THE PROFESSIONAL DEVELOPMENT OF SECONDARY EDUCATION SCIENCE TEACHERS: A CASE STUDY AS METHODOLOGICAL INTEGRATION

Bartolomé Vázquez-Bernal[1,2], Roque Jiménez-Pérez[2] and Vicente Mellado[3]

[1] Secondary school physics and chemistry teacher, Huelva, Spain
[2] Dept. of Science Education and Philosophy, Faculty of Education, University of Huelva, Spain
[3] Dept. of Science and Mathematics Education, Faculty of Education, University of Extremadura, Badajoz, Spain

Abstract

The work that we describe here is a case study of a secondary education science teacher, whom we shall refer to as Ana, about the interaction between action-oriented reflection and action itself, and their influence on professional development. The study was carried out from two different perspectives —one with a qualitative orientation using diverse data collection and analysis instruments, and the other collaborative action-research to form the backbone of Ana's professional development. In our theoretical outline, we stress two concepts— that of reflection which sustains the theoretical-practical dialectic, and that of complexity as a progression hypothesis of central importance in which we distinguish the three dimensions of technique, practice, and criticism.

The results showed Ana to be in transition from a technical to a practical dimension, with her reflection and her classroom practice being closely integrated and in the process of becoming more complex. A central core of obstacles was observed that impeded her professional development.

Acknowledgements

This work was financed by Research Projects SEJ2006-04175 of the Ministry of Education and Science (Spain) and European Regional Development Fund (ERDF).

1. Professional Development as the Integration of Reflection and Practice: A model Based on Complexity

For many years the 'professional development' (PD) of science teachers focused almost exclusively on renovating and increasing knowledge of scientific content. In the last two decades, however, pædagogical content knowledge (Shulman, 1986) has also found a place in this development, and has been the motivation of numerous studies with science teachers

VÁZQUEZ-BERNAL, B., JIMÉNEZ-PÉREZ, R., & MELLADO, V. (2008). The Professional Development of Secondary Education Science Teachers: A Case Study As Methodological Integration. In In Ingrid V. Ericsson (Ed.) *Science Education in the 21st Century*, pp. 137-164. New York: Nova Science Publishers, Inc. ISBN: 978-1-60021-951-1.

(Gess-Newsome & Lederman, 1999). A number of educators have taken a broader sociocultural or social constructivist perspective in PD models (Bell & Gilbert, 1998; Elliot, 1993; Hewson *et al*., 1999; Howe & Stubbs, 2003; Kepler, 1999; Luft, 1999, 2001; Marx *et al*., 1998).

Nevertheless, there have been many approaches to PD. A synthetic description is given in Mellado et al. (2006), including the union of the social and the personal (Hargreaves, 1996), long-term sustained support (Sánchez & Valcárcel, 2000), the didactics of science as the axis of teacher education (Tobin & McRobbie, 1996; Tobin et al., 1997), and action-research (Lyons et al., 1997; Roth, 1998). 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 (Bell, 1998; Hargreaves, 1996; Mellado et al., 2006; Milicic et al., 2004; Sánchez & Valcárcel, 2000).

The present study of PD reformulates some of these proposals. For convenience, we divide PD into three 'stages' (Fig. 1) in the sense of 'levels of perception', by which we mean that the teacher's development involves progressing from observing events as examples of generic classes to seeing them in increasing detail and complexity.

In a first stage, we accept the view that teachers' development involves professional, social, and personal growth (Bell & Gilbert, 1994; Bell, 1998).

In a second stage, PD is linked more particularly to three spheres: (i) a sphere of knowledge – knowledge of the practice of the profession; (ii) a sphere of know-how – procedures for the development of the teacher and for curricular innovation through action-research (Stenhouse, 1987); and (iii) a sphere of being – of attitudes, of a search for identity as a member of a community of continually evolving learners.

The third stage is the most explicit, with complexity in both reflection and classroom practice. In this stage, we will inquire into some of the obstacles that teachers face in developing this complexity of reflection and of classroom practice, and their mutual integration.

Experienced teachers have very stable personal practical knowledge and beliefs. These have become consolidated throughout their careers, and are very resistant to the change. Moreover, there exist conditioning elements that reinforce traditional models, and are obstacles to changing them (Shwartz, Ben-Zvi & Hofstein, 2005; Tobin, 1998; Verjovsky & Waldegg, 2005).

As suggested by Lakatos's metaphor of competition between research programs (Lakatos, 1983), there is undoubtedly a central core in teachers' conceptions and practice which is very resistant to change (Mellado, 2003). If we can determine just what these core obstacles are, we will then have a real possibility of reconstructing more complex practical theories (Fourez, 1994; Niaz, 2002).

VÁZQUEZ-BERNAL, B., JIMÉNEZ-PÉREZ, R., & MELLADO, V. (2008). The Professional Development of Secondary Education Science Teachers: A Case Study As Methodological Integration. In In Ingrid V. Ericsson (Ed.) *Science Education in the 21st Century*, pp. 137-164. New York: Nova Science Publishers, Inc. ISBN: 978-1-60021-951-1.

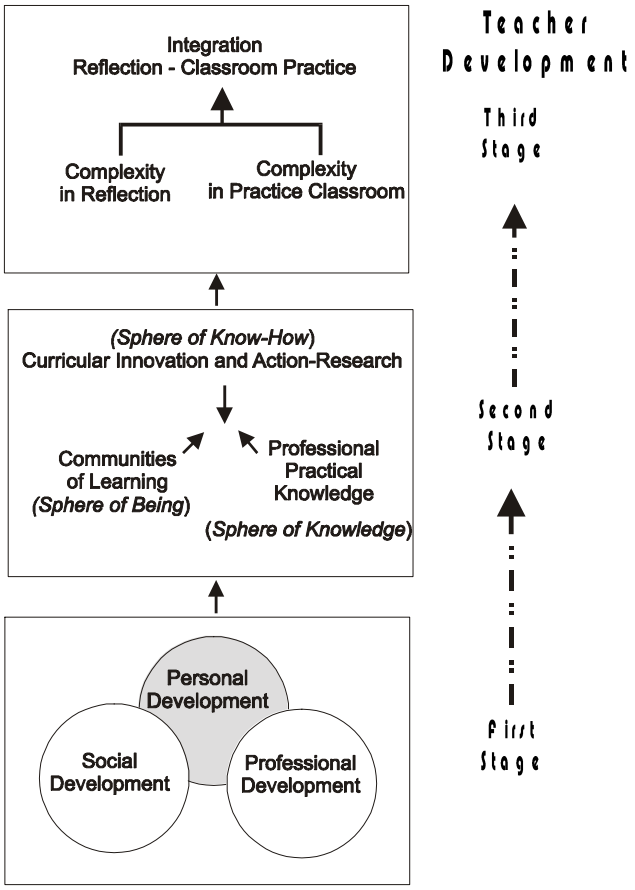

Figure 1. Stages in our proposal of Teacher Development.

2. The complexity of Reflection and Practice

Advances in education research have led to growing recognition of the processes of reflection (Goodman, 1987; Kemmis, 1999; Loughran, 1996; Schön, 1983; Zee & Roberts, 2002; Zeichner, 1993; 1995). Reflection is interpreted as an act inherent to practice itself (Jiménez et al., 1999) or as a necessary catalyst for the development of professional knowledge (Bryan & Atwater, 2002). This opening to personal and shared dialogue is especially important for teacher development (Gunstone & Northfield, 1994), since change is usually continuous and gradual, and takes place in collaboration with colleagues (Mellado et al., 2006; Reyes et al., 2001). Our present interest is in particular to understand and interpret reflection and its relationship with practice (Baird et al., 1991; Gunstone et al., 1993, 1994; Gunstone, 1999; Windschtil, 2003).

We establish the hypothesis of complexity, the heir of earlier theoretical developments in the field of science education, above all of the different approaches to the evolution of the teacher-centred models of education. There then arises the search for personal models of education that are specific to each teacher. One result of such studies was the elaboration of

VÁZQUEZ-BERNAL, B., JIMÉNEZ-PÉREZ, R., & MELLADO, V. (2008). The Professional Development of Secondary Education Science Teachers: A Case Study As Methodological Integration. In In Ingrid V. Ericsson (Ed.) *Science Education in the 21st Century*, pp. 137-164. New York: Nova Science Publishers, Inc. ISBN: 978-1-60021-951-1.

the Hypothesis of Progression on Teachers' Professional Knowledge (Porlán & Rivero, 1998; Wamba, 2001; Jiménez & Wamba, 2003).

Although the literature mostly shows a preference for the existence of three levels associated with reflection (in chronological order: Hoyle, 1974; van Manen, 1977; Tom, 1984; Zimpher & Howey 1987; Carr & Kemmis, 1988; Louden, 1991; Schön, 1998; Elliot, 1999), studies of a complex nature require approaches of a diverse conceptual nature (Herrán, et al., 2005). On the basis of the foregoing contributions, we proposed a Hypothesis of Complexity (Vázquez-Bernal, 2006) in which we differentiated three dimensions in place of the three levels described by the aforementioned authors, but now associated with a somewhat different concept. Feldman (1994, 2002), in a reflection on the necessity to analyze how teachers reason, on their practices, and on the social and political context, suggested a metaphor of horizons — a teacher's view of his or her educational horizon is in some way like a physical horizon. In this same sense, we associate metaphorically the capacity for reflection with the concept of dimension. Thus, we distinguish three dimensions: technical, practical, and critical. In our hypothesis, each dimension becomes more complex, adding increasing complexity to reflection itself from purely instrumental interests in the technical dimension, through practical problem solving, to the social awareness and emancipating role of education in the critical dimension.

In the Hypothesis of Complexity, we recognize an increasing level of complexity in teachers' reflection linked to their classroom practice. Zeichner (1993) and Cachapuz (1995) reject the reduction of the process of reflection to the consideration of teaching skills and strategies, to the exclusion of the ends of education. We concur with the view of reflection as a promoter of knowledge described by Cochran-Smith & Lytle (2003), who distinguish between knowledge for practice which is generated in the university, knowledge in practice which is generated in everyday classroom practice, and knowledge of practice which is the merging of the former two.

Our basis is the necessary integration of teachers' classroom practice and the quality of their reflection as generator of knowledge. From our perspective, this has to result in a certain degree of complexity in their professional development. Figure 2 is a graphical representation of the Hypothesis of Complexity in which we emphasize the increasing degree of complexity as the teacher advances from one dimension to the next.

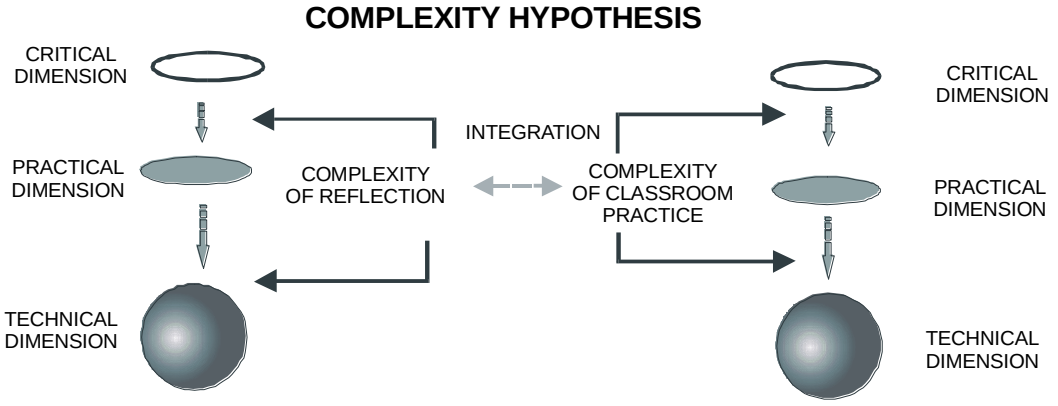

Figure 2. The integration of reflection and classroom practice.

VÁZQUEZ-BERNAL, B., JIMÉNEZ-PÉREZ, R., & MELLADO, V. (2008). The Professional Development of Secondary Education Science Teachers: A Case Study As Methodological Integration. In In Ingrid V. Ericsson (Ed.) *Science Education in the 21st Century*, pp. 137-164. New York: Nova Science Publishers, Inc. ISBN: 978-1-60021-951-1.

How to actually develop and practise reflection is a teacher's own choice based on his or her context and personal history. This does not mean that we do not defend a complex and systemic view of a teacher's discourse, with the incorporation of different voices or models (Pozo, 1999). The notion of complexity, extensively developed by Morin (1995), is a value, thought, and action orienting ideological option, and a perspective on action and the construction of knowledge (Bonil & Pujol, 2005).

3. Case Studies as Methodological Integration

Various authors (Colás & Buendía, 1998; Latorre et al., 1996) have described the existence of three predominant philosophical currents in educational research — logical empiricism, interpretative theory, and critical theory. Indeed, these approaches coexist in educational research today. Nevertheless, given the complex and multidimensional nature of education itself, other authors (Herrán et al., 2005) consider it necessary to formulate a new research paradigm specific to education which they call 'Complexity', and which integrates theory and practice.

With respect to the professional development of science teachers, some authors have questioned whether the professional perspectives of these teachers have improved with the projects that were implemented three decades ago (Lesh & Lovitts, 2000). To respond as to how a PD project may have influenced teaching practice requires studies that extend over time and are undertaken in natural contexts. For that reason, researchers in education need to recognize the sociocultural, historical, systemic, political, cognitive, affective, and psychological aspects of teaching and learning (Nelly & Lesh, 2000). In sum, as indicated by Romberg & Collins (2000), there exists no single qualitative research program, but multiple approaches characterized by the levels at which the research is targeted: ontological, epistemological, methodological, and technical. The choice of method is conditioned by the nature of the research problem and its related questions. Nevertheless, it needs to be emphasized that no method can provide answers to all the questions that can arise in education research (Mestre, 2000). But they do share a common objective — to generate scientifoc-educational knowledge using a scientific methodology (Fox, 1981; Bartholomew, 1984; De la Orden, 1985; Parrilla, 1992; Latorre et al., 1996; Colás & Buendía, 1998; Sandín, 2003). This form of dealing with the subject requires medium and long term longitudinal studies, since the changes occur over long periods of time, and only longitudinal studies will show whether those changes are ephemeral or permanent (White & Arzi, 2005).

In our research in particular, we used a case study as a tool for methodological integration. In the terminology of Stake (1998), this would be a study of an instrumental nature as it was aimed at trying to understand the problematic situations that arise from the research itself, although it has a critical aspect (Keeve, 1998) in that it has the additional goal of inducing change, and an evaluational aspect in its objective of determining results.

VÁZQUEZ-BERNAL, B., JIMÉNEZ-PÉREZ, R., & MELLADO, V. (2008). The Professional Development of Secondary Education Science Teachers: A Case Study As Methodological Integration. In In Ingrid V. Ericsson (Ed.) *Science Education in the 21st Century*, pp. 137-164. New York: Nova Science Publishers, Inc. ISBN: 978-1-60021-951-1.

4. Research Questions

Our work forms part of an action-research program carried out in a state secondary-education school in a town of 20 000 inhabitants in the province of Huelva, located in the southwest of Spain. It was carried out by a teacher from the same school, with four other teachers from the school and university science education researchers. In another work (Vázquez et al., submitted for publication), we described the case of Marina, another of the participating teachers. In the present article we will centre on the case of a teacher we will refer to as Ana, one of the teachers participating in the research. Although the results are specific for each teacher, both are part of the same research group, so that the context, method, and presentation of the results have many aspects in common.

We summarize in the form of questions the problems that we set ourselves:

a) Methodologically, can we find a balance between methods following different paradigms without reducing the credibility of the research?

b) Is it possible to base professional development on the integration and complexity of reflection and classroom practice?

c) Is there a degree of convergence between reflection and classroom practice? How do they both evolve over time?

d) In which dimension of the Complexity Hypothesis is Ana situated, both for reflection and classroom practice?

e) What kind of obstacles hinder the integration of reflection and classroom practice, preventing the desirable development?

f) In what way can a program of action-research affect the professional development of teachers?

5. Research Methods

To put into operation the process followed with the teachers, we applied the Kemmis and McTaggart (1988) action-research model, whereby successive methodological cycles of planning, acting, observation, and reflection are established. The work was carried out during two consecutive school years, 2001-2002 and 2002-2003, with students of the 3rd year of Secondary Obligatory Education (S.O.E.: 14-15 year-olds). Ana, the pseudonym of our second case, is a chemistry graduate. On joining the working group in the 2001-2 school year, she had twelve years experience as a teacher. She has tenure, so that her administrative situation is one of stability. On occasions Ana describes herself as "the mother". Previous research has shown that the metaphors used by teachers allow one to discover the implicit referents that sustain the teacher and that have a powerful influence on his or her teaching behaviour in the classroom (McRobbie & Tobin, 1995; Mellado et al., 2006; Tobin et al., 1994).

VÁZQUEZ-BERNAL, B., JIMÉNEZ-PÉREZ, R., & MELLADO, V. (2008). The Professional Development of Secondary Education Science Teachers: A Case Study As Methodological Integration. In In Ingrid V. Ericsson (Ed.) *Science Education in the 21st Century*, pp. 137-164. New York: Nova Science Publishers, Inc. ISBN: 978-1-60021-951-1.

Instruments of Data Collection and Analysis

We shall classify the instruments according to their methodological function: first order (data collection), second order (category systems, theoretical and taxonomic models), and third order (presentation and interpretation of the data).

The reflection data collection instruments were the teacher's diaries and memos, transcriptions of the work group meetings, questionnaires, and interviews. For the classroom practice, the ethnographic notes and extracts from the videotapes of the class sessions, and other documentary sources such as the programs and teaching units, or the work produced by the students (first-order). The fundamental instrument for data analysis, both for reflection and practice, was the Reflection Analysis Categories System, R.A.C.S. (second-order: Annex I). We also used third-order instruments for the representation, such as complexity spheres for reflection and practice and the reflection-practice integration horizon, which allowed the evolution of the teacher to be viewed over the course of the two school years that the study lasted, as well as giving an overall representation of the integration of reflection and practice.

The variety of instruments allowed us to undertake a triangulation from different perspectives. Thus, for reflection we distinguished three forms according to the context: introspective, inquiry oriented, and obtained from the diaries; interrogative, statement oriented, and obtained from the memos and interviews; and group, interaction oriented, and obtained from the records of the group meetings.

We considered six analytical frames to elaborate the R.A.C.S.: ideological, teacher education, psychological, contextual, epistemological, and curricular. We included in the ideological frame the influence of ideologies on the teaching environment and the relationship occupied by the teachers and their context. The teacher education frame included the education of teachers in general, and that specific to science education. The psychological frame included the way in which the teachers view school-level learning and their understanding of the obstacles in the teaching-learning process. In the contextual frame we included the interactive teacher-student relationships, and social and scheduling organization. In the epistemological frame, we included school-level knowledge and how the teachers perceive it, the criteria with which they select the sources of information, and the utility and construction of this kind of knowledge. Finally in the curricular frame we included the types of problems that are proposed in the classroom, the sequences of activities, the curricular material employed, and evaluation. To analyze the classroom practice we used the Practice Analysis Categories System. This consists of the psychological, contextual, epistemological, and curricular frames. The ideological and teacher education frames were excluded, not because they have no influence, but because they are not directly inferred from the data available.

We distinguished three dimensions in the Complexity Hypothesis —technique, practice, and critique— for each analysis structure or substructure that characterize each frame. Annex I gives the categories associated with the different frames. As an example, Table I includes the four categories associated with “Curricular Materials or Information Sources” (T. D. = technical dimension; P. D. = practical dimension; C. D. = critical dimension). Each of them has an associated code (TTEX, PSOU, and CSIM) formed from its meaning in English, and which we shall use in the representations of the analysis of the results.

VÁZQUEZ-BERNAL, B., JIMÉNEZ-PÉREZ, R., & MELLADO, V. (2008). The Professional Development of Secondary Education Science Teachers: A Case Study As Methodological Integration. In In Ingrid V. Ericsson (Ed.) *Science Education in the 21st Century*, pp. 137-164. New York: Nova Science Publishers, Inc. ISBN: 978-1-60021-951-1.

Table I. Categories associated with the "Curricular Materials" structure.

FRAMES	STRUCTURES	SUBSTRUC-TURES	CATEGORIES	CODES
Curricular	Curricular materials or information sources	For the teacher / student	T.D.: Use of the textbook as principal source of information.	TTEX
			P.D.: Use of different sources of information.	PSOU
			C.D.: Socially important problems.	CSIM

The information was processed using the AQUAD computer program. Its application was mainly centred on coding, search options, calculation of the information unit frequency, associations in simple coding sequence formats, and the verification of links (Huber, Fernández & Herrera, 2001). The documents that were analyzed by means of AQUAD were the diaries, memos, minutes of the meetings, interviews, and ethnographic records. Besides the frequency calculations, the AQUAD program allowed us to obtain the linkages of the categories that appear clustered in grouped sequences of two or three. From the links between the codes, we obtained the core categories which stand out because of their high frequency rates, or the nucleating agents which also link positively with other categories.

6. Results

Frequency Analysis of Reflection Categories

Table II. Frequencies of reflection categories for Ana during the school year 2002/3.

	Technical dimension	Practical dimension	Critical dimension
Ideologies in the educational environment	TAPO (0)	POPT (0)	CADM (6), CENV (2), CINQ (1), CHIS (0), CIDE (0)
Interactive teacher-student relationships	TBOX (2)	PTWK (3)	CPRO (1)
Teacher education	TACC (2)	PPER (22)	CREF (10)
Science education	TRES (2), TDOM (3)	PREA (0), PPCK (14)	CEXP (2)
School-level learning	TMEM (7), TASS (10)	PMEA (1)	CLSC (0)
Obstacles in the teaching-learning process	TUND (37)	PDIF (54)	COBS (2)
Student motivation	TIND (22), TMTV (10)	PPAR (33)	CDIS (5)
Classroom atmosphere	TCON (5)	PATM (3)	CREG (1)
Social organization	TCOM (0)	PSWK (9)	CSOC (15)
Temporal organization	TTIM (8)	PADA (9)	CDYN (2)
School-level knowledge	TSCI (99)	PDLY (32), PAPD (1)	CEPI (0)
Selection criteria for the information sources	TEFF (21)	PANS (4)	CDEC (1)
Use of school-level knowledge	TPRG (1)	PSKI (11)	CCIT (4)
Construction of school-level knowledge	TSOL (1), TREI (17)	PINT (21)	CNEG (0)
Types of problems	TCAP (14)	POPR (12)	CRSP (5)
Sequence of activities	TRIG (3)	PFLE (15)	CDIV (2)
Curricular materials or	TTEX (1)	PSOU (13)	CSIM (1)

information sources			
Objective of evaluation	TOBJ (1)	PSUB (3), PIDE (2)	CCEN (1)
Purpose of evaluation	TSAN (0)	PSUM (4)	CDEV (2)
Participation in evaluation	TGUA (5)	PSTU (0)	CCOE (0)
Instruments of evaluation	TEXA (8)	PDSE (15)	CMET (0)

Reflection was analyzed from three perspectives: frequency analysis, linkage analysis, and content analysis. For the first two, we used the AQUAD computer program. Because of its length, we shall not show the content analysis in the present work. Table II gives in parentheses the frequencies of appearance of the code associated with a given category within each form of reflection for the 2002–3 school year, as the sum of the three forms of reflection.

The category that appears with greatest frequency (99) is scientific knowledge as the fundamental knowledge of the curricular content (TSCI), belonging to the technical dimension. This is followed by reflection on the difficulties of the students (PDIF), from the practical dimension (54). These two categories were also the most frequent with Marina, another of the participating teachers (Vázquez et al., submitted for publication). Next appear allusions to the students' lack of understanding (TUND: 37), the effort and participation of the student as extrinsic factors (PPAR: 33), reference to the daily experience of the student (PDLY: 32), the individual effort of the student as an intrinsic factor (TIND: 22), attention to the students' interests (PINT: 21), acritical efficacy and its role in improvement (TEFF: 17), the reinforcement of the ideas presented by the teacher (TREI: 17), support for the socially more needy (CSOC: 15), and the use of problems with closed answers (TCAP: 14). We would highlight the presence of categories of a technical nature in the teacher's reflections, even though in an emergent form: ranked second in her reflections is her interest in the students' difficulties.

Table III presents the evolution of the frequency analysis for Ana in the two school years studied. During the year 2002/3, we observed a tendency towards the practical and critical dimensions, although the most important increase in complexity towards the practical dimension occurred in the interrogative reflection (final interview). Group reflection remained the same in both years, ending at the same level as introspective reflection.

Table III. Evolution of Ana's reflection frequencies during the two school years.

Type of reflection	Nº of Participants	Oriented towards	Analysis instruments 2002	Results for Ana 2001 (704 codes)	Results for Ana 2002 (662 codes)
Introspective	One	Inquiry	Teacher's diary *(187 codes)*	Technical dim.: 87% Practical dim. 13% Critical dim.: 0%	Technical dim.: 56% Practical dim.: 43% Critical dim.: 1%
Interrogative	Two	Statement	Interview *(55 codes)*	Technical dim.: 53% Practical dim.: 35% Critical dim. 12%	Technical dim.: 36% Practical dim.: 32% Critical dim.: 32%

Grouped	More than two	Interaction	Record of meetings *(396 codes)*	Technical dim.: 53% Practical dim.: 44% Critical dim.: 3%	Technical dim.: 42% Practical dim.: 47% Critical dim.: 11%

Figure 3 shows this evolution graphically. One observes that the teacher is more technical when she is reflecting alone (diary) than when she is interacting with the others.

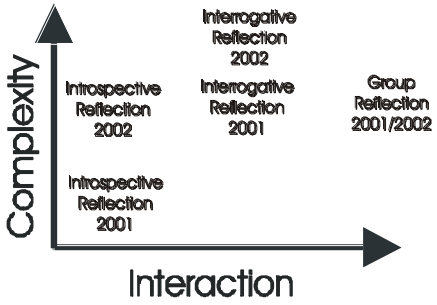

Figure 3. Complexity vs interaction.

Analysis of the Reflection Category Linkages

The linkage analysis allowed us to determine the associations between two and three categories that appeared over 10 consecutive lines in a segment of text, and to establish hypotheses of linkages between these categories. Selecting the most frequent linkages in each school year, we elaborated the diagrams shown in Figure 4 for the categories in the technical dimension.

Figure 4. Most significant links between Ana's technical dimension categories in the two school years.

The stability of Ana's reflections is shown in the existence of similar linkages in the two study years. However, in that second school year, there disappeared the reflections with regard to the inflexibility of the activities (TRIG). Observing the linkages between categories in Figure 4, one can indicate that scientific knowledge as fundamental knowledge of the curricular content (TSCI), the students' lack of understanding (TUND), the use of closed-answer problems of purely scientific content (TCAP), as well as the use of an acritical and

technological way of thinking based on criteria of efficiency (TEFF) form the irreductible core of Ana's explicit theories in the technical dimension.

For the practical dimension the most significant linkages are those represented in Figure 5. Observing the categories, one appreciates that they have little stability, i.e., they only appear in a single school year. Moreover, they are linked to technical categories, which indicates the influence that the latter exert on the teacher's thinking. We also would highlight that the practical categories are not linked to each other in either of the school years under study.

Figure 5. Most significant links between the categories of the practical dimension in the two school years analyzed.

In the school year 2002/2003 the central category is that of reflection on students' difficulties (PDIF). However, this category appears to be closely linked to categories of the technical dimension, being affected by that of efficiency criteria (TEFF), scientific knowledge as fundamental knowledge of the curricular content (TSCI), the students' lack of understanding (TUND), the use of closed-answer problems of purely scientific content (TCAP), as well as the use of rigid activities (TRIG). The irreductible core is much smaller than that analyzed previously for the technical dimension, above all because the absolute values at which the links appear are much lower in most cases. The practical categories of greatest frequency in Table II (PDIF, PPAR, PDLY, PINT) do not appear directly linked to each other.

The categories of the practical dimension that appear most linked in Figure 5 are reflection on the students' difficulties (PDIF), the use of different sources of information (PSOU), and pædagogical content knowledge (PPCK). These constitute the nucleating agents around which Ana's reflection evolves.

Figure 6 shows the most significant links for the critical dimension. In the first school year, one finds the critical category on the school's role in overcoming social inequalities (CINQ) to be associated with the practical category of the recognition of what is personal as starting point in the teacher's improvement (PPER).

In the second school year, the central critical category in the linkages is the use of problems of research into the social and natural environment (CRSP). Other critical categories that appear are the educational administration and its pressure as political fact (CADM) and the formation of citizens with critical capacity concerning advances in science and technology (CCIT). Their interest lies in that they are linked to categories of a practical nature. One observes, however, that the categories of a critical nature that appear are different

in the two school years and have no linkage with each other, reflecting their instability in the teacher's reflections.

By way of synthesis, the analysis of the two school years indicates that the irreductible core of the explicit theories in the technical dimension is consolidated around certain categories. This core has many similarities with the case of Marina, another of the participating teachers (Vázquez et al., submitted for publication). The two teachers have a strong initial education in their discipline and very similar career histories. The categories are those of reflections involving the students' lack of motivation and understanding, the use of closed problems of purely scientific content, the use of an acritical and technological way of thinking based on criteria of efficiency and the inflexibility of the activities. The category of reflection on students' difficulties in the teaching-learning process is the nucleating agent of Ana's explicit theories, and a true zone of future development towards complexity.

Figure 6. Most significant links between the critical dimension categories.

The Complexity Sphere for Ana's Reflection

Figure 7, the complexity sphere, is a synthesis of the results for Ana's reflection over the two school years of the study. This is a representation of our complexity hypothesis metaphor, displaying its different dimensions. We have put the technical dimension on the first inner ring (one-dimensional), the practical dimension on the outer ring simulating therefore a (two-dimensional) surface, and the critical dimension at a certain height above the two rings thus giving a spherical perspective (three-dimensional).

We have adopted a set of keys to interpretation so as to facilitate rapid access to the information. These keys are on two levels — codes and arrows. A code can be of three types — solid black (the code appears in both school years), open black with white fill (the code appears in a single school year), and solid white (the code does not appear in either school year). The arrows express movement towards increasing complexity. Thus, a solid black arrow indicates there has been a completed transition of complexity from an initial dimension to the next, a white arrow that there still exists no complexity, and a dashed arrow that the transition is in progress.

When the evolution of the teacher's reflection is observed overall, one perceives the existence of a process of undoubted complexity. This holistic vision, found in all the frames of analysis, shows the teacher to be in a situation of transition from the technical towards the practical dimension. A closer view of the complexity sphere shows that the structures that

VÁZQUEZ-BERNAL, B., JIMÉNEZ-PÉREZ, R., & MELLADO, V. (2008). The Professional Development of Secondary Education Science Teachers: A Case Study As Methodological Integration. In In Ingrid V. Ericsson (Ed.) *Science Education in the 21st Century*, pp. 137-164. New York: Nova Science Publishers, Inc. ISBN: 978-1-60021-951-1.

have most evolved towards complexity are the social organization of the classroom, the criteria for the selection of the information sources, and the purpose of evaluation. On the contrary, the teacher's understanding of how school-level learning takes place and who participates in evaluation shows structures that are less complex and more resistant to change.

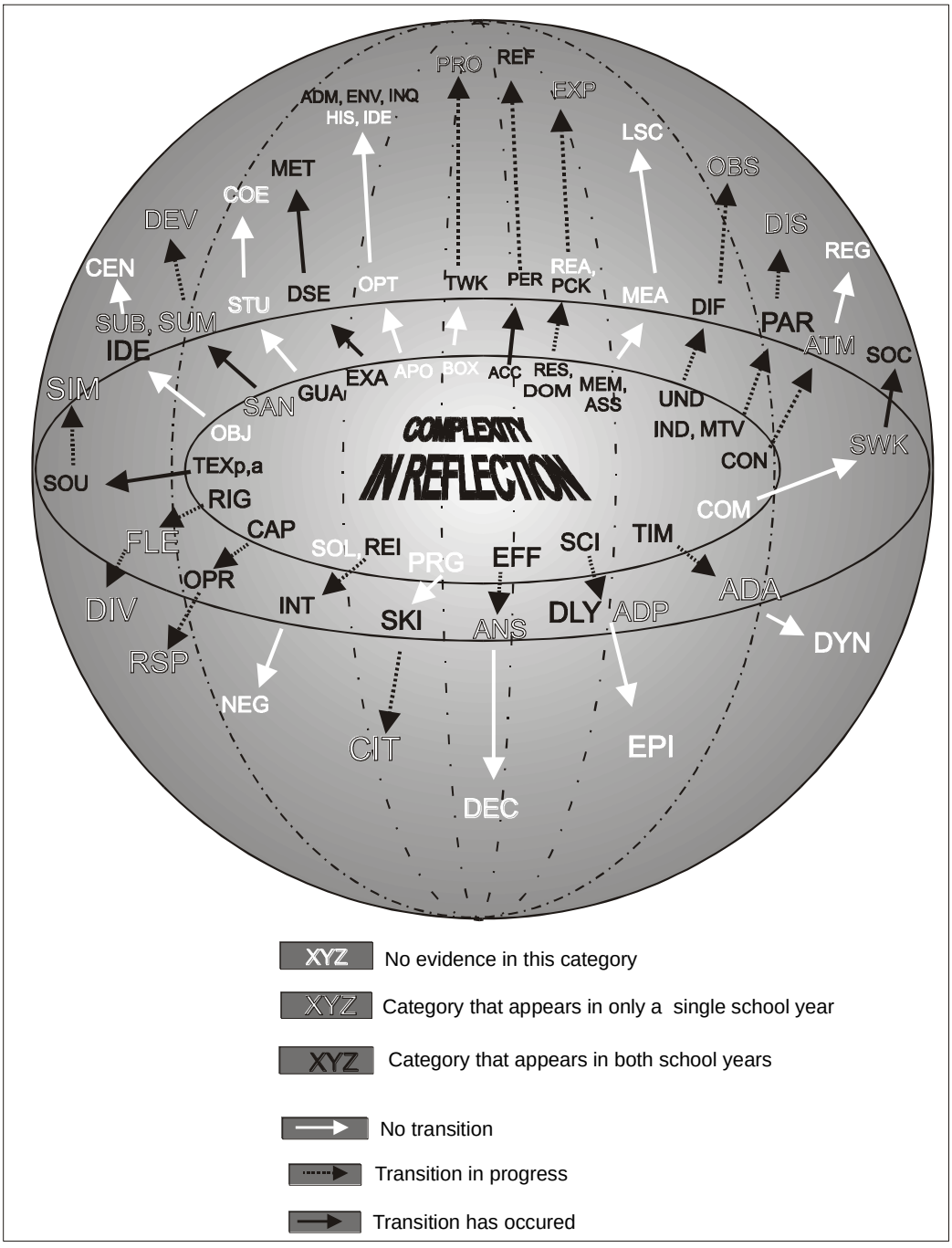

Figure 7. Complexity sphere for the evolution of Ana's reflection.

VÁZQUEZ-BERNAL, B., JIMÉNEZ-PÉREZ, R., & MELLADO, V. (2008). The Professional Development of Secondary Education Science Teachers: A Case Study As Methodological Integration. In In Ingrid V. Ericsson (Ed.) *Science Education in the 21st Century*, pp. 137-164. New York: Nova Science Publishers, Inc. ISBN: 978-1-60021-951-1.

Analysis of Classroom Practice

As an example of the classroom practice results, we shall describe the structure of the intervention corresponding to "Student Curricular Materials or Information Sources".

Technical dimension: The analysis of the ethnographic notes indicates that the main source of information for the students is the set of notes (TTEX) prepared by the teacher. These consist of a considerably revised adaptation of textbooks based on program-guides of Hierrezuelo et al. (1998). The teaching unit was prepared anew, however, to adapt it to the new guidelines and agreements that came out of the work group. Corresponding to the first time that these notes were used is the following extract from the ethnographic notes (RET1–2002: ethnographic record 1 of school year 2002–3):

> "11:22 h. Gives specifications of how to recover the corresponding parts. Adds that, for this subject, photocopies are going to be given out.
> "11:23 h. Says to Gema that if she keeps up with her attitude being just as positive, her results will improve and that she will see it.
> "11:24 h. The teacher comments that last year they saw the complete unit. RET1–2002."

In sum, it is clear the importance that the teacher gives to the teaching unit notes as the main curricular material for her students. This constitutes a true obstacle in the development of her classroom practice.

Practical dimension: Among the diverse sources of information for the students (PSOU), there was the use of an educational documentary in video format on Molecular Kinetic Theory, followed by a questionnaire on the content of the documentary. The following is an extract from the ethnographic notes:

> "Adds that they will do the theory that comes next tomorrow. Says that now they are going to watch the MKT video, adding 'you have to take notice of what it says'. Antonio seems a bit unruly.
> "12:59 h. The teacher asks the students to come up closer to see the video. The students seem to be getting a bit jumpy, especially Antonio.
> "13:00 h. The teacher prepares the film. The students are talking among themselves. RET7–2002.
> "Projects a video documentary 'Journey to the Interior of Matter'. RET152002."

The students are also asked to look for information on food labels about the composition and concentration of certain foodstuffs, as is expressed in the following extract:

> "When you arrive home, look at the composition of some bottled foods (at least three, and at most five), and answer:
> "What are the components?
> "Which is the solvent and which the solute(s)?
> "What is the concentration of each? RET10–2002."

In sum, together with the use of the activity program-guides, the teacher uses other sources of information for the students such as video materials and documents that can be found in everyday life.

Critical dimension: Proposed as an important social problem (CSIM) was to investigate the 'sinking of a oil-carrying barge at Algeciras'. This was related to the 'Prestige' oil-spill

VÁZQUEZ-BERNAL, B., JIMÉNEZ-PÉREZ, R., & MELLADO, V. (2008). The Professional Development of Secondary Education Science Teachers: A Case Study As Methodological Integration. In In Ingrid V. Ericsson (Ed.) *Science Education in the 21st Century*, pp. 137-164. New York: Nova Science Publishers, Inc. ISBN: 978-1-60021-951-1.

catastrophe, a subject of burning interest in the mass media throughout the time at which the teachers were doing the practical development of the teaching unit, and was naturally considered important for treatment in class. The following shows the first time that the teacher told her students that they were going to use this social problem in their class:

> "8:44 h. Expresses that they are going to make posters about the sinking of a barge carrying fuel in Algeciras. She says that oil is a solution with solvent and solutes, as they will see at the end of the topic. She requests them to bring material to do this tomorrow, since it is about approaching the problem of contamination. RET11–2002."

Another important social problem was the treatment of drug abuse and its effects on health, a topic of especial importance to the students in that class. The following extract from the notes refers to the first time that this topic was dealt with in class:

> "8:25 h. They are going to begin reading page 11 on drug abuse. She designates Antonio to read, who protests. José volunteers and reads the text.
> "8:26 h. The teacher says: 'Think if using them is worth it.' The teacher comments a little on it. Later she says that the substances from 'joints' remain in the urine for 2 days to 3 weeks. Several students show interest in that. RET19–2002".

For the structure 'Student Curricular Materials or Information Sources', Ana makes use of diverse sources without abandoning the prepared teaching unit. In this aspect, she is making her teaching practice more complex. Because of her use of important social and environmental problems from articles in newspapers, magazines, and written media in general, we think that she has initiated the transition towards the critical dimension. As an illustration of this spatio-temporal synthesis, Fig. 8 shows the result of the analysis of classroom practice for this structure.

Figure 8. The evolution of the complexity of Ana's classroom practice for the structure 'Student Curricular Materials or Information Sources'.

In Fig. 9, we show the complexity sphere for classroom practice obtained from the analysis of the two school years studied.

The overall analysis of the classroom practice shows a perceptible complexity from the technical dimension towards the practical. Areas belonging to the psychology and curricular frames, such as school-level learning and participation in evaluation, present technical positions. At the opposite end, such areas as the selection criteria for the information sources, obstacles in the teaching-learning process, and the purpose of evaluation, lie within the critical dimension, or are in transition towards it. These aspects represent practical theories that are firmly established in the teacher.

VÁZQUEZ-BERNAL, B., JIMÉNEZ-PÉREZ, R., & MELLADO, V. (2008). The Professional Development of Secondary Education Science Teachers: A Case Study As Methodological Integration. In In Ingrid V. Ericsson (Ed.) *Science Education in the 21st Century*, pp. 137-164. New York: Nova Science Publishers, Inc. ISBN: 978-1-60021-951-1.

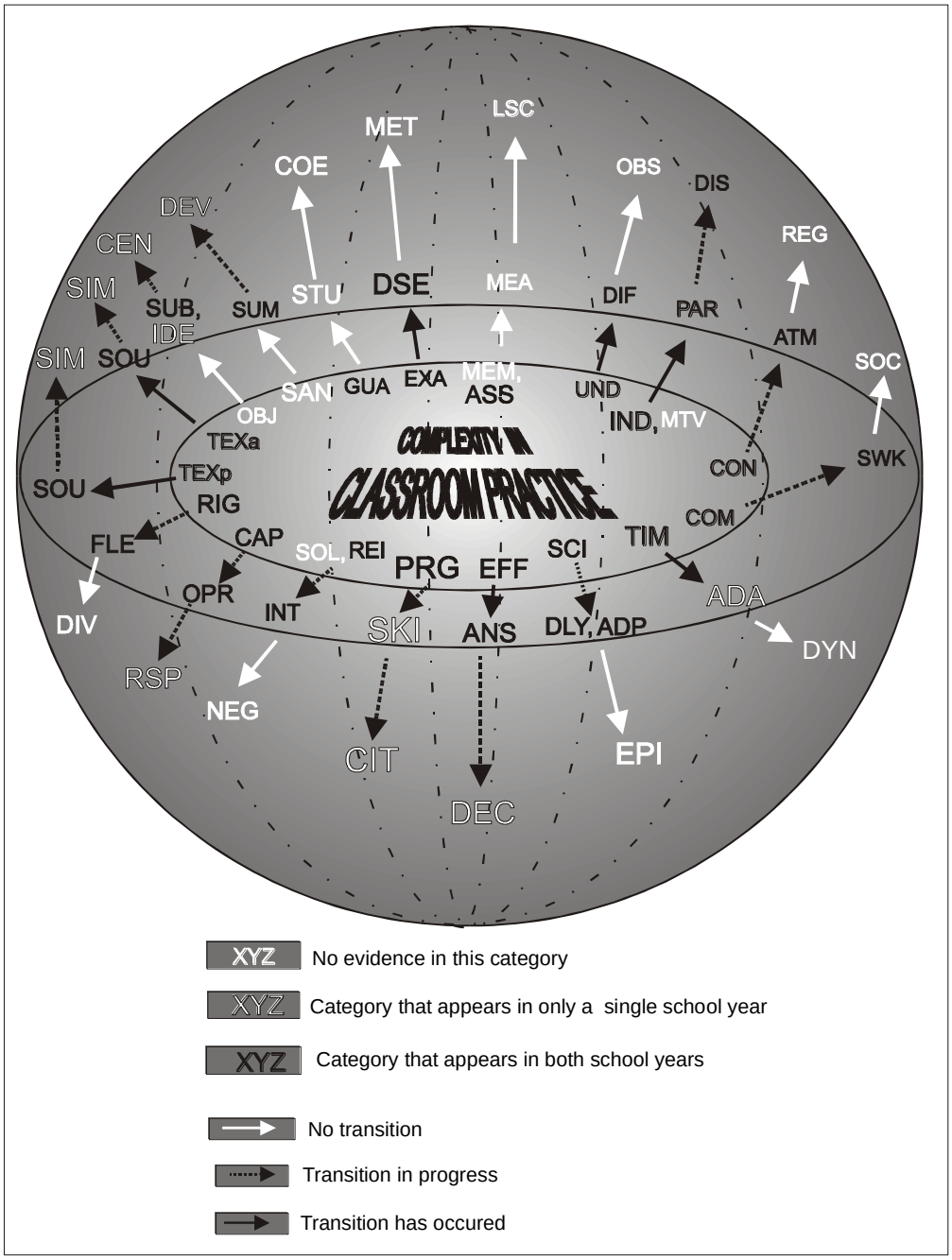

Figure 9. Complexity sphere for the evolution of Ana's classroom practice.

The interaction between reflection and practice: The integration horizon

The analysis of the interaction between classroom reflection and practice requires the convergence of diverse sources of information: analysis of the reflection from the different

VÁZQUEZ-BERNAL, B., JIMÉNEZ-PÉREZ, R., & MELLADO, V. (2008). The Professional Development of Secondary Education Science Teachers: A Case Study As Methodological Integration. In In Ingrid V. Ericsson (Ed.) *Science Education in the 21st Century*, pp. 137-164. New York: Nova Science Publishers, Inc. ISBN: 978-1-60021-951-1.

proposed perspectives, analysis of the classroom practice, and comparison with the teacher's initial conceptions. Figure 10 is a synthesis of the results for the integration between classroom reflection and practice. This is therefore a third-order instrument which we call the integration horizon.

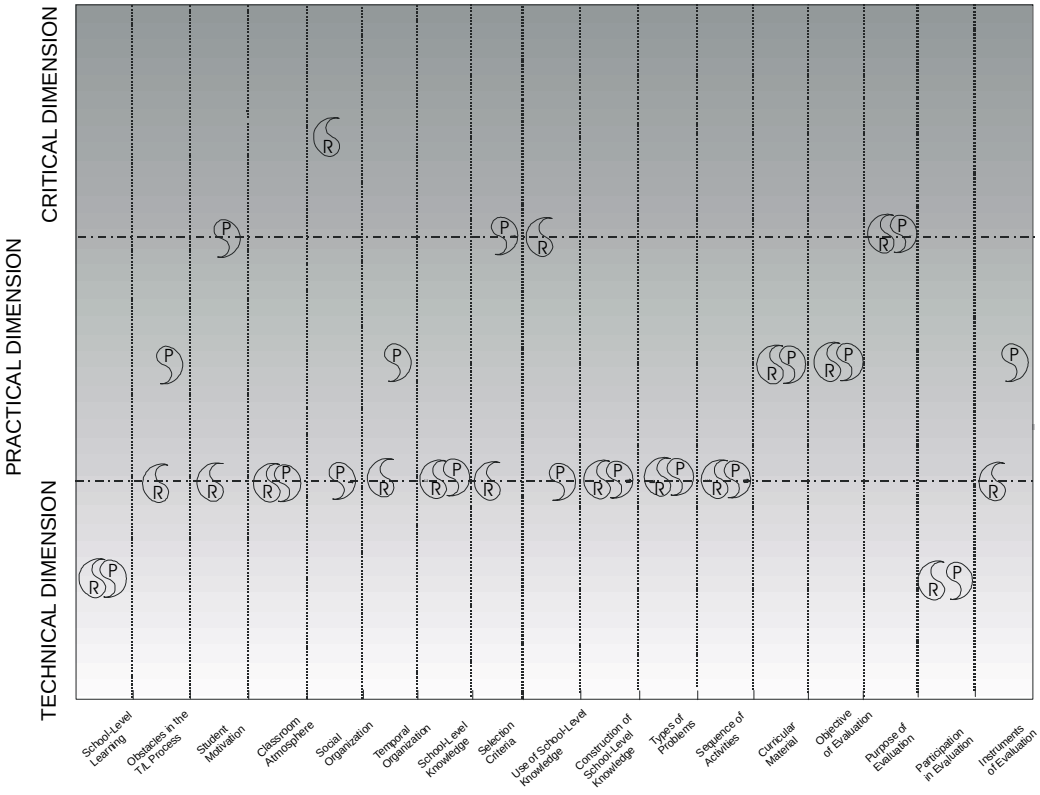

Figure 10. Ana's reflection-practice integration horizon.

All the structures and substructures common to Ana's reflection and classroom practice are distributed along the horizontal axis. The three zones corresponding to the critical, practical, and technical dimensions are located on the vertical axis, and between them there are two intermediate zones, represented by dash-dotted lines, which symbolize the transition towards the practical or critical dimensions. In the centres of each dimension are the zones of the dimensions themselves. These forms of representation express the degree of complexity obtained in each structure or substructure analyzed. At the same time, the possible integration or non-integration is represented by the corresponding symbol. Two paired halves of the sphere indicate integration, and unpaired halves non-integration. The left half corresponds to reflection, and the right to classroom practice.

The results of integration lead to us to make the observations presented in Table IV from the two analytical perspectives of integration and complexity.

VÁZQUEZ-BERNAL, B., JIMÉNEZ-PÉREZ, R., & MELLADO, V. (2008). The Professional Development of Secondary Education Science Teachers: A Case Study As Methodological Integration. In In Ingrid V. Ericsson (Ed.) *Science Education in the 21st Century*, pp. 137-164. New York: Nova Science Publishers, Inc. ISBN: 978-1-60021-951-1.

Table IV. The integration and complexity perspectives in the case of Ana.

The integration perspective	The complexity perspective
• There exists a degree of total integration in the following study areas: school-level learning, classroom atmosphere, school-level knowledge, construction of school-level knowledge, type of problem, activity sequence, teacher and student curricular materials, objective of evaluation, purpose and participation in evaluation. They belong to four frames without distinction — psychological, contextual, epistemological, and curricular. • A degree of partial integration is observed in the obstacles in the teaching-learning process, the temporal organization, and evaluation instruments. • A lack of integration is noticeable, however, in the remaining areas: social organization (more complex in reflection), student motivation (more complex in classroom practice), selection criteria for the information sources (more complex in classroom practice), and use of school-level knowledge (more complex in reflection). These areas belong to the contextual and epistesmological frames, respectively.	• A transition zone is perceived between the technical and practical dimensions in which most of the structures or substructures analyzed are located. • In a second zone of the purely technical dimension, there are only three representations — school-level learning, and participation in evaluation. • Lastly, there is a transition zone between the practical and critical dimensions in which the integrated purpose of evaluation are located. The indication of the preceding results is that Ana is essentially in a phase of complexity from the technical towards the practical dimension.

7. Conclusions and Implications

In the following paragraphs, we will present our conclusions in terms of the questions that guided the study, with emphasis given to the main methodological aspects that underlay the case study.

a) The research instruments were conditioned by the theoretical and methodological framework of the 'Complexity Hypothesis'. This required the use of diverse and versatile instruments characteristic of different methodological approaches. Our choice of quantitative instruments was aimed at obtaining the information given by the count, comparison, and evolution of the frequencies of the codes (corresponding to the R.A.C.S. categories), and at the possible establishment of hypotheses of linkages between those categories using a Boolean method of quantitative comparison. We used a diversity of qualitative instruments — participant observation (ethnography), structured interviews ('Grounded Theory'), diaries (biography), video records (speech analysis), and conversation records (phenomenology). As characteristic of the critical methodological approach, we planned cycles of action-research with a clearly emancipatory conception of education. Finally, the model of complexity gave us an interactive and systemic perspective on education (García Díaz, 2005). The case study

VÁZQUEZ-BERNAL, B., JIMÉNEZ-PÉREZ, R., & MELLADO, V. (2008). The Professional Development of Secondary Education Science Teachers: A Case Study As Methodological Integration. In In Ingrid V. Ericsson (Ed.) *Science Education in the 21st Century*, pp. 137-164. New York: Nova Science Publishers, Inc. ISBN: 978-1-60021-951-1.

has therefore shown itself to be a system that is capable of integrating diverse methodological approaches, and has allowed enrichment of the generation of new knowledge.

b) Our Complexity Hypothesis allowed us to establish In the following paragraphs, we will present our conclusions in terms of the questions that guided the study, with emphasis given to the main methodological aspects that underlay the case study.

a) The research instruments were conditioned by the theoretical and methodological framework of the 'Complexity Hypothesis'. This required the use of diverse and versatile instruments characteristic of different methodological approaches. Our choice of quantitative instruments was aimed at obtaining the information given by the count, comparison, and evolution of the frequencies of the codes (corresponding to the R.A.C.S. categories), and at the possible establishment of hypotheses of linkages between those categories using a Boolean method of quantitative comparison. We used a diversity of qualitative instruments — participant observation (ethnography), structured interviews ('Grounded Theory'), diaries (biography), video records (speech analysis), and conversation records (phenomenology). As characteristic of the critical methodological approach, we planned cycles of action-research with a clearly emancipatory conception of education. Finally, the model of complexity gave us an interactive and systemic perspective on education (García Díaz, 2005). The case study has therefore shown itself to be a system that is capable of integrating diverse methodological approaches, and has allowed enrichment of the generation of new knowledge.

b) Our Complexity Hypothesis led to the establishment of six frames of influence — ideological, teacher education, psychological, contextual, epistemological, and curricular— which proved to be effective filters through which to gain insight into Ana's reflections and actions. The establishment of levels of increasing complexity has permitted us to orient and make explicit the degree of development of the participating teachers.

c) From the results of the integration of reflection and classroom practice, the analysis confirmed that there existed a degree of full integration between reflection and classroom practice in 10 of the 17 areas studied. In other areas, however, there was only a degree of partial integration or even an evident lack of integration between reflection and practice. These results largely coincide with those reported in another work (Vázquez *et al*., submitted for publication) for the case of Marina, one of the same team of teachers although they both maintain their own particular characteristics. While we can not claim that this fact is extendable to all science teachers, it does serve to make one reflect on the model of initial teacher education that these teachers experienced, and in general on the design of teacher education courses in Spain (Oliva, 2005).

Our results indicated that progress occurred in reflection and classroom practice, but many areas were frequently out of phase, although it could not be said in general terms that one of them was more advanced than the other. In some domains, there existed full integration between reflection and practice, but in others explicit reflection was more advanced than the teacher's actual practice, or, *vice versa*, practice was more advanced than reflection. This is coherent with our fundamental premise that reflection not only guides action, but is in turn guided by it in a process of mutual and convergent interaction, and that a

VÁZQUEZ-BERNAL, B., JIMÉNEZ-PÉREZ, R., & MELLADO, V. (2008). The Professional Development of Secondary Education Science Teachers: A Case Study As Methodological Integration. In In Ingrid V. Ericsson (Ed.) *Science Education in the 21st Century*, pp. 137-164. New York: Nova Science Publishers, Inc. ISBN: 978-1-60021-951-1.

program of professional development has to take both aspects into account. Previous research has shown that teachers' advanced concepts may not be converted into classroom practice if the teachers lack schemes of practical action that are coherent with their beliefs (Gess-Newsome & Lederman, 1993; Mellado, 1998).

d) The existence of a process of increasing complexity is clearly perceived when the evolution of Ana's reflection and classroom practice are observed overall, and, interpreted holistically, one sees how the teacher is in transition from the technical towards the practical dimension. It is clear that Ana's pædagogical model has not undergone a total change, but rather a gradual evolution with some aspects having evolved more than others. For us, particularly noteworthy was her conception of school-level learning, since previous research has shown that a fundamental factor that stimulates science teachers' change is becoming aware of the existence of the students' alternative ideas, and moving from a content-centred model to one that is more student centred (da Silva *et al*., 2007; Hewson *et al*., 1999).

e) As a result of our inquiry into the obstacles to professional development, we would highlight that Ana conceives of learning as a process of assimilation, not of construction of knowledge. The intrinsic character of motivation makes her think that if the students' ideas do not progress, it is because the students are not making the necessary effort. There persists the pressure of time in preventing diversification of the activities and attending to different rates of learning in the classroom. In her stated conceptions of the nature of science, she showed an empiricist outlook, imbued with a certain epistemological absolutism, and an accumulative view of scientific knowledge. The acritical efficacy, inflexibility in the activities, the use of closed problems, the punishment aspect of evaluation, and setting herself at the centre of most of the classroom activities, form part of the difficult to reduce core of obstacles hindering her professional development (Vázquez *et al*., 2006a). These obstacles are closely related to the structures that have remained in the technical dimension, making it difficult for her to evolve. Such structures are strongly ingrained and consolidated by years of professional experience, and for them to evolve it is necessary to continue working with and providing support to teachers (Vázquez *et al*., 2007). This claim is based on our having compared and contrasted the results of the different case studies that we have performed within the same group of teachers, since they all share a similar core of conceptions and practices that are refractory to change.

f) We believe that the action-research program has had a very positive impact on the professional development of all the participating teachers, in spite of their presenting cores of obstacles that are very resistant to change. At the time of writing, the group of teachers has dissolved for motives of professional mobility. This leads us to meditate on the difficulty of establishing stable work groups of teachers actively involved in their professional development and sympathetic to curricular innovation. Our research is currently continuing with one of the teachers of the group (Marina), focusing on the uses of the new information technologies, on the consequences of classroom practice for the students' learning, and on the importance of pædagogical content knowledge (Gárritz & Trinity-Velasco, 2004). All these facets, together with the other contributions from Science Education research, constitute the central axis for teachers' professional development (Vázquez *et al*., 2006b).

VÁZQUEZ-BERNAL, B., JIMÉNEZ-PÉREZ, R., & MELLADO, V. (2008). The Professional Development of Secondary Education Science Teachers: A Case Study As Methodological Integration. In In Ingrid V. Ericsson (Ed.) *Science Education in the 21st Century*, pp. 137-164. New York: Nova Science Publishers, Inc. ISBN: 978-1-60021-951-1.

Annex I

Reflection Analysis Categories System (R.A.C.S.)

FRAMES	STRUCTURES	SUBSTRUC-TURES	CATEGORIES	CODES
Ideological	Ideologies in The Educational Environment		D.T.: No ideological referents exist, it being an apolitical activity.	TAPO
			P.D.: Ideology as personal option.	POPT
			C.D.: Educational administration and its pressure as political fact. Influence of the social environment. The school's role in overcoming social inequalities. History as conforming the current educational situation. The analysis of ideologies in the educational context.	CADM CENV CINQ CHIS CIDE
	Teacher-Environment Relationship		T.D.: Resistance to break with the sensation of the classroom as a black box.	TBOX
			P.D.: Teacher team work.	PTWK
			C.D.: Educational profession in continual interaction with the context.	CPRO
Educational	Teacher Education		T.D.: Teacher education as a mere accumulation of credits.	TACC
			P.D.: The personal as the starting point in the improvement of the teacher.	PPER
			C.D.: Recognition of reflection as guarantor of personal change.	CREF
	Science Teaching		T.D.: Resistance to reading pædagogical material. Insecurity in the curricular domain of the material being taught.	TRES TDOM
			P.D.: Interest in reading pædagogical material. Pædagogical content knowledge.	PREA PPCK
			C.D.: Belonging to a community of professionals in which science teaching experiences are exchanged.	CEXP
Psychological	School-Level Learning		T.D.: Role of memory as principal guarantor of learning. Assimilation as guarantor of learning.	TMEM TASS
			P.D.: Construction as guarantor of meaningful learning.	PMEA
			C.D.: Learning as social construction.	CLSC
	Obstacles in the Teaching-Learning Process		T.D.: Students' lack of understanding.	TUND
			P.D.: Reflection about the students' difficulties.	PDIF
			C.D.: Collective inquiry into the nature of the obstacles behind the difficulties.	COBS

VÁZQUEZ-BERNAL, B., JIMÉNEZ-PÉREZ, R., & MELLADO, V. (2008). The Professional Development of Secondary Education Science Teachers: A Case Study As Methodological Integration. In In Ingrid V. Ericsson (Ed.) *Science Education in the 21st Century*, pp. 137-164. New York: Nova Science Publishers, Inc. ISBN: 978-1-60021-951-1.

Reflection Analysis Categories System (R.A.C.S.) (Continued)

Contextual	Interactive Teacher-Student Relationships	Student Motivation	T.D.: Individual effort of the student as intrinsic factor. Motivation already present in the groups of students.	TIND TMTV
			P.D.: Student effort and participation as extrinsic factors.	PPAR
			C.D.: Positive discrimination towards students with special educational needs and/or social deprivation.	CDIS
		Classroom Atmosphere	T.D.: Discipline and control of the class.	TCON
			P.D.: Negotiation about the working atmosphere in the classroom.	PATM
			C.D.: Systematic use of contracts with the students to regularize classroom work.	CREG
	Social Organization		T.D.: Competitiveness as impulse to learning.	TCOM
			P.D.: Student team work.	PSWK
			C.D.: Support for the socially needy.	CSOC
	Temporal Organization		T.D.: The lack of time characterizes the form of classroom intervention.	TTIM
			P.D.: The time factor is made flexible and adapted to classroom intervention.	PADA
			C.D.: Time is dynamically adapted to the different rates of learning.	CDYN
Epistemological	School-Level Knowledge		T.D.: Scientific knowledge as fundamental knowledge of the curricular content.	TSCI
			P.D.: Reference to the daily experience of the student. Adaptation of the scientific content to the school environment.	PDLY PAPD
			C.D.: School science possesses its own epistemological status inherent to its social character.	CEPI
	Selection Criteria for the Information Sources		T.D.: Acritical efficacy and its role in improvement.	TEFF
			P.D.: Providing answers to open questions that are proposed.	PANS
			C.D.: Making decisions and acquiring commitments.	CDEC
	Use of School-Level Knowledge		T.D.: Concern to attain objectives and complete the programming.	TPRG
			P.D.: Acquisition of basic skills in solving problems	PSKI
			C.D.: The formation of citizens with critical capacity concerning advances in science and technology.	CCIT
	Construction of School-Level Knowledge		T.D.: The teacher as the sole constructor of school-level knowledge. Reinforcement of the ideas presented by the teacher.	TSOL TREI
			P.D.: Attention to the students' interests.	PINT
			C.D.: Negotiation with the students on aspects of the curriculum.	CNEG

Reflection Analysis Categories System (R.A.C.S.) (Continued)

Curricular	Types of Problems		T.D.: Use of closed-answer problems.	TCAP
			P.D.: Use of open problems.	POPR
			C.D.: Use of research problems into the social and natural environment.	CRSP
	Sequence of Activities		T.D.: Rigid activities.	TRIG
			P.D.: Flexibility in the sequences of teaching.	PFLE
			C.D.: Sequences of flexible diversified activities taking the students' different rates of learning into account.	CDIV
	Curricular Materials or Information Sources	For the Teacher	T.D.: Use of the textbook as principal source of information.	TTEX
			P.D.: Use of different sources of information.	PSOU
			C.D.: Socially important problems.	CSIM
		For	T.D.: Use of the textbook as principal source of information.	TTEX
			P.D.: Use of different sources of information.	PSOU
			C.D.: Socially important problems.	CSIM
	Evaluation	Objective (what to evaluate)	T.D.: Objectivity of evaluation.	TOBJ
			P.D.: Subjectivity of evaluation. Evolution of the students' ideas.	PSUB PIDE
			C.D.: Acquisition of student-centred skills.	CCEN
		Purpose of Evaluation	T.D.: Santioned evaluation.	TSAN
			P.D.: Evaluation as summary and overview of the process.	PSUM
			C.D.: Evaluation as centred on the development of the individual as a social entity.	CDEV
		Participation in Evaluation	T.D.: The teacher as sole guarantor of the evaluation process.	TGUA
			P.D.: Participation of the student in the evaluation process.	PSTU
			C.D.: Co-evaluation carried out by teachers and students.	CCOE
		Instruments of Evaluation	T.D.: Use of the final examination.	TEXA
			P.D.: Diversity of sources for the evaluation.	PDSE
			C.D.: The students' productions based on metacognition and self-evaluation.	CMET

References

Baird, J.R., Fensham, P.J., Gunstone, R.F. & White, R. (1991). The importance of reflection in improving science teaching and learning. *Journal of Research in Science Teaching*, **28** (2), 163-182.

Bartolomé, M. (1984). La Pedagogía experimental. In A. Sanvincens (Ed.) *Introducción a la pedagogía experimental*. Barcelona: Barcanova.

Bell, B. & Gilbert, J. (1994). Teacher development as professional, personal and social development. *Teaching & Teacher Education*, **5**, 483-497.

Bell, B. (1998). Teacher development in science education. In B. J. Fraser & K. G. Tobin (Ed.): *International Handbook of Science Education* (pp. 681-693). Dordrecht: Kluwer.

Bonil, J. & Pujol, R. M. (2005). La aventura de integrar la complejidad en la educación científica de la ciudadanía. *Actas del VII Congreso Internacional sobre Investigación en la Didáctica de las Ciencias. Número Extra. Enseñanza de las Ciencias*. Barcelona.

Bryan, L. & Atwater, M.M. (2002). Teacher beliefs and cultural models: A challenge for science teacher preparation programs. *Science Education*, **86**(6), 821-839.

Cachapuz, A. (1995). Da investigação sobre e para professores à investigação com e pelos professores de Ciências. In L.J. Blanco & V. Mellado (eds): *La Formación del Profesorado de Ciencias y Matemáticas en España y Portugal* (pp. 243-254). Badajoz (Spain): Diputación Provincial.

Carr, W. & Kemmis, S. (1988). *Teoría crítica de la enseñanza*. Barcelona: Martínez Roca.

Cochran-Smith, M. & Lytle, S.L. (2003). Más allá de la certidumbre: adoptar una actitud indagadora sobre la práctica. In A. Lieberman & L. Miller (Ed.): *La indagación como base de la formación del profesorado y la mejora de la educación* (pp. 65-79). Barcelona: Octaedro.

Colás, M. P. & Buendía, L. (1998). *Investigación Educativa*. 3rd edition. Sevilla: Alfar.

Confrey, J. (2000). Improving research and systemic reform towards equity and quality. In Anthony E. Kelly & Richard A. Lesh (Eds.): *Handbook of Research Design in Mathematics and Science Education* (87-106). Mahwah, New Jersey: LEA.

Cook T. D. & Reichrdt, CH. S. (1997). *Métodos cualitativos y cuantitativos en investigación educativa.* 3rd edition. Madrid: Morata.

da-Silva, C., Mellado, V., Ruiz, C. & Porlán, R. (2007). Evolution of the conceptions of a secondary education biology teacher: Longitudinal analysis using cognitive maps. *Science Education*, **91**(3), 461-491.

De La Orden, A. (1985). *La investigación educativa. Diccionario Ciencias Educación*. Madrid: Anaya.

Elliot, J. (1993). Conocimiento, poder y evaluación del profesor. In W. Carr (Ed.): *Calidad de la enseñanza e Investigación-Acción* (pp. 155-174). Sevilla: Díada.

Elliot, J. (1999). La relación entre comprender y desarrollar el pensamiento docente. In A. Pérez-Gómez, J. Barquín & J. F. Angulo (Ed.): *Desarrollo profesional del docente: Política, investigación y práctica* (pp. 364-378). Madrid: Akal.

Feldman, A. (1994). Erzberger's dilemma: Validity in action research and science teacher's need to know. *Science Education*, **78**(1), 83-101.

Feldman, A. (2002). Multiple perspectives for the study of teaching: Knowledge, reason, understanding, and being. *Journal of Research in Science Teaching*, **39** (10), 1032-1055.

Fourez, G. (1994). *La construcción del conocimiento científico*. Madrid: Narcea.

Fox, D. (1981). *El proceso de investigación en educación.* Pamplona: EUNSA.

García Díaz, J. E. (2005). Complejidad y construcción del conocimiento. *Actas del VII Congreso Internacional sobre Investigación en la Didáctica de las Ciencias. Número Extra. Enseñanza de las Ciencias*. Barcelona.

Gárritz, A. & Trinidad-Velasco, R. (2004). El conocimiento pedagógico del contenido. *Educación Química*, **15**(2), 1-6.

Gess-Newsome, J. & Lederman, N.G. (1993). Preservice biology teachers' knowledge structures as a function of professional teacher education: A year-long assessment. *Science Education*, **77**(1), 25-45.

VÁZQUEZ-BERNAL, B., JIMÉNEZ-PÉREZ, R., & MELLADO, V. (2008). The Professional Development of Secondary Education Science Teachers: A Case Study As Methodological Integration. In In Ingrid V. Ericsson (Ed.) *Science Education in the 21st Century*, pp. 137-164. New York: Nova Science Publishers, Inc. ISBN: 978-1-60021-951-1.

Gess-Newsome, J. & Lederman, N.G. (1999). *Examining Pedagogical Content Knowledge*. Dordrecht: Kluwer A.P.

Goodman, J. (1987). Reflexión y formación inicial del profesor: Estudio de casos y análisis teórico. *Revista de Educación*, **284**, 223-244.

Gunstone, R., Slattery, M., Baird, J R. & Northfield, J.R. (1993). A case study exploration of development in preservice science teachers. *Science Education*, **77** (1), 47-73.

Gunstone, R. & Northfield, J. (1994). Metacognition and learning to teach. *International Journal of Science Education*, **16** (5), 523-537.

Gunstone, R. (1999). Content knowledge, reflection, and their intertwining: a response to the paper set. *Science Education*, **19** (3), 394-396.

Hargreaves, A. (1996). *Profesorado, cultura y modernidad*. Madrid: Morata.

Herrán, A. de la, Hashimoto, E. & Machado, E. (2005). *Investigar en educación. Fundamentos, aplicación y nuevas perspectivas*. Madrid: Dilex S.L.

Hewson, P. W., Tabachnick, B. R., Zeichner, K.M & Lemberger, J. (1999). Educating prospective teachers of biology: Findings, limitations, and recommendations. *Science Education*, **19** (3), 375-384.

Hierrezuelo, J. et. al. (1998). *Ciencias de la Naturaleza, Física y Química, 3ºESO*. Málaga: Elzevir.

Howe, A.C. & Stubbs, H. (2003). From science teacher to teacher leader: Leadership development as meaning making in a community of practice. *Science Education*, **87**(2), 281-297.

Hoyle, E. (1974). Professionality, professionalism and control in teaching. *London Educational Review*, **3**, 13-19.

Jiménez, R., Pérez, J. & Rodríguez, C. (1999). Los condicionantes de la formación inicial del profesorado en España: Presupuesto para un nuevo modelo de formación. In A. Pérez Gómez, J. Barquín Ruiz & J.F. Angulo Rasco (Ed.): *Desarrollo profesional del docente: Política, investigación y práctica* (pp. 146-180). Madrid: Akal.

Jiménez, R. & Wamba, A. M. (2003). ¿Es posible el cambio en los modelos didácticos personales? Obstáculos en profesores de Ciencias Naturales de Educación Secundaria. *Revista Interunivesitaria de Formación del Profesorado*, **17**(1), 113-131.

Keeves, J. P. (1998). Methods and processes in research in science education. In B. J. Fraser & K. G. Tobin (Ed.): *International Handbook of Science Education*, 1127-1155. Dordrecht: Kluwer.

Kemmis, S. (1999). La investigación-acción y la política de reflexión. In A. Pérez-Gómez, J. Barquín & J.F. Angulo (Ed.): *Desarrollo profesional del docente: Política, investigación y práctica* (pp. 95-118). Madrid: Akal.

Kepler, K. (1999). Investigación en la enseñanza: implicaciones para los programas de formación del profesorado. In A. Pérez Gómez, J. Barquín & J. F. Angulo (Ed.): *Desarrollo profesional del docente: Política, investigación y práctica* (pp. 339-363). Madrid: Akal.

Kuhn, T. (1962). *The Structure of Scientific Revolutions*. Chicago: University of Chicago Press.

Lakatos, I. (1983). *La metodología de los programas de investigación científica*. Madrid: Alianza Editorial.

VÁZQUEZ-BERNAL, B., JIMÉNEZ-PÉREZ, R., & MELLADO, V. (2008). The Professional Development of Secondary Education Science Teachers: A Case Study As Methodological Integration. In In Ingrid V. Ericsson (Ed.) *Science Education in the 21st Century*, pp. 137-164. New York: Nova Science Publishers, Inc. ISBN: 978-1-60021-951-1.

Latorre, A. (2003). *La investigación-acción. Conocer y cambiar la práctica educativa*. Barcelona: Graó.

Lesh, R. & Lovitts, B. (2000) Research agendas: Identifying priority problems and developing useful theoretical perspectives. In A. E. Kelly & Richard A. Lesh (Eds.): *Handbook of Research Design in Mathematics and Science Education* (pp. 45-71). Mahwah, New Jersey: LEA.

Louden, W. (1991). *Understanding Teaching: Continuity and Change in Teachers' Knowledge*. London: Casell / New York: Teachers' College Press, Columbia University.

Loughran, J.J. (1996). *Developing reflective practice: Learning about teaching and learning through modelling*. Washington, D.C.: Falmer Press.

Luft, J.A. (1999). Teachers' salient beliefs about a problem-solving demonstration classroom in-service program. *Journal of Research in Science Teaching*, **36** (2), 141-158.

Luft, J.A. (2001). Changing inquiry practices and beliefs: The impact of an inquiry-based professional development programme on beginning and experienced secondary science teachers. *International Journal of Science Education*, **23** (5), 517-534.

Lyons, L.L., Freitag, P.K. & Hewson P.W. (1997). Dichotomy in thinking, dilemma in actions: Researcher and teacher perspectives on a chemistry teaching practice. *Journal of Research in Science Teaching*, **34** (3), 239-254.

McRobbie, C. & Tobin, K. (1995). Restraints to reform: The congruence of teacher and students actions in a chemistry classroom. *Journal of Research in Science Teaching*, **32**(4), 373-385.

Marx, R.W., Freeman, J., Krajcik, J. & Blumenfed, P. (1998). Professional development of science education. In B. J. Fraser & K. G. Tobin (Ed.): *International Handbook of Science Education* (pp. 667-681). Dordrecht: Kluwer.

Mellado, V. (1998). The classroom practice of preservice teachers and their conceptions of teaching and learning science. *Science Education*, **82**(2), 197-214.

Mellado, V. (2003). Cambio didáctico del profesorado de ciencias experimentales y filosofía de la ciencia. *Enseñanza de las Ciencias*, **21** (3), 343-358.

Mellado, V., Ruiz, C., Bermejo, M. L. & Jiménez, R. (2006). Contributions from the philosophy of science to the education of science teachers. *Science & Education*, **15**(5), 419-445.

Mestre, J. P. (2000). Progress in research: The interplay among theory, research questions, and measurement techniques. In A. E. Kelly & Richard A. Lesh (Eds.): *Handbook of Research Design in Mathematics and Science Education* (pp. 151-168). Mahwah, New Jersey: LEA.

Milicic, B., Utges, G., Salinas, B & Sanjosé, V. (2004). Creencias, concepciones y enseñanza en la Universidad: Un estudio de caso de desarrollo profesional colaborativo centrado en un profesor de física. *Revista Española de Pedagogía*, **229**, 377-389.

Morin, E. (1995). *Introducción al pensamiento complejo*. Barcelona: Gedisa.

Nelly, A. E. & lesh, R. (2000) Trends and Shifts in Research Methods. In A. E. Kelly & R. A. Lesh (Eds.) *Handbook of Research Design in Mathematics and Science Education* (pp. 35-44). Mahwah, New Jersey: LEA.

Niaz, M. (2002). Understanding nature of science as progressive transitions in heuristic principles. *Science Education*, **86** (6), 684-690.

VÁZQUEZ-BERNAL, B., JIMÉNEZ-PÉREZ, R., & MELLADO, V. (2008). The Professional Development of Secondary Education Science Teachers: A Case Study As Methodological Integration. In In Ingrid V. Ericsson (Ed.) *Science Education in the 21st Century*, pp. 137-164. New York: Nova Science Publishers, Inc. ISBN: 978-1-60021-951-1.

Oliva, J.M. (2005). Sobre el estado actual de la revista Enseñanza de las Ciencias y algunas propuestas de futuro. *Enseñanza de las Ciencias*, **23** (1), 123-132.

Parrilla, A. (1992). Análisis de procesos de clase. Una perspectiva ecológica. In C. Marcelo (comp.), *La investigación sobre la formación del profesorado. Métodos de investigación y análisis de datos*. (pp. 227-257). Madrid: Cincel.

Porlán, R. & Rivero, A. (1998). *El conocimiento de los profesores. Una propuesta formativa en el área de ciencias*. Sevilla: Díada.

Pozo, J. I. (1999). Más allá del cambio conceptual: el aprendizaje de la ciencia como cambio representacional. *Enseñanza de las Ciencias*, **17**(3), 479-492.

Reyes, L., Salcedo, L. E. & Perafán,G. (2001). *Acciones y Creencias IV: Análisis e interpretación de creencias de docentes de Biología y Ciencias Naturales*, Universidad Pedagógica Nacional, Bogotá.

Richardson, K. (2001). *Modelos de desarrollo cognitivo*. Madrid: Alianza Editorial.

Romberg, T. A. & Collins, A. (2000). The impact of standards-based reform on methods of research in schools. In A. E. Kelly & R. A. Lesh (Eds.): *Handbook of Research Design in Mathematics and Science Education* (pp. 73-85). Mahwah, New Jersey: LEA.

Roth, W.M. (1998). Science teaching as knowledgability: a case study of knowing and learning during coteaching. *Science Education*, **39**(3), 253-282.

Sánchez, G. & Varcálcel, M.V. (2000). ¿Qué tienen en cuenta los profesores cuando seleccionan el contenido de enseñanza? Cambios y dificultades tras un programa de formación. *Enseñanza de las Ciencias*, **18**(3), 423-437.

Sandín, M.P. (2003). *Investigación cualitativa en educación. Fundamentos y tradiciones*. Madrid: McGraw-Hill.

Schön, D. (1983). *The Reflective Practitioner. How Professionals Think in Action*. London: Temple Smith.

Schön, D. (1998). *El profesional reflexivo*. Barcelona: Paidós.

Shwartz, Y., Ben-Zvi, R. & Hofstein, A. (2005). The importance of involving high-school chemistry teachers in the process of defining the operational meaning of 'chemical literacy'. *International Journal of Science Education*, **27**(3), 323-344.

Shulman, L. S. (1986). Paradigms and research programs in the study of teaching: A contemporary perspective. In M. Wittrock (Ed): *Handbook of Research on Teaching* (pp. 3-36). New York: McMillan.

Stake, R. E. (1998). *Investigación con estudio de casos*. Madrid: Morata.

Stenhouse, L. (1987). *Investigación y desarrollo del currículo*. Madrid: Morata.

Tobin, K., Tippins, D.J. & Gallard, A.J. (1994). Research on instructional strategies for teaching science. In D.L. Gabel (ed.), *Handbook of Research on Science Teaching and Learning* (pp. 45-93), New York: McMillan P.C.

Tobin, K. & McRobbie, C. (1996). Cultural myths as constraints to the enacted science curriculum. *Science Education*, **80**(2), 223-241.

Tobin, K., McRobbie, C. & Andersos, D. (1997). Dialectical constraints to the discursive practices of high school physics community. *Journal of Research in Science Teaching*, **34** (5), 491-507.

Tobin, K. (1998). Issues and trends in the teaching of science. In B.J. Fraser & K. Tobin (eds.): *International Handbook of Science Education* (pp. 129-151). Dordrecht: Kluwer A. P.

VÁZQUEZ-BERNAL, B., JIMÉNEZ-PÉREZ, R., & MELLADO, V. (2008). The Professional Development of Secondary Education Science Teachers: A Case Study As Methodological Integration. In In Ingrid V. Ericsson (Ed.) *Science Education in the 21st Century*, pp. 137-164. New York: Nova Science Publishers, Inc. ISBN: 978-1-60021-951-1.

Tom, A. (1984). *Teaching as a moral craft*. New York: Longman.

Van Manen, M. (1977). Linking ways of knowing with ways of being practical. *Curriculum Inquiry*, **6**, 205-228.

Vázquez-Bernal, B. (2006). *La interacción entre la reflexión y la práctica en el desarrollo profesional de profesores de ciencias experimentales de enseñanza secundaria. Estudio de casos*. [*The interaction between reflection and practice in the professional development of secondary education science teachers: Case study.*] Proquest Information and Learning: Michigan (USA).

Vázquez, B., Jiménez, R., & Mellado, V. (2007). La reflexión en profesoras de ciencias experimentales de enseñanza secundaria. Estudio de casos. *Enseñanza de las Ciencias*, **25**(1), 73-90.

Vázquez, B., Jiménez, R., Mellado, V. Martos, M. & Taboada, C. (2006a). Evolución de la reflexión y práctica de aula en la resolución de problemas. El caso de dos profesoras de ciencias de secundaria. *Campo Abierto*, **25**(1), 133-152.

Vázquez, B., Jiménez, R., Mellado, V. & Taboada, C. (2006b). El análisis de la epistemología en el medio escolar. Estudio de un caso. *Revista Mexicana de Investigación Educativa*, v. 11, nº 31, 1259-1286.

Vázquez, B., Jiménez, R., Mellado, V. & Wamba, A. (submitted for publication). The interaction between reflection and practice in the professional development of a secondary education science teacher. *Journal of Research in Science Teaching.*

Verjovsky, J. & Waldegg, G. (2005). Analyzing beliefs and practices of a Mexican high school biology teacher. *Journal of Research in Science Teaching*, **42**(4), 465-491.

Wamba, A.M. (2001). *Modelos didácticos y obstáculos para el desarrollo profesional: Estudios de caso con profesores de Ciencias Experimentales en Educación Secundaria*. Proquest Information and Learning: Michigan (USA).

White, R. T. & Arzi, H.J. (2005). Longitudinal studies: Designs, validity, practicality, and value. *Research in Science Education*, **35**(1), 137-149.

Zee, E. H. Van & Roberts, D. (2002). Using pedagogical inquiries as a basis for learning to teach: Prospective teachers' reflections upon positive science learning experiences. *Science Education*, **85**(6), 733-757.

Zeichner, K. (1993). El maestro como profesional reflexivo. *Cuadernos de Pedagogía*, **220**, 44-45.

Zeichner, K.M. (1995). Los profesores como profesionales reflexivos y la democratización de la reforma escolar. In *Volver a pensar la educación*, Vol. II, 385-398. Madrid: Morata-Paideia.

Zimpher, K. L. & Howey, K.R. (1987). Adapting supervisory practices to different orientations of teaching competence. *Journal of Curriculum and Supervision*, **2**(2), 102-112.

VÁZQUEZ-BERNAL, B., JIMÉNEZ-PÉREZ, R., & MELLADO, V. (2008). The Professional Development of Secondary Education Science Teachers: A Case Study As Methodological Integration. In In Ingrid V. Ericsson (Ed.) *Science Education in the 21st Century*, pp. 137-164. New York: Nova Science Publishers, Inc. ISBN: 978-1-60021-951-1.