SCIENCE TEACHER EDUCATION: ISSUES AND PROPOSALS

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ABSTRACT

Research in science teacher thinking and constructivist pedagogy calls for an expanded knowledge base of teaching, and raising the issue of teaching and understanding of such knowledge by students during teacher education. In the present paper we discuss certain recent studies concerning teachers' knowledge base; besides we present and discuss a framework for developing and investigating courses in science teacher education; finally, in the third part, we present aspects of a case study illustrating the suggested framework.

1. INTRODUCTION

Influenced by the conception of teaching as a thinking profession, teacher education researchers have displayed great interest in the basis of teachers' knowledge and cognition (Clark & Peterson, 1986, Gess-Newsome & Lederman, 1999). Moreover, in the field of science education, research into students' conceptions of natural phenomena influenced researchers interests in science teachers' conceptions about scientific concepts and phenomena, as well as about teaching and learning science (Cochran & Jones, 1998, Hewson, Kerby & Cook, 1995). Researchers investigating the character of teachers' knowledge have advocated a broad conception of the expert teacher knowledge base, suggesting that such knowledge is grounded in acts of pedagogical reasoning (Van Driel, Beijaard & Verloop, 2001). From the perspective of pedagogy, constructivist approaches, as the practices of teaching for student learning with understanding, commonly call for a greatly expanded knowledge base for teaching. How an extensive knowledge of teaching, can be developed at all, and what courses are favourable to it during the brief period allotted to teacher preparation, are critical research and development issues (Hewson et. al., 1999). In this context the main purposes of the present paper are to discuss recent studies concerning teachers' knowledge base and to present a framework for developing and investigating courses in science teacher education, including scientific and pedagogical knowledge.

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2. SCIENCE TEACHERS KNOWLEDGE AND VIEWS ON SCIENCE AND SCIENCE TEACHING

Central issues in teachers' knowledge base are the importance of the subject that teachers teach and their views on teaching and learning science.

Knowledge of subject matter is an area that only recently has drawn the interest of researchers who have started to investigate the complex issues related to the development of it by science teachers. One consistent, striking result from several studies is that many student teachers are deficient in their understanding of important aspects of scientific knowledge that they learn to teach, despite having previously completed a number of scientific courses (De Jong, Korthagen & Wubbels, 1998). Specifically, primary teachers hold conceptions about physical phenomena and scientific concepts similar to those held by school children, although to a lesser degree and expressed in a more sophisticated language (Cochran & Jones, 1998). To some extent this applies to novice secondary teachers, particularly when they are questioned outside their major subject. Certain studies suggest that the subject matter knowledge structures of prospective teachers are often vague and fragmented, and in some cases it has been noted that student teachers are unable to present their subject matter knowledge in a coherent manner (Gess-Newsome, 1999).

Other studies all over the world, consistently point out that teachers hold a variety of conceptions on teaching and learning science (Gao & Watkins, 2002, Koballa et al., 2000). These can be merged into two broad orientations (Marentic-Pozarnik, 2002). In the first, called didactic/reproductive, teaching is regarded as a process of transmitting knowledge and learning as a process of absorbing scientific content. In the second, called facilitative/transformative, teaching is the process of facilitating learning, which involves the construction or transformation of knowledge by students, leading possibly to conceptual change. It is remarkable that student teachers' views on the teaching of science are largely determined by their learning experiences in scientific course during schooling and even during teacher education. Student teachers seem in practice to pay scarce attention to academic theories they are told about, such as constructivist approaches. This may be an explanation for the contradiction between exposed facilitative-constructivist views and underlying didactic practices in actual teaching, or even in planning instruction (De Jong, Korthagen & Wubbels, 1998).

It appears that teachers' beliefs and conceptions on teaching and learning act as a filter in relation to the learning of new approaches, with the result that these are frequently rejected either in whole or in part (Gunstone et al., 1993). However, there is ample evidence to suggest that science teachers have difficulties in developing constructivist views; in teaching they perform in terms of an expository model (Stofflet & Stoddart, 1994). For example, studies have pointed out that while students following a research base course appeared to have understood constructivist strategies, few of them challenged their initial conceptions, falling into the didactic/reproductive orientation (Mintrop, 2001)**.** Yet learning a variety of teaching approaches (and the theoretical positions underlying them) can make a substantial contribution to the development of a teacher's professional ability to teach science (Joyce, Galhoun & Hopkins, 1997). The more representations and strategies teachers have at their disposal within a certain domain, and the better they understand their students' learning process in the same domain, the more effectively they teach in that domain by adopting constructivist methods.

3. DEVELOPING TEACHING LEARNING SEQUENCES FOR SCIENCE TEACHER EDUCATION

Teacher education in general, and pre-service teacher education in particular, should be regarded as an enterprise in which teachers learn about what to teach and how to teach it in a coherent program. A sound basis is necessary for making a student teacher an inquirer and a reflective practitioner who is capable of learning with and from others in a life long process and of moving smoothly from pre-service teacher education to ongoing professional development in the course of his/her career (Hewson et al., 1999). Such a situation seems rather ideal. Pre-service teacher education is often described as being delivered in the form of isolated components (Northfield, 1998). Both the fragmentary nature of courses and the differences and tensions between pedagogies in various courses, especially content courses and courses such as didactics of science, result in student teachers claiming little gain from university education apart from their teaching practice.

The development of programs in which such tensions can be resolved is a critical issue that draws the attention of researchers. As the links between pedagogical knowledge and content knowledge appear to be rather loose in graduate student teachers' minds, an improved teacher education program would draw on a sound cognitive basis of research on teacher knowledge and cognitions (Northfield, 1998). In this context, beyond existing ordinary programs, a growing number of science education researchers have been developing and investigating the design and effectiveness of research-based proposals aimed at providing appropriate conditions for learning, instead of telling student teachers what they ought to do. In line with a developmental perspective, it is envisioned that this will lead to teachers and student teachers beginning to be transformed from practitioners and students into teacher-learners capable of conceptualising and controlling their own learning, not only in terms of scientific but also in regard to pedagogical knowledge. A pre-eminent goal of research based approaches is to create science teacher education leading to a coherent understanding and the integration of scientific and pedagogical knowledge. Towards this end, which is the focus of the present paper, we distinguish two kinds of works: namely, programs that have rather broad aims and attempt to link several courses on subject matter and pedagogy over several years, and specific medium scale courses combining targeted instruction on aspects of science and pedagogy, particularly conceptual change strategies (e.g. Hewson et al. 1999, Stofflet & Stoddart, 1994).

In line with studies in science education, we consider these small-scale courses in science teacher education as innovative teaching-learning sequence (TLS) that focuses on the potential construction of fruitful links between the designed teaching and expected student learning (Lijnse, 1995). A TLS is often both a research process, bringing research and teaching closer in several contexts, and a product, like a traditional curriculum unit package that includes well researched teaching/learning activities and possible students' learning pathways (for a research review, see Méheut & Psillos, 2004). It is at this level that targeted TLSs can contribute substantially to a deep understanding of teacher learning and understanding of both scientific and pedagogical knowledge in given contexts, in analogy with science education, despite some possible reservations that such research is rather limited in scope.

A review of recent studies in science teacher education shows that several TLSs focus on the learning of scientific and pedagogical knowledge and their combination, mainly from a constructivist perspective. Work*s* concerning scientific content investigate the thesis that learning of scientific topics in a constructivist manner may provide practical experiences out of which students can develop their understanding of constructivist models and specifically of conceptual change strategies (Kruger, Placio & Summers, 1991). In this respect, a shared assumption is that a coherent understanding of scientific knowledge provides a basis for the development of pedagogical knowledge related to teaching and learning science. Other studies advance the hypothesis that the learning of subject-specific teaching strategies, as an important part of teachers' pedagogical knowledge, would involve the interlacing of scientific content and instructional methodology with the simultaneous provision of information to teachers on pupils' views (Stofflet & Stoddart, 1994). However, there is disagreement among researchers whether instructional strategies form part of *general pedagogical* knowledge, or form an integral part of *pedagogical content* knowledge; different views have implications on the teaching of instructional strategies to student teachers (Morine-Dershimer & Kent, 1999, Smith, 1999

The design and effectiveness of TLS in science teacher education appears at present to be an open issue which warrants further theoretical discussion and empirical investigation. A few published studies have a model-based perspective, while others involve implicit assumptions and decisions that affect, to a considerable degree, the design and development of the corresponding teaching approaches which are not widely reported and may not even be clearly presented. One point to consider is that the scientific content in a number of published TLSs is clearly described and transformed to adapt to student teachers' conceptions, whereas the pedagogical knowledge to be taught from a constructivist perspective is rather vaguely articulated (Din Yan Yip, 2001). In this context, we suggest that theoretical works referring to TLS for the learning of science by students may provide insights and powerful tools for developing TLS in science teacher education, if they are extended to include pedagogical knowledge.

At the theoretical level, the "educational reconstruction" model developed by Kattmann et al., (1995), provides a framework for designing and validating TLS that is characterised by an emphasis on the analysis of both scientific knowledge and students' conceptions. We argue that "educational reconstruction" can be extended and applied to science teacher education, providing a framework for designing and validating TLS in an integrated perspective that includes both scientific and pedagogical knowledge. In its original form, educational reconstruction attempts to combine a hermeneutic approach to scientific knowledge with constructivist approaches to teaching and learning. Educational reconstruction holds that clarification of science subject matter is a key issue when instruction in a particular science topic is to be developed. This is a process leading to the construction of core ideas of the content to be taught. The educational reconstruction model closely links considerations of the science concept structure with analysis of the educational significance of the content in question, as well as with empirical studies on students' learning processes and interests (Duit et al., 1999).

We suggest that such design principles may be adopted, not only in terms of the scientific knowledge but also of the pedagogical knowledge. This implies that clarification of pedagogical knowledge is a key issue if instruction in, say, constructivism is to be developed. Such a process leads to the construction of the core pedagogical ideas to be taught taking into account both epistemic dimensions and context and applications. Student teachers' conceptions about teaching and learning science are considered in adapting and reconstructing the pedagogical content structure to their views, which are dominated by the didactic/reproductive model.

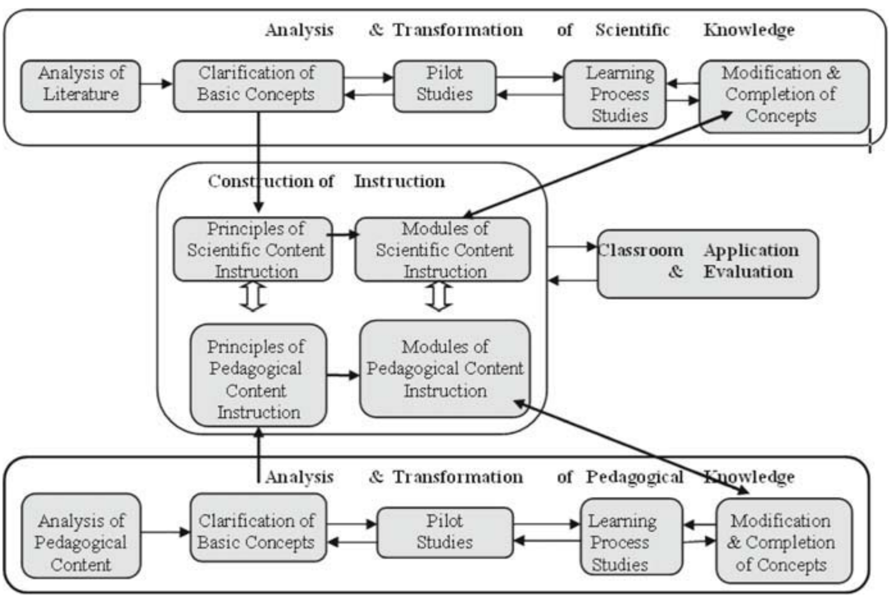

Figure 1: An adapted model for designing teaching-learning sequences in science teacher education

The main features of the adapted "education reconstruction" model for designing TLS in science teacher education is illustrated in Figure 1. Briefly, the top line concerns the scientific knowledge, and the bottom one refers to the pedagogical knowledge. The construction of instruction is depicted in the middle line with four boxes relating both the pedagogical and the scientific knowledge. This process takes place when a particular interlaced content structure for instruction has to be developed; it is transformed in order to adapt the student teachers' point of view, more specifically to their pre-instructional conceptions and their learning pathways during instruction. The science content structure, the pedagogical content structure, and student teachers' conceptions about scientific and pedagogical concepts and phenomena are seen as being equally important parameters in the process of educational reconstruction. The model involves a non-linear design and construction of instruction. Information from one of the components influences the activities and the interpretation of the results of the other components; their interlacing, in a cycling dynamic process in which reflection on the practices during application of instruction, gives rise to new insights concerning the integration of scientific and pedagogical knowledge. Underlying the model is the assumption that knowledge is actively constructed by individual students, and that it involves social interactions in certain material settings. Scientific and pedagogical knowledge are viewed as tentative social constructions. The results of the analysis of both pedagogical and scientific knowledge, as well as preliminary ideas about the construction of an integrated instruction, play an important role in planning empirical studies on teaching and learning scientific and pedagogical knowledge. The results of empirical studies influence the processes of educational analysis, scientific and pedagogical knowledge transformation, and even the setting of goals for the specific sequence.

4. A STUDY OF A TEACHING LEARNING SEQUENCE

In this section we present a brief retrospective account of the development of a TLS in terms of the adapted educational reconstruction model.

i) Context. This TLS has been applied in the sixth semester (out of eight) at the Department of Primary Education, Aristotle University of Thessaloniki. The student teachers were prospective all-subject primary education teachers whom had taken courses in foundation studies (e.g. sociology, psychology), pedagogy, and discipline studies (e.g. science, mathematics, language), and whom already had some practical experience in classrooms followed by a laboratory-based course in Didactics of Science. The TLS integrated the teaching of scientific knowledge (energy content) and the teaching of the pedagogical knowledge (teaching strategies) within a constructivist framework.

ii) Analysis and Transformation of scientific knowledge. Analysis of the research literature and university and school textbooks pointed out that the concept of energy constitutes a unifying concept in science. Preliminary empirical studies of both student teachers' and pupils' conceptions suggested that, while students are able to relate the concept of energy with life and movement, they find it difficult to comprehend basic features of energy, e.g. energy storage and energy conservation, in line with those found in the literature. Analysis and empirical investigations suggested that energy provides an appropriate scientific content in which students can be involved in true construction of knowledge. An educational reconstruction of the energy concept was deemed appropriate; the TLS was based on a qualitative treatment of five energy characteristics: storage, transformation, transfer, degradation, and conservation. However, in retrospect we may note that instead of an in-depth study, only scant observation of students' learning pathways in energy took place.

iii)Analysis and Transformation of pedagogical knowledge. Subject-specific teaching strategies were chosen as appropriate content for pedagogical knowledge (Smith, 1999). Analysis of the research literature in (science) education revealed broad conceptualisations of expository, discovery, and constructivist strategies, but a lack of specific unified modelling in terms of teaching-learning activities comprehensible to students. Initial questionnaires were addressed to the students, and in-depth learning process studies were carried out concerning the evolution of student views on teaching and learning science. Both the initial and the learning process studies found that students' initial didactic/reproductive teaching conceptions and their alternative ideas on the scientific content seemed to be two essential components of their difficulty to learn constructivist views. Indeed, it became evident that these two components were highly interdependent. In addition, the results suggested that, while constructivist strategies were broadly understood, their differences with expository and with discovery strategies, particularly, needed to be clearly identified.

Following these results, innovative unit models of these strategies (lasting from one to two hours) were developed and adapted for students. Such units were reconstructed in order to enact theoretical assumptions and avoid ambivalent terms concerning teaching strategies. The strategies were described on the basis of syntax and reaction principles. As argued by Joyce, Galhoun, & Hopkins (1997), syntax refers to the type and the structure of activities performed by both teacher and students in one teaching hour, while reaction principles refer to the type of teacher reactions to whatever his/her pupils do (Spyrtou, Kariotoglou & Psillos, 2002).

iv) Construction of instruction. In terms of the model, the final form of the TLS has emerged as a product of dynamic interrelations between the above components and reflections on applications (Figure 1). Besides understanding energy, one main goal of the TLS is to render students able to design constructivist teaching units, develop clear criteria when choosing the type of teaching strategy, and discern the constructivist from the expository and discovery strategies. The achievement of these goals is pursued within an integrated constructivist teaching framework involving both the scientific and the pedagogical content (Spyrtou & Kariotoglou, 2001). Through the teaching of energy, we aim for students to understand that learning does not involve only addition or extension of their previous knowledge, e.g. as characteristics of transformation and transfer, but that it also involves a conceptual change process, e.g. as with storage, degradation, and conservation. We should not hesitate to mention that we do not want students to reject their initial teaching conceptions but to extend them through experiencing and reflecting on constructivist ones. We note that the modules on teaching strategies provided the conceptual space for reflecting on the learning practices applied during the scientific modules. This TLS comprises 11 modules out of which 5 are applied for teaching the energy content and 6 are used for teaching about expository, discovery, and (particularly) constructivist strategies (Spyrtou & Kariotoglou, 2001). As presented elsewhere, results suggest that the TLS was reasonably successful in facilitating students' planning of strategies (Spyrtou, Kariotoglou & Psillos, 2002). Moreover, the TLS provided a tool for investigating their learning pathways, for example by revealing that the distinction between discovery and constructivist models was quite difficult for these students (Psillos, Spyrtou & Kariotoglou, 2002). In retrospect, we consider that such a distinction was not pursued in depth in applying and investigating this TLS.

5. CONCLUSIONS

It appears that expert (science) teachers develop gradually integrative schemes influencing their practice, which are referred to with many concepts such as practical knowledge, implicit and subjective theories, and pedagogical content knowledge (e.g. De Jong, 2003, Van Driel, Beijaard & Verloop, 2001). However, student teachers seem to relate to a less degree subject matter views with pedagogical knowledge. We consider that TLS in general, and specifically the suggested adapted educational reconstruction model, may provide powerful tools for investigating in depth the intertwining of pedagogical and scientific knowledge by the student teachers, and for designing model- based courses that lead to their integration.

REFERENCES

Clark, C. & Peterson, P. (1986). Teachers' Thought Processes. In Wittrock M.C. (Ed.), 4rth *Handbook of research on teaching* (pp.255-296). New York: Macmillan.

Marentic Pozarnik, B. (2002). Professional Development of Teachers as a (Re)construction of their Conceptions and Teacher's Role. *Paper presented at the 6th ESERA Summer School. Aug, 25-31*, Radovlijkca, Slovenia.

Cochran, K. & Jones, L. (1998). The Subject matter knowledge of Preservice Science Teachers In *B.J. Fraser and K.G. Tobin (Eds.),* International Handbook of Science Education (pp 707-717). Dordrecht: Kluwer.

De Jong, (2003). Exploring Science Teachers' Pedagogical Content Knowledge. In D. Psillos, P. Kariotoglou, V. Tselfes, E. Hatzikraniotis, G. Fassoloupolos & M. Kallery, (Eds.), *Science Education Research in the Knowledge Based Society* (pp.373-381). Dordrecht: Kluwer..

De Jong, O., Korthagen, F. & Wubbels, T. (1998). Research on Science Teacher Education in Europe: Teacher Thinking and Conceptual Change. In B.J. Fraser and K.G. Tobin (Eds.*), International Handbook of Science Education (pp.745-758).* Dordrecht: Kluwer.

Din Yan Yip, (2001). Promoting the development of a conceptual change model of science instruction in prospective secondary biology teachers. *International Journal of Science Education*, 23(7), 755-770.

Gao, L. & Watkins, D.A. (2002). Conceptions of teaching held by school science teachers in P. R. China: identification and cross-cultural comparisons. *International Journal of Science Education*, 24(1), 61-79

Gess-Newsome, J. (1999). Secondary teachers' knowledge and beliefs about subject matter and their impact on instruction. In J. Gess-Newsome & N. G. Lederman (Eds.), *Examining pedagogical content knowledge*, (pp. 51-94). Dordrecht: Kluwer.

Gess-Newsome, J. & Lederman, N. G. (Eds.), *Examining pedagogical content knowledge*. Dordrecht: Kluwer.

Gunstone, R. and Slattery, M., Baird, J. & Northfield, J. (1993). A Case Study of Development in Pre-service Science Teachers. *Science Education,* 77(1), 47-73.

Joyce, B., Galhoun, E. & Hopkins, D. (1997). *Models of learning-tools for teaching.* Buckingham-Philadelphia: Open University Press.

Hewson, P., Kerby, H. & Cook, P. (1995). Determining the conceptions of teaching science held by experienced high school science teachers. *Journal of Research in Science Teaching*, 32(5), 503-520.

Hewson, P.W., Tabachnick, B.R., Zeichner, K.M. & Lemberg, J. (1999). Educating Prospective Teachers of Biology: Findings, Limitations, and Recommendations. *Science Education*, 83(3), 373-384.

Kattmann U., Duit R., Gropengieber, H.& Komorek, M., (1995). A model of Educational Reconstruction. Paper presented at *The NARST annual meeting*. San Francisco.

Koballa, T., Gräber, W., Coleman D. & Kemp, A. (2000). Prospective gymnasium teachers' conceptions of chemistry learning and teaching. *International Journal of Science Education,* 22(2), 209-224

Duit R., Roth, W-M, Komorek, M. & Wilbers, J. (1998) Studies on educational reconstruction of chaos theory. *Research in Science Education 27*, *Research in Science Education 27*, 339-357

Kruger, C., Palacio, D. & Summers, M. (1991). Understanding energy. *Primary School Teachers and Science (PSTS) Project*. Oxford: Oxford University Department of Educational Studies.

Lijnse P.-L. (1995). "Developmental Research" as a Way to an Empirically Based "Didactical Structure" of Science, *Science Education* 79(2,), 189-199.

Meheuet, M. & Psillos D. (2004). Teaching – learning sequences: aims and tools for science education research. *International Journal of Science Education,* Special Issue (forthcoming).

Morine-Dercshimer, G. & Kent, D. T (1999). The Complex Nature and Sources of Teachers' Pedagogical Content Knowledge. In J. Gess-Newsome & N. G. Lederman (Eds.), *Examining pedagogical content knowledge*, (pp. 21-50). Dordrecht: Kluwer.

Mintrop H. (2001). Educating Students to Teach in a constructivist Way – Can It All Be Done? *Teachers College Record*, 103(2), 207-239.

Nortfield *J.* (1998). Teacher educators and the Practice of Science Teacher Education. *International Handbook of Science Education* (pp. 707-717). Dordrecht: Kluwer.

Psillos, D., Spyrtou A. & Kariotoglou P. (2002). Investigating the complexity of teacher's conceptions on science teaching: issues and tools. *Invited workshop for the 6th ESERA Summerschool. Aug, 25-31,* Slovenia.

Smith, D.C. (1999). Changing our teaching: The role of pedagogical content knowledge in elementary science. In J. Gess-Newsome & N.G. Lederman (Eds.), *Examining pedagogical content knowledge* (pp. 163-197). Dordrecht: Kluwer..

Spyrtou, A. & Kariotoglou, P. (2001) Interlacing content and methodology in educating primary student teachers. In M. Bandiera, S. Caravita, E. Torracca, M. Vicentini (Eds.), *Research Education in Europe: The Picture Expands, (*pp.651-658). Rome: Litoflash..

Spyrtou, A., Kariotoglou, P. Psillos, D. (2002). A 3-D approach to investigate the development of lesson planning. *Paper presented at the Third Panellenic Conference, Didactics of Science & Application of New Technologies in Education. May 2-5, Heraklio, Crete.*

Stofflett, R. & Stoddart, T. (1994). The Ability to Understand and Use Conceptual Change Pedagogy as a Function of Prior Content Learning Experience. *Journal of Research in Science Teaching*, 31(1), 31-51.

Van Driel, J.H., Beijaard, D. & Verloop, N. (2001). Professional Development and Reform in Science Education: The role of Teachers' Practical Knowledge. *Journal of Research in Science Teaching*, 38(2), 137-158.