Educational change in two secondary science teachers with different levels of experience participating in a longitudinal program of professional development

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Abstract. We describe the cases of Alicia and Mónica, two secondary education physics teachers in Cordoba (Argentina), who are participants in a program of professional development based on collaborative guided reflection. Alicia is a novice teacher, and Mónica an experienced teacher. We analyze the initial state and the evolution (over a period of 6 years or cycles for Alicia and 5 for Mónica) of their explicit educational and epistemological conceptions, of the theories they use and the underlying implicit theories, and of their educational models in the classroom.

Initially, the declared conceptions of both teachers were far more advanced than their practice. But their educational changes were very different. For Alicia, the greatest change took place during the second cycle of the study in her behaviour associated with the pupils' construction of knowledge. For Mónica evolution was gradual, involving the resolution of conflicts between rival positions in her pupils' process of construction of knowledge, in her organization and management of the class, and in evaluation.

At the end of the study, both secondary teachers showed considerable concordance between their explicit and implicit beliefs and their declared and actual educational models, both of which were close to an action-research–constructivist perspective. Nonetheless, the process of guided reflection affected the participating teachers very differently according to their teaching experience and particular school context. This implies that there is a need to individualize professional development according to the personal and social characteristics of the secondary teacher with whom one is collaborating.

Keywords: Educational change. Secondary science teachers. Novice and experinced teachers. Professional development. Collaborative guided reflection.

1. Introduction

There is currently broad consensus that the teacher is the key to qualitative improvement of education systems, and determines the success or failure of whatever curricular reform or innovation it is desired to implement (Dori & Herscovitz, 2005; Hewson, 2007; Tobin et al., 1994). An important topic in research on science teachers is the process of their educational change, because a teacher's professional development and educational change are strongly interdependent. Understanding the factors that favour or hinder the processes of science teachers' educational change is an essential element in the planning and practice of teacher education and professional development programs (Banilower, Heck & Weiss, 2007; Davis, 2003; Hargreaves et al., 1999; Mellado et al., 2006).

Structural and curricular changes alone are insufficient to cause teachers to make the

concomitant educational change required to lead to improved teaching. Teachers are not technicians limited to applying the reforms and instructions drawn up by the experts. Rather they have values, attitudes, and conceptions, and make decisions on the basis of many factors, including their own history and personal situation, and the social and professional context in which they work. This complexity means that, unless particular attention is paid to teacher education and change, educational reforms have little influence on life in the classroom.

The secondary schools are becoming ever more complex and heterogeneous, as are the pupils themselves and the social context in which the school is a part. Longer obligatory schooling, growing interculturality, conflictiveness in the classroom, the loss of teachers' traditional role of authority, and the new technologies which give the pupils access to many sources of information and communication, represent a constant challenge to secondary teachers many of whom find a mismatch between what was taught them in their professional education and what is actually expected of them (Mellado et al., 2006). Studies with secondary science teachers arrive at the disheartening conclusion that, although the teachers use the innovative discourse of the reforms formally, in their classrooms most of them continue to use the same methods of teaching that they used before (Banet, 2007; Pro, 2006).

As a consequence of Shulman's (1986) work on pedagogical content knowledge, the teacher thinking paradigm has undergone a major evolution towards a greater degree of compromise with the specific content that teachers actually teach (Anderson & Mitchener, 1994). Shulman considers that teachers develop specific knowledge, termed Pedagogical Content Knowledge, concerning the form of teaching their subject. This knowledge – that is specific to how each particular subject is taught, and a form of reasoning and educational action by means of which teachers transform the subject matter into representations that are comprehensible to the pupils – has been the impulse behind many studies of science teachers, since the content to be taught conditions both the teacher's role and the teaching strategies (Abell, 2007; Friedrichsen et al., 2009; Gárritz et al., 2008; Gess-Newsome & Lederman, 1999; Lee & Luft, 2008) and teacher change takes place referred to particular content, not in the abstract (Gunstone & Northfield, 1994).

In previous works we have analyzed the processes of change in the science teacher (Mellado et al., 2006; Mellado et al., 2010). Our purpose in this chapter is to attempt to understand the educational change in two secondary science teachers with different levels of experience participating in a longitudinal program of professional development.

2. Educational change in science teachers

From a constructivist perspective, science teachers are considered to have conceptions about the nature of science, about scientific concepts, and about how to learn and teach them (Hewson & Hewson, 1989). However, teachers do not easily change their conceptions, and even less so their educational practices. Several studies have found that, depending on the teacher and the context, conceptions and practices are often out of phase with each other, and even plainly in contradiction, and that changes in one are not necessarily accompanied by a change in the rest (Brown & Melear, 2006; Farré & Lorenzo, 2009; Freitas, Jiménez & Mellado, 2004; Lederman, 1992; Marx et al., 1998; Mellado, 1998; Mellado et al., 2008; Roehrig & Luft, 2004; Simmons et al., 1999; Tsai, 2002).

Many constructivist-based science teacher education programs encourage conceptual change through reflection on cognitive conflict (Pintó, Couso & Gutiérrez, 2005). Nevertheless, although dissatisfaction and cognitive conflict are necessary elements for change, they are not sufficient, and they could also turn and work against change when the level of dissatisfaction and the mismatch between the teachers' expectations (whether self-established or externally imposed) and what they actually do is excessive and not under their own control, and no viable alternative is apparent. Secondary science teachers have frequent motives for dissatisfaction (Hargreaves, 1996, Mellado et al., 2006): they see how the old certainties are collapsing, their teaching strategies are subjected to criticism, their authority is questioned, their roles are not those they went into the profession expecting, and reforms and proposals for innovation come one after another creating an added overload that often leads not to change but to fatigue, frustration, guilt, discouragement, disenchantment, depression, cynicism, and even abandonment of the profession.

While there is general agreement on the need for reflection on teachers' initial ideas and practices, even if there is dissatisfaction with them and alternatives are available, this is not enough for teachers' educational change to take place. There must also be motivation and confidence in the changes that are to be put into effect, as well as anticipation in preparing strategies for classroom action (Davis, 1996; Hashweh, 2003). Teachers will only change their personal theory when they perceive it as being irrelevant for their own practice, and when they have new strategies and resources available that they find useful for their everyday teaching of their specific subjects and for the learning process of their pupils (Mellado et al., 2006; Ritchie & Rigano, 2002).

Educational change is stimulated by successive processes of metacognitive self-regulation (Copello & Sanmartí, 2001), based on the teachers' reflection, comprehension, and monitoring of what they think, feel, and do, and of the changes that they put into effect. This involves awareness

of what problems of teaching and learning might be improvable, elaborating new activities, materials, and teaching proposals (Powell & Anderson, 2002), putting them into practice in the appropriate context, successive reflection on their teaching and on the results in the pupils' learning, and comparing their practices with other cases to again revise and self-regulate them (Marx et al., 1998; Mellado et al., 2006). This requires time, much sustained support, and therefore medium- and long-term longitudinal study (Davis, Petish & Smithey, 2006).

Professional change has to go together with personal and social development (Bell & Gilbert, 1994; Proweller & Mitchener, 2004), taking affective aspects into account (Blanco et al., 2009; Brígido et al., 2009; Friedrichsen & Dana, 2005), reinforcing the teacher's self-esteem, encouraging constructive collaboration, strengthening the culture of the corresponding school, and building on the good practice that the teachers are already carrying out (Hargreaves, 1996). Social aspects are fundamental for science teachers' professional development. The teacher is an integral part of the community of a school, and it is very difficult for change to be individually implemented, and even more so for it to be consolidated, against the current of that school's educational culture and socially accepted norms (Hargreaves, 1996). The cultural context of a school conditions the professional development of novice (Munby, Cunningham & Lock, 2000), and experienced secondary education teachers (Reyes, Salcedo & Perafán, 2001; Verjovsky & Waldegg, 2005).

In sum, secondary science teachers' educational change is a complex process involving numerous variables, obstacles, and hindrances (Davis, 2003; Vázquez, Jiménez & Mellado, 2008). One of the variables to consider is the teacher's number of years of teaching experience. Research with novice and experienced science teachers indicates that there are aspects in the two groups that affect the process of change in different ways (Hargreaves, 2005; Meyer, 2004).

Novice science teachers

One very important stage is teachers' initiation to teaching during the first years of their career, when as novices they are subjected to tension, dilemmas, and overload, but also when their teaching routines and strategies are fixed (Marcelo, 2009). Plummer and Barrow (1998) point out that novice science teachers typically experience five distinct stages of development as they learn to teach: early idealism, survival, recognizing difficulties, hitting plateaus, and moving on. In prospective and novice teachers, their conceptions are the fruit of the many years they themselves spent at school. They use pedagogical methods that are very similar to those they preferred in their own teachers when they were students, or simply teach in the same way as they themselves were taught

(Ford & Fargo, 2007; Gunstone et al., 1993; Huibregtse, Korthagen, & Wubbels, 1994; Mellado, 1998; Tobin et al., 1994).

Novice science teachers usually present many contradictions between their implicit theories and those they have to expound on (Lederman, 1999; Tsai, 2002). They may have teacher-centred conceptions, but perceive themselves as student-centred (Simmons et al., 1999). Nevertheless the student-centred beliefs held by beginning teachers are crucial in implementing inquiry-based instruction (Roehrig & Luft, 2004). Unlike experienced teachers, novice teachers are usually more traditional in their teaching behaviour than the intentions that they express in their prior conceptions, both on the nature of science (Bell, Lederman & Abd-El-Khalick, 2000; Lederman, 1992; Mellado, 1997) and on science teaching and learning (Davis, Petish & Smithey, 2006; Freitas, Jiménez & Mellado, 2004; Mellado, 1998; Rodríguez & López y Mota, 2006).

If novice teachers receive sufficient support, it will be the stage in which their capacity for change is greatest (Hargreaves, 2005; Luft & Patterson, 2002), but the beginning teachers can also strengthened, sustained or constrained their beliefs about teaching science, their pedagogical content knowledge or their classroom practice, depending upon the induction programme in which they participated (Luft, 2009).

Experienced science teachers

Experienced science teachers have conceptions and teaching models that have been consolidated by their own professional experience which are very stable and resistant to change (Friedrichsen & Dana, 2005; Jeanpierre, Oberhauser & Freeman, 2005; Lee et al., 2004; McRobbie & Tobin, 1995). Moreover, there exist aspects of the educational system and the teaching community itself that reinforce traditional models, and are obstacles to changing them (Reis & Galvao, 2004; Shwartz, Ben-Zvi & Hofstein, 2005; Tobin, 1998; Vázquez, Jiménez & Mellado, 2008; Verjovsky & Waldegg, 2005).

Research with science teachers has also found that the process of teacher change is continuous but gradual. Teachers do not usually make drastic changes. Instead, they progressively put the ideas that seem to them to be important and at the same time attainable into practice (Gunstone et al., 1993; Rogan, 2007). For experienced teachers, professional development does not necessarily mean change, but a rather a process of adding levels of complexity (Greensfeld & Elkad-Lehman, 2007; Vázquez, Jiménez & Mellado, 2008). For these teachers, professional development can not be designed and presented as a "change" from one model to others, but rather as an internal process of

"growth" and "gradual development" based on what they already think and do (Day, 1999; Mulholland & Wallave, 2005), on the real problems of science teaching and learning, on their everyday concerns, and on the context in which they work (Hashweh, 2003). The prime aim is to support and enhance their motivation, confidence, willingness, collaboration, and commitment to their own professional development.

3. Research questions

In this article we describe the cases of two secondary education science teachers with very different levels of teaching experience, who are participants in a program of professional development based on collaborative guided reflection. One is a novice teacher, whom we shall call Alicia. We analyze her first year of teaching and her evolution over a 6-year period. The other, whom we shall call Mónica, already had 25 years teaching experience when she joined the research program. We analyze her initial state and her evolution over a 5-year period.

For both teachers, we shall consider the evolution of their explicit educational and epistemological conceptions, of the theories they use, their implicit conceptions, and their educational models (both those they feel desirable and those actually manifest in their classrooms). This will allow us to consider the interaction between their conceptions and classroom practice during the different phases of the study. The aim is to analyze how a teacher's beliefs mediate in the complex systemic process of teaching and learning at the stage which Jackson (1991) termed interactive, and how guided reflection constitutes a strategy for professional development which helps to overcome certain obstacles and contribute to the improvement of practice (Vázquez, Jiménez & Mellado, 2008).

The focus is on the following research questions:

a) How would Alicia's beliefs, educational models, and the theories she uses evolve during the six cycles of the study?

b) How would Mónica's beliefs, educational models, and the theories she uses evolve during the five cycles of the study?

c) What is the nature of the obstacles to their professional development?

d) How may a collaborative guided reflection program affect their professional development?

4. Methods

Alicia graduated in physics in 1998 from the Universidad Nacional of Córdoba (Argentina), and

was doing a doctorate in physics education in another Argentinian National University. She began her secondary education teaching career in 1999. Since then, she has been carrying out her teaching activity in a private school of the city of Cordoba in which the corresponding part of the study was performed. This is an institution with renovative characteristics, attended by pupils of a middle and middle-high social level. All cycles of the study were carried out in physics classes of the third course, with pupils of 14–15 years of age. Alicia has a good education in physics content, is highly motivated, and has high expectations for her own learning, which has been shown to be an important factor for professional development (Jeanpierre, Oberhauser & Freeman, 2005).

Mónica is also a physics teacher. She graduated in 1974 from a non-university teacher-education institution as a secondary education teacher of mathematics, physics, and astronomy. She subsequently took a postgraduate course in natural sciences at the National University of Córdoba. Her teaching experience consists of over 25 years in the same school, teaching mathematics and physics at the secondary level. This is a traditional school of great prestige, which is attached to the University. With the educational reform that began to be implemented in Argentina in 1993, the school adapted its curriculum to introduce physics content beginning in the first year. The school has a humanities oriented curriculum. Her pupils, of between 11 and 12 years in age, belong to a middle and middle-high social level.

The longitudinal ethnographic study was centred on the process of guided reflection about their epistemological and educational beliefs (with respect to teaching and learning), including not only the explicit beliefs, but also the implicit beliefs underlying their interactive discourse in the classroom. For White and Arzi (2005), the two conditions for an educational study to be considered longitudinal are that there is at least one year between the different phases of data collection, and that the methodological approach allows comparison of the results between the different periods of time.

The study began with an initial exploratory phase (in 2000 for Alicia and in 2001 for Mónica), during which a log was kept of what happened in 4 classes, and collection was begun of data on knowledge of the teacher's explicit epistemological and educational beliefs. This was followed by a cyclic process of investigation comprising five phases (Figure 1).

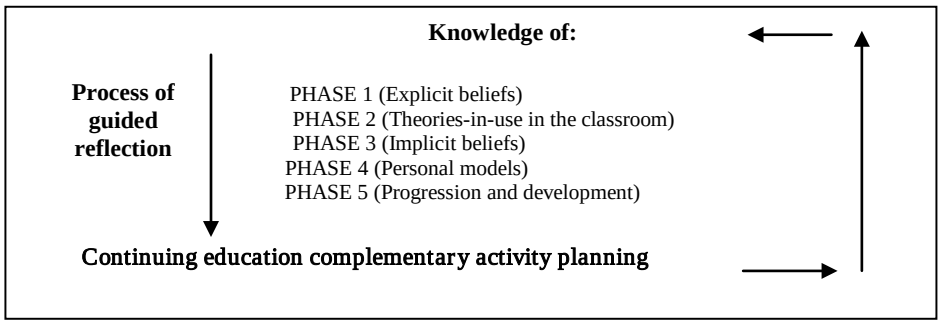


Figure 1. Phases of the research cycles

A process of guided reflection was carried out in each cycle. It constituted the axis of the educational process, and of the design and execution of other complementary activities in accordance with Alicia's and Mónica's needs and the obstacles to their professional development. Collaborative reflection has been found essential in other work on teachers' professional development (Bailey, Scantlebury & Johnson, 1999).

Alicia's 6-year study included six cycles carried out in the Argentinian school years corresponding to 2001, 2002 (two cycles), 2003, 2004, and 2005. Mónica's 5-year study included five cycles carried out in the school years corresponding to 2002, 2003, 2004 (two cycles), and 2005. Each new cycle involved a reiteration of Phases 2 to 5 of the guided reflection process and activity planning.

The instrument used for the interpretation of the data was the "substantive theory" described by Peme-Aranega et al. (1999). This consists of two theoretical conceptual categories (C): Science Teaching, and Epistemology (or the Image of Science). Each category is divided into subcategories (SC) (Table I). In turn, each subcategory consists of dimensions of analysis, which are aspects of the subcategory expressed in terms of opposite poles. At the positive pole are educational and epistemological conceptions close to the current orientation of the scientific community (Peme-Aranega, 2006).

Subcategories (SC) corresponding to Epistemology (or the Image of Science):

SC I. Characterization of the sciences, of scientists, and of scientific knowledge and theories.
SC II. Characterization of scientific progress. Importance of historical, social, and political factors in the development of science.
SC III. Methods. Role of observation, experiment, data, theories.
SC IV. Conception of theories and of rival theories.
SC V. Realism, instrumentalism, interactionism.

Subcategories (SC) corresponding to Science Teaching

SC I. The relationship between everyday knowledge and the construction of scientific knowledge.
SC II. Characterization and relationships between everyday knowledge, school-level knowledge, and scientific knowledge.
SC III. Characterization of knowledge and of learning.
SC IV. Characterization of school-level scientific learning.
SC V. Characterization of the teaching, didactics, profession, and education of science teachers.
SC VI. Conceptualization of science teaching.
SC VII. Conceptualization of the teaching function.
SC VIII. Conception of teaching in general and of institutional teaching in particular.
SC IX. Conception of programming.
SC X. Conception of methods.
SC XI. Conception of evaluation.

Table I. Categories of substantive theory

With respect to the procedures, instruments, and materials used in the study, the explicit beliefs were inferred from: (a) semi-structured interviews done at the beginning of the study, which were subjected to "content analysis" (Bardin, 1986), and subsequently interpreted using "substantive theory" by consensus between two judges; (b) Porlán's Inventory of Pedagogical and Scientific Beliefs, INPECIP (da Silva et al., 2007); and (c) the Inventory of Epistemological and Didactic Beliefs, ICDE (Peme-Aranega et al., 1999) which has been studied psychometrically and applied in work on small and large samples of science teachers (Mellado et al., 2003; Peme-Aranega, 2001; Peme-Aranega & Baquero, 2001). The two inventories were applied on three occasions during the study: at the beginning (2000 for Alicia and 2001 for Mónica), in the middle (2003), and in the last year (2005).

As in other studies (De Longhi, 2000), interactive discourse in the classroom was a major source of data. The theories-in-use were deduced from the teacher's verbal behaviour, in the 36 classes analyzed of Alicia and 19 of Mónica, with a researcher attending as a participating observer. After several readings of the data recorded in each class, the principal researcher and an external evaluator reached agreement on its division into significant units of verbal analysis. These were also reviewed by the teachers themselves. To a list of types of verbal behaviour drawn up in earlier work with other science teachers, other types were added that were typical of Alicia and Mónica. In each class, we considered the sequenced behaviour comprising the units, and constructed a frequency table of the types of behaviour observed and the most commonly repeated sequences. These data were used to derive Alicia's and Mónica's theories-in-use in the different cycles by reaching

consensus with the teachers themselves. Their evolution throughout the study period was then analyzed.

The behaviour arising from the interactive discourse in the classroom was subsequently interpreted by classifying it into the different subcategories and dimensions of "substantive theory". On the basis of the agreement between the principal researcher and the external evaluator, and in consensus with Alicia and Mónica themselves, we deduced the implicit theories underlying her theories-in-use in each cycle, and the progress that was shown during the study.

The reference framework to identify Alicia's and Mónica's models was based theoretically on, amongst others, the studies of Porlán and Rivero (1998) and Pozo and Gómez (1998). The models were inferred from the indicators corresponding to explicit beliefs, and the real or practical models from the theories-in-use (supported by implicit beliefs). Comparison of the initial explicit and implicit beliefs allowed us to infer the beginning professional level, to establish hypotheses of progression, and to determine the obstacles against the teacher's professional development. Their professional evolution was obtained by comparing their initial professional level with the subsequent differences between their explicit and implicit conceptions, and by analyzing the change in their declared and practical models.

The process of collaborative guided reflection formed the axis of Alicia's and Mónica's ongoing education in the study. It covered the entire process of the study, and was based on consensus reached between the principal researcher and the teacher about the following aspects: "substantive theory"; the procedures of analysis and interpretation of explicit and implicit beliefs; the theories-in-use and the underlying theories; the desired and real models; the initial professional level; the hypotheses of progression; the obstacles to their professional development; the results; the evolution demonstrated over the course of the study cycles; and the conclusions and implications.

Consensus was also reached on other complementary ongoing education activities adapted to Alicia's and Mónica's particular needs, obstacles, and practical problems. These included reading and discussing previous research (in particular, with reference to situations for problem-solving), different models or educational approaches used in the science education literature, and the transfer to the classroom of the epistemological knowledge that they had received in post-graduate courses.

Finally a workshop was organized on planning teaching units for particular topics of the curriculum. Planning teaching units with practical activities is an important aspect of professional development (Pro, 1999). A greater emphasis on developing activities that foster the learning of processes could be an indicator that the teacher is beginning to change towards more innovative

orientations (Bartholomew & Osborne, 2004; Martínez-Losada & García-Barros, 2005).

5. Results

5.1. Alicia's evolution over the six years of the study

At the beginning of the study Alicia demonstrated explicit educational beliefs that were quite up-to-date. She showed a simplified constructivist psychological approach (López-Ruiz, 1994), and curricular and organizational constructivism, with signs of spontaneist and technological approaches (Porlán & Rivero, 1998). Epistemologically her initial declared model was of mixed character, with relativist, spontaneist, falsationist, and contextualized views of science and its progress.

In the classroom, her theories-in-use at the beginning of the study clearly showed a far more traditional real picture than what she had declared. With respect to the epistemological aspects, she reflected an absolutist conception of knowledge, and a rigid and infallible view of the scientific method. Her verbal behaviour during the interactive process in the classroom was categorized into three groups: one referring to the pupils' construction of knowledge, another related to the organization and management of activities, and one linked to evaluation.

At the beginning of the study, she showed theories on the construction of knowledge in the classroom that were centred on herself, not on the pupils, and based on the presentation to the class of prepared knowledge. Meyer (2004) noted that novice science teachers held static conceptions of knowledge and they consider learning as an accumulation of information. Other studies agree in noting that novice science teachers plan almost exclusively by conceptual content (Aguaded et al., 1998). The Alicia’s typical behaviour was plain exposition, continuation of her set discourse, questions that she herself answered, and reinforcement of the pupils' correct answers and correction of wrong answers. Such expositions, almost always exclusive for the entire class, followed the logic of her own reasoning by means of continuous discourse, without considering what was the level of meaning for the pupils. As is usual in a novice teacher, Alicia was unable to really take her pupils' thinking into account until she had begun to see herself as a teacher and had mastered basic classroom routines (Levin, Hammer & Coffey, 2009; Roehrig & Luft, 2004). Instead, she tried to maintain the thread of her discourse, only interrupting it to ask the pupils leading questions aimed at seeking answers that would allow her to return to her main idea, or by asking questions that she herself answered with the same purpose. She reinforced the pupils positively when they answered in accordance with what she expected, and otherwise corrected them as a form of channeling.

With respect to her management of the classroom, her initial theories-in-use were clearly directive – she left no doubt that it was she who set the activities and the timing. Verbal indicators of her implicit beliefs about evaluation were practically null. She only used questions to consider the pupils' answers. At the beginning of their career, it is usual that secondary teachers are concerned about the daily routine and the problems of managing the classroom (Roehrig & Luft, 2004).

In sum, at the beginning of the work with this teacher, there existed a major difference between her declared and her implicit conceptions, i.e., between what she wanted to do and what she really did in the classroom. Her real models lagged considerably behind what she declared as desirable. As with many inexperienced teachers who have been analyzed in other work, during her first year Alicia was unable to transfer to the classroom her more up-to-date explicit conceptions, since she did not have the practical strategies and routines of action consistent with these beliefs (Furió & Carnicer, 2002; Gallegos, Flores & Valdez, 2004; Gess-Newsome & Lederman, 1993; Jaen & Banet, 2003; Koballa, Glynn & Upson, 2005; Lederman, 1999; Mellado et al., 2008; Tobin, 1993).

Over the course of the six years of the study, in the different dimensions of all the subcategories, Alicia's explicit educational and epistemological beliefs ever more closely approached modern views of science education. She passed from a simplified constructivist perspective, in which the pupils' ideas were of almost no consequence for the construction of knowledge, to another more complex perspective. By the end of the study, her initial restrictive spontaneist approach to teaching methods had been replaced with declared models corresponding more to a problem-solving oriented action-research category (Dass et al., 2008).

In classroom practice, Alicia began with a certain conflict between opposing theories-in-use. She evolved, however, from strategies centred on herself to those centred on the pupils, from monologue to dialogue, from simple discourse to multiple interactions, from presenting finished products to their construction, from control of the direction of the class to pupil self-determination, and from authoritarianism to participation.

With respect to her theories-in-use related to the construction of knowledge in the classroom, Alicia's verbal behaviour during the first cycle was clearly centred on herself as teacher. The greatest change occurred in the second cycle, reflected fundamentally in her use of more student-centred strategies. Because of the discontinuity of this change, it could be said to have been of a Kuhnian nature (Mellado et al., 2006). As in the case of the novice secondary teachers analyzed by Roehrig and Luft (2004) a strong content knowledge combined with student-centered beliefs and a

contemporary view of the nature of science increased the likelihood that inquiry-based lessons would be implemented in the classroom. Decisive for Alicia was the process of collaborative guided reflection, and the discussions with university mentor (Luft, 2009), which changed the orientation of her classroom practice on the pupils' construction of knowledge from one centred on herself and the content to another whose focus was the pupils and their learning. This result is very significant, since previous studies (Bañas et al., 2009; Chiu & Lin, 2008; da Silva et al., 2007; Domingos-Grilo et al., 2009) have shown the importance for a teacher's professional development of his or her becoming aware of the pupils' ideas and their process of construction of knowledge.

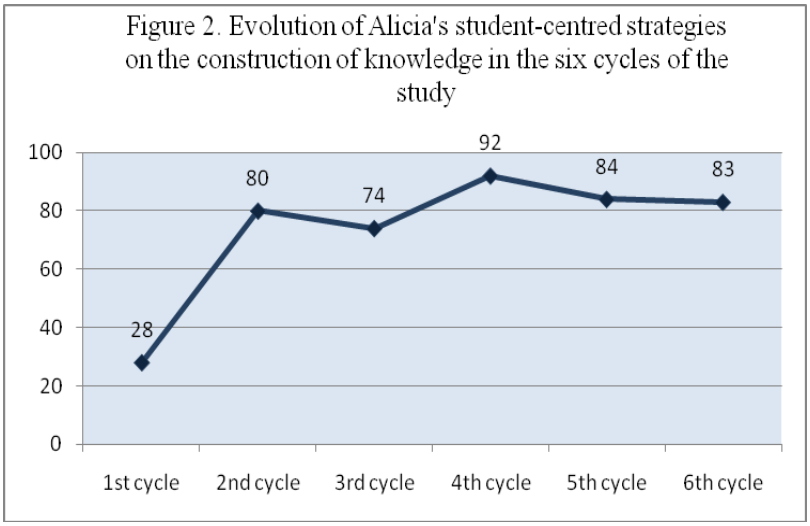
In subsequent cycles, these strategies increased in frequency and diversity, and there was consolidation of the study of problems by guided research, in the sense of orienting the process of socializing the construction of knowledge and putting it into a problem-solving setting. Also, when she was asked to participate, this took on a different meaning. What before were simple opinions now became foundation and argument (Jiménez-Aleixandre & Reigosa, 2006), giving explanations to the other participants, presenting syntheses, relationships, and the search for solutions to her own and her companions' proposals. She was encouraging her pupils to use ever more complex cognitive processes in their collective construction of knowledge. The problems she set, whether or not in experimental contexts, required the pupils to take an ever more creative approach to the reasoning process and the search for solutions. It is known that pupils' reactions, positive or negative, considerably influence teachers' attitudes and their sense of self-efficacy (Flores, 2004).

After the second cycle, her evolution was gradual but continuous, with consolidation of the student-centred strategies in a process that could be called Toulminian (Mellado et al., 2006). The third cycle saw strengthening of verbal behaviour supported on a basis of constructive dialogue, with her participation limited to the strictly necessary. Beginning with the fourth cycle, she stressed the importance of the history of science in understanding physical concepts. At the same time, her verbal participation sought the pupils' greater understanding by simplifying questions which they did not answer. In the fifth cycle, her participation was more complex, using other means to attain better understanding such as the use of analogies, examples, and drawings, reflecting an enrichment of her pedagogical content knowledge (Shulman, 1986). Her exposition was becoming one of presenting the necessary new knowledge by synthesizing, integrating, and reconstructing previous concepts, and establishing relationships with everyday experience. In this sense, she began to use questions designed for the pupils to recall previous concepts, to relate what they were learning with phenomena of everyday life, to think of examples, to sketch things, to synthesize what they had learned, and to respond to questions from their peers.

Verbal behaviour related to proposing problem situations for the pupils to solve appeared in the second cycle. In the fourth, she presented a true problem, and, since then, much of her behaviour was associated with a new role – that of being a provider of problem situations to solve. Her discourse showed itself to be student-oriented in various processes of problem-solving: formulating hypotheses, finding answers to her proposals, designing and implementing experiments, and drawing conclusions. This was very different from the behaviour shown at the beginning when, in setting exercises, she was looking for the use of algorithmic forms of solution. Particularly noteworthy was her change of metaphor in the fourth cycle, since research has shown that changes are consolidated when teachers are able to construct new roles by way of a process of critical reflection at the same time as adopting or constructing new metaphors that are compatible with the changes (McRobbie & Tobin, 1995; Tobin et al., 1994).

Figure 2 shows how Alicia's theories-in-use in the classroom concerning the construction of knowledge evolved over the six cycles of the study. The vertical axis corresponds to the percentage of Alicia's strategies on the construction of knowledge that were student-centred, and the horizontal axis to the six cycles of the study.

One clearly observes in this figure the major change that occurred in Alicia's discursive behaviour in this category between the first and second cycles.



From the beginning until the third cycle, her behaviour and verbal sequences relative to the organization and management of classwork reflected a rivalry of two theories-in-use: one with authoritarian characteristics designed to mold the pupils' behaviour, and the other with quite contrary characteristics orienting the pupils towards autonomy. There was a progressive and continuous consolidation of the latter set of characteristics over the course of the study. From the second cycle, the verbal units and sequences reflecting theories that showed that it was she who determined the activities and their timing began evolving towards a discourse aimed at the pupils understanding the meaning of the new tasks. From the third cycle, she allowed them to decide on which activities to follow and their

implementation. In the fourth, she proposed unconventional tasks which the pupils had freedom to complete in more flexible amounts of time, with the only condition that they should be creative. She also evolved in the sense of democratizing classroom roles. In the fourth cycle, she allowed the pupils to ask her questions about her teaching strategies, and responded by explaining them. In the fifth, she herself explained her behaviour. Lederman (1999) pointed out that beginning teachers have to develop a variety of instructional routines and schemes that allow them to feel comfortable with the organization and management of instruction.

In the second cycle there appeared theories-in-use related to evaluation. They evolved in a progression through explanation of the procedures (third cycle) and criteria (fourth cycle) used, to the foundation and justification of the evaluation procedures (fifth cycle). In her verbal behaviour, she used unconventional techniques, including forms of self-evaluation by the pupils. As also in the case of the novice teacher analyzed by Bejarano & Carvalho (2003), the change in evaluation practice occurred after the change in her model of the construction of knowledge.

The greatest obstacles to Alicia's professional development were found at the beginning of the study, during the first cycle. Among them we might mention: an élitist and academist view of science and teaching influenced by the prestigious university centre from which she graduated; separate and disconnected views of theory and practice; self-sufficiency in her teacher education in spite of her educational deficiencies; a perception of the school context as an obstacle to her attaining her teaching goals; and, above all, an educational and epistemological absolutism with a strong influence on her role as teacher, her management of the class, and the form in which she approached the question of her pupils' construction of knowledge. Many novice science teachers who have studied in prestigious universities see themselves more as scientists than as teachers (Bianchini et al., 2003), and consider teaching to be a second-order career choice (Martínez, García & Mondelo, 1993).

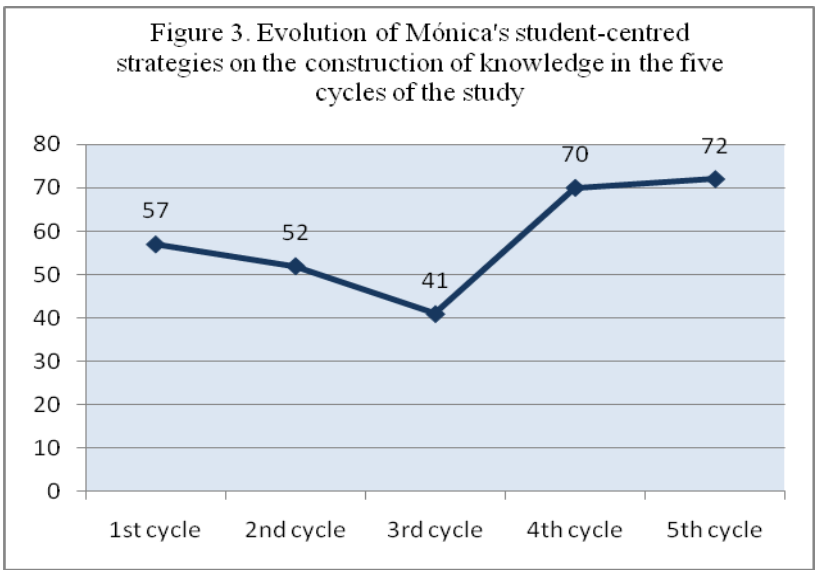
5.2. Mónica's evolution over the five years of the study

At the beginning of the study, Mónica showed a set of beliefs of a mixed nature, with signs of having surpassed the traditional transmissive model, a predominance of the technological model which she was beginning to follow, and very little evidence of a constructivist approach. She stated her agreement with a simplified psychological constructivist approach (López-Ruiz, 1994), while also considering that school knowledge is a simple replacement of everyday knowledge. Epistemologically, her initial declared model was quite similar to Alicia's: of a mixed character,

with relativist, spontaneist, falsationist, and contextualized views of science and its progress.

In the classroom, her theories-in-use at the beginning of the study reflected a teaching model that was more traditional than the model she had declared. With respect to epistemological aspects, she also showed an absolutist conception of knowledge, and a rigid and infallible view of the scientific method. With respect to her management of the classroom, her initial theories-in-use showed two opposing tendencies, one hetero-structural based on fixed directives and dealing uniformly with the group of pupils as a whole, and the other inter-structural based on guidance and with a diversified treatment of the group (Not, 1983). At the beginning of the work, hardly any indicators concerning evaluation were detected.

The evolution of Mónica, a teacher with 25 years of teaching experience, over the course of the five years of the study was completely different from that of Alicia. With respect to her theories-in-use related to the construction of knowledge in the classroom, at the beginning of the study, Mónica's teaching model in the classroom was already more student-centred than Alicia's (Figure 3). Her participation in the program helped her reflect on the advantages for her pupils' learning of current models of science teaching. This reflection, however, led to distress and defensive sentiments concerning these models. In the first three cycles, Mónica experienced conflict between the traditional teacher- and teaching-centred models prevailing in her professional environment and the new models of teaching which are more student- and learning-centred. The consequence in the first three cycles was reinforcement of her teacher-centred strategies with which she felt more secure. As in other cases of experienced science teachers, there was a marked divergence between what Mónica would like to do and what she actually did in the classroom (Luna & García, 2003). As was described for the teacher studied by Reyes, Salcedo & Perafán (2001), her desire for change was not translated into action in the classroom.



Only in the fourth cycle, with the aid of the teacher-guide in the preparation of class activities, did Mónica finally internalize and put into practice in the classroom more learner-centred strategies. As

noted by Day (1999), teachers' change is not just a matter of the head, but also of the heart. It will be difficult to put changes into effect unless they are compensated affectively and contribute to greater personal job satisfaction. Research with teachers has found that, while teachers agree with the objectives of the innovations of curricular reforms, they will not put them into practice in their classrooms when the prospect causes them anxiety and insecurity and they feel that their identity and roles as teachers are affectively and emotionally challenged (Hargreaves, 2005; Lasky, 2005).

From the fourth cycle of the study onwards, Mónica inquired into her pupils' prior concepts, and submitted individual contributions to the judgement of the group. She also extended the dialogue in the group in the sense of accepting every response for consideration.

In the fifth cycle, she asked the pupils for greater precision in their responses, and limited their explanations to giving only the information necessary for the different situations. The last two classes of the fifth cycle, which were prepared in tandem, presented the most new verbal interactive sequences. These were associated with the study of experimental problems and ways of stimulating the processes involved in their resolution: formulating hypotheses, seeking responses to the proposals, using imagination, specifying the experimental measurements to make, subjecting the procedures used to the judgement of the group, etc. They also had the most units showing a personal role of accompanying the pupils: helping them to conjecture possible situations and to resolve technical problems in the laboratory, assisting pupils' verbal participation with drawings and graphs, etc.

During the period of the study, there was conflict between rival positions concerning her pupils' process of construction of knowledge. Mónica's evolution could be called Lakatosian in nature (Mellado et al., 2006; Niaz, 2008). In analogy with the change-resistant core components of Lakatos, teachers do not easily change their conceptions, and even less their educational practices. They limit their changes to secondary aspects, equivalent to the auxiliary hypotheses of Lakatos (Blanco & Niaz, 1998). Experienced teachers' theories and practices are strongly resistant to change, and when this does occur it is because the teachers have alternatives available with which they can feel more satisfied.

With respect to her management and organization of the classes, up to the fourth cycle, Mónica showed evidence of following opposing theories. Some were normative and corrective in the sense that she made it clear that she was the one who determined, directed, and established the content and the time spent on the activities. In others, she sought more autonomous processes in her pupils, such as discussing a theme that they themselves had prepared, asking them for criteria with which

to evaluate the activity, and fostering their appreciation of the contributions of the other groups of their classmates. In the fourth cycle, there was a decline in the former normative type of behaviour patterns, and an increase in the latter participative type. There also appeared other patterns – relaxing the planned study schedule in response to what she observed in the pupils, and giving them the opportunity to choose which activity to continue doing and how. By the fifth cycle, there was hardly any sign of the normative and corrective patterns. Instead, these had been replaced by behaviour that fostered greater autonomy and considered the pupils' needs, interests, time, and decisions. There also appeared another type of behaviour related with the search for autonomy – encouraging her pupils to find answers to their own proposals. With respect to evaluation, in the third cycle of the study there appeared units and interactive verbal behavioural sequences such as using hetero-evaluation, and asking her pupils for criteria with which to evaluate an activity, even though finally she used this to reinforce what she herself considered appropriate.

Working with Mónica meant working in a context of conflict between opposing implicit beliefs, with a reasoned choice finally having to be made among the different alternatives. Each time such a choice had to be made, her distress about the changes increased. The old forms had served her well and were recognized and accepted by her environment. The new were still untested, and she did not know how they would be received. As a result of reflecting on her practice, she sought ways to change it, and to test and evaluate the results. The apparent limitations of her environment began to cease to be felt as such, and the conflicts between her beliefs began to be sharply defined. Her earlier vacillation between the opposing forms of action began to take on a clear direction, although she lacked certain elements to feel safe in applying the model of guided research which she eventually chose, beginning with the fourth cycle. Her analysis and reflection on these classes provided her with the elements that she considered necessary to continue advancing. As in many other cases of science teachers with years of teaching experience, traditional school culture is a major obstacle against putting more innovative teaching into practice (Reyes, Salcedo & Perafán, 2001; Verjovsky & Waldegg, 2005).

At the beginning of the process of guided reflection, Mónica's educational and epistemological absolutism was clearly an obstacle to change. As the study progressed, we perceived that this obstacle was reinforced by other aspects that originated from her past and present contexts, her experience, and her personality. Indeed, her academic training was actually a constraint and a cause of insecurity. We had to find ways to resolve this constraint that were consistent with her academic needs, since she was using academic knowledge as a secure basis from which she was trying to introduce changes. We also had to work on the impact of the authoritarian context in which she

herself had been educated, and hence on the behavioural, directive, and unreflective educational models that she had picked up in that period. In sum, for Mónica the traditional culture of the school represented the greatest obstacle to her putting more innovative teaching into practice. We acted indirectly by generating as counterweight a democratic climate of discussion and consensus that would allow her to become aware of and reflect on these constraints. This first step also permitted her to continually discover new elements that she needed to change. As she gained in security in implementing changes, she began to question aspects of the school context with which she herself was identified, and finally to seek ways of changing them as well. With her process of reflecting on and experimenting with alternatives, she ceased to experience the apparent constraints of her environment as such, the conflicts between opposing currents took focus, and the orientation of their resolution was ever more explicitly towards an inquiry-based model.

6. Conclusions and implications

The process of collaborative guided reflection was based on teachers' beliefs, and was systematized using a criterion of consensus about the interpretations that included the judgement of the teachers themselves. As a methodological approach to continuing teacher education, this showed itself to foster the development of complementary activities and, for both secondary science teachers, the evolution of their desired or declared models of teaching and of the real models that they actually applied in their classroom practice. The result was a contribution to the improvement of their discursive practice and their professional development.

The process of collaborative guided reflection was decisive for both secondary science teachers, which changed the orientation of their classroom practice on the pupils' construction of knowledge from one centred on themselves and the content to another whose focus was the pupils and their learning. The educational changes were, however, very different in both teachers. For Alicia, a novice teacher, the greatest change took place during the second cycle of the study in her behaviour associated with the pupils' construction of knowledge. For Mónica, an experienced teacher, evolution was gradual, involving the resolution of conflicts between rival positions in her pupils' process of construction of knowledge, in her organization and management of the class, and in evaluation.

At the beginning of the study and during the first year of teaching, Alicia's real model in the classroom was far more traditional than the one she said she followed. Her explicit beliefs and desired models evolved gradually over the course of the six cycles of the study. The evolution of her classroom practice was, however, very different. The major change in her teaching model as

reflected in her practice, especially with respect to the pupils' construction of knowledge, occurred from the first to the second cycles. From the second to the sixth cycles, there was a more gradual evolution of her professional development, in both educational and epistemological aspects. By the end of the six years of the study, there was considerable concordance between her explicit and implicit beliefs, and between her declared and practical teaching models, both of which were close to an action-research–constructivist perspective. As a novice teacher, her first two cycles were decisive in overcoming these obstacles. During that period, there were a series of factors that facilitated and stimulated change and professional development: a personal desire for improvement and a positive attitude in the search for alternatives; awareness of what she actually did in practice; the search for concordance between her classroom activity and her goals; improvement in her pupils' learning; and, above all, the recognition of problems in the pupils' construction of knowledge, which allowed her to surpass her initial epistemological and educational absolutism. From the second cycle onwards, she maintained the role of reflective teacher who investigates and isolates the problems in her practice.

At the beginning of the study Mónica showed evidence of a mixed set of explicit beliefs. In the classroom, her theories-in-use reflected a real teaching model that was more traditional than what she had declared, but more student-centred than Alicia's. Mónica's evolution was completely different from that of Alicia. Her participation in the program helped her reflect on the advantages for her pupils' learning of current models of science teaching. This reflection, however, led to distress and defensive sentiments concerning these models. In the first three cycles, Mónica experienced conflict between the traditional teacher- and teaching-centred models prevailing in her professional environment and the new models of teaching which are more student- and learning-centred. The consequence in the first three cycles was reinforcement of her teacher-centred strategies with which she felt more secure. In these three cycles, Mónica's real models in the classroom were strongly resistant to change. Only in the fourth cycle, with the aid of the teacher-guide in the preparation of class activities, did she finally internalize and put into practice in the classroom more learner-centred strategies. By the end of the five years of the study, there was considerable concordance between her explicit beliefs and practical teaching models, both of which were close to an action-research–constructivist perspective.

With respect to the implications of this study, we believe that guided reflection affects participating secondary science teachers very differently according to their initial teacher education, their teaching experience, the particular school context, etc. This implies that there is a need to individualize professional development according to the personal and social characteristics of the

teacher with whom one is collaborating. Of particular importance would be specific programs of initiation to teaching, since this is a stage in which classroom strategies and routines are being formed and consolidated, and which will be far harder to change later (Ford & Fargo, 2007). If novice teachers receive sufficient support, it will be the stage in which their capacity for change is greatest (Hargreaves, 2005; Luft & Patterson, 2002; Luft, 2009).

Other implication is that teaching science is more than a cognitive process and is highly charged with feelings. Zembylas (2001, 2002 & 2004) revises the relationship between science teaching and emotion, and argues that emotions, both positive and negative, play an important role in teachers' construction of pedagogical content knowledge, curriculum planning and relationships with children and colleagues. Other recent results in science education recognize the importance of emotions in teaching, and advocate the need to consider the cognitive and affective dimensions (Brígido et al., 2009; Koballa & Glynn, 2007).

Finally, we wish to emphasize that, in future research, it will be necessary to relate secondary science teachers' professional development to their pupils' learning, paying particular attention to the pupils' process of construction of knowledge (their difficulties, progression, construction of meanings, evaluation, etc.), and to the teachers' pedagogical content knowledge (Friedrichsen et al., 2009; Gárritz et al., 2008; Luft, 2009). We also believe that it will be important to focus on specific topics of the school science curriculum, taking advantage of studies already carried out on the construction and progression of school-level knowledge in these topics (Jiménez-Aleixandre & Reigosa, 2006). In this way, the participating teachers would have referents to form a basis for the process of their pupils' construction of knowledge.

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