & Abell, 1999), one cannot expect any science teacher to leave the Science Teaching Methods Course ready to start teaching science on his/her own.

Teacher training needs to help prospective teachers to bridge the gap between what they had already learnt at university, particularly in Science Teaching Methods, and what they need to do in their school classes. This requires updated supervisors that not only allow but also encourage teacher trainees to put into practice the previously acquired knowledge. Moreover, it requires supervisors that help teacher trainees to resist to the negative socialising effect (Watts, Jofili & Bezerra, 1997) that easily erases all the knowledge about teaching in their minds and leads them to teach as they have been taught or as their colleagues do.

We believe that the supervisor has a key role in the professional development of his/her teacher trainees. We hope these prospective teachers' supervisors help them to maintain the high level of motivation shown at the end of the course to teach Physics and Chemistry in different ways from the traditional one.

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