In-service and pre-service Physics teacher education and Pedagogical Content Knowledge construction

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Abstract

The complexity of our days’ society and the rapidly changing requests it poses to the today citizens with respect to the understanding of new technologies and their subsequent correct use require a parallel restructuring of Science, and in particular Physics, Education. In this, a fundamental role is played by teachers, to which it is assigned the difficult role of guiding the scientific cultural formation of the youngest. To productively accomplish this, new models of in-service and pre-service Physics teacher education have to be thought and experimented to transform and deepen teachers’ understanding of subject matter and to redirect their habitual ways of thinking about subject matter for teaching.
This paper describes the today worrying situation of the scientific culture in the developed countries and notes the need of new teaching methods for scientific disciplines, a need that soon translates in the search for new models of physics teacher education.

Sommario

La complessità della società dei giorni nostri e le richieste, in rapidissima evoluzione, che essa pone al cittadino rispetto alla comprensione delle nuove tecnologie messe in gioco nella vita di tutti i giorni, richiede un parallelo processo di ristrutturazione della formazione scientifica, e, in particolare, di quella relative alla Fisica. In tale processo un ruolo fondamentale è giocato dai docenti, ai quali è affidato il non semplice ruolo di guida alla formazione culturale dei giovani. Per sviluppare efficacemente tutto ciò è, tuttavia, necessario pensare a modelli di formazione degli insegnanti di Fisica in servizio e in pre-servizio che possano essere messi alla prova al fine di verificarne l’efficacia nel trasformare e rendere più profonda la comprensione dei docenti relativamente ai contenuti scientifici e nel re-indirizzare le conoscenze acquisite e le capacità di interpretazione dei fenomeni fisici verso un uso appropriato nella didattica.
Questo articolo fa brevemente il punto della situazione attuale e descrive alcuni modelli di rinnovamento della formazione e aggiornamento dei docenti di fisica nelle scuole italiane.

1. Introduction.

In these last years a worrisome haemorrhage of interest of the young population towards the scientific culture is being faced, especially in the more technologically developed countries. Such situation is evidenced also by the alarming lessening of the enrolment in the scientific university faculties, that made some people predict that, without reverting, in a few decades some countries, like Italy, will be forced to import researchers and technicians from other countries, less economically and technologically developed but still possessing ample resources in the young scientific researchers population.

Diagnosis for such situation must take in consideration several factors, amongst which it is certainly necessary to include social and cultural ones, but it would be at least unfair not to take into account some responsibilities of local educative systems, the ones in charge of guiding young people to choose their educative pathways in a far-sighted way:

- a form of global dissonance between the basic formation offer and its acceptance by the average student population;
- the lack of a noticeable evolution in scientific teaching (from programs to texts to methodologies) facing the general cultural and scientific progress.
- A less than sufficient attention to science teacher education, very often delegated to university courses traditionally aimed at forming researchers and not school teachers.

This situation is even worse in Physics, a discipline facing today a general collapse in interest by new generations of science learners, having passed the great popularity period of the first part of the XX century. New methods of scientific teaching are needed to make again pupils feel Physics near and responding to everyday problems and this very often results in the need for new pedagogical models of physics teacher preparation.

2. A new approach to Physics education ?

Many research papers have pointed out the effectiveness of an approach to physics education considering real world living experience as the first step in order to help pupils to build an appropriate scientific knowledge (Tiberghien et al., 1998; Viennot, 1996). This approach is substantially different from the more traditional one, in which the starting point is the analysis of specific and already formalized situations, and the comparison of these situations with processes belonging to observable world is considered as the final step. It considers learning aspects as prevalent with respect to the teaching ones and the topics to teach are organized not only by considering the intrinsic structure of the discipline but mainly taking into account pupils mental representations of real life phenomena. Moreover, the knowledge of pupils' cognitive difficulties is considered a fundamental point in the task of building didactic activities that can be really helpful in improving the pupil understanding of the physical models describing and interpreting real life situations (Pfundt and Duit, 1995).

Besides, many research studies supporting the pedagogical efficacy of real time laboratory systems (Thornton, 1990) and of simulating/modelling environments (Wells and Hestenes, 1995) have shown that the use of pedagogical tools based on information and communication technology (ICT) can greatly improve this process of knowledge construction, supporting the pupil conceptual changes necessary to effectively move from common knowledge to scientific knowledge systems.

On the other hand, the development and actual use of model-oriented pedagogic activities and the specific characteristics of ICT tools require a deep change of the teacher's role, concerning his interaction with pupils as well as the development of new professional competences (International Journal of Science Education – Special Issue on Teacher Development, 1994. As a consequence, the initial and in-service teachers' education courses need to take into account new educational objectives and new competencies. Unfortunately, the subject-matter and pedagogic understanding pre-service teachers exhibit in teacher education course works is very often different from what they will need to posses and improve to help their future pupils to develop an effective scientific culture. This has been shown in many field of science education (Mellado, 1998; Zuckerman, 1999), and Physics in particular, where it is well documented (Tiberghien et al., 1998) that the procedural understanding of Physics that pre-service teachers typically exhibit in university courses is not adequate to teach Physics according to many proposed innovations involving deep changes in contents and pedagogical methods.

A central task of pre-service teacher preparation courses should, then, be to transform and deepen prospective teachers' understanding of subject matter, and to redirect their habitual ways of thinking about modelling and, more in general, about subject matter for teaching.

3. Models, modelling and pupils' personal views

For modelling we mean the cognitive process finalized to apply the basic elements of a theory to build a model of an object or real process. In Physics, the first phase of the description of an object or process consists in the choice of the variables (operationally defined) found relevant for the object or process. The model built in this first phase can be called "primary model" or "physical model". We are in the same situation of a photographer using a black and white film: he chooses to take into account the grey scales and not the different colours. Our photo is a physical model of the subject: physical because it extracts information really existing, model because it extracts only part of the available information. For this reason, the model is a creation of the human mind, arising from the choice of what to observe and to measure.

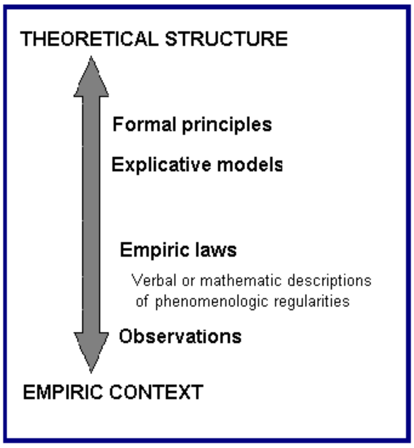

Figure 1. a schema of the knowledge used to build a scientific explanation of some empiric content.

But physical systems modelling is not a mere mental activity (even if a model is a human mind creation) because it needs interactions with real objects to actually observe and experiment.

Figure 1 shows the kinds of knowledge used to "make science". It is worth noting that, when trying to move from empiric laws to explicative models, inductive reasoning plays a role, but an important point is also the analogical reasoning, i.e. the ability to see similarities and differences between a "source" (something perceived as similar to what we are going to analyse) and the "target" (the real phenomena object of our study).

A model is, then, a representation of objects or systems and to them it has to be somehow related.

Figure 2 shows a generalization of the cyclic process of building a real world system's model and of the subsequent empirical evaluation of the model.

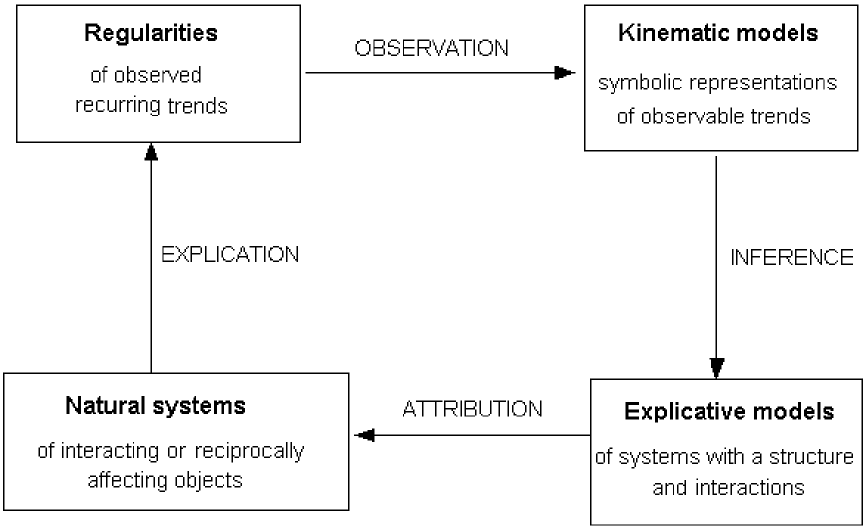

Figure 2. The cyclic process of building a model and empirically evaluating it

An explicative model is different from a descriptive model in that the first supposes the system possesses properties not directly observable but playing a role in the observed regularities. Indeed, the model's construction and validation process requires the building of several hypotheses typologies: empiric laws hypotheses, synthesis of regularities (arising from phenomenological observations and condensed in rules) and hypotheses for the construction of explicative models, introducing theoretical representations and often containing non-observable entities.

As an example, molecules, fields, waves are not simply syntheses of empirical observations but they are rather inventions, implying new "theoretical objects", part of the vision scientists have of the world and somehow can be found in "data". A consequence of this distinction is, for example, that to be able to make a prediction on the basis of the empiric gas law (PV = NRT) is not equivalent to the ability of explaining the behaviour of a gas in terms of a model of molecules similar to little, moving balls.

Unlike a phenomenological law, the model gives a description of hidden processes, explaining a "working mode" of the gas and giving answers about the gas different behaviour when temperature and pressure vary. Moreover, in relation to its explicative capabilities, the model suggests us questions able to better specify or to broaden the theory.

It is widely accepted that understanding Physics means understanding physical models. Models allow scientists to simplify and classify complex phenomena, to predict trends and to explain mechanisms and processes and many research studies (Berry et al., 1986; Gilbert et al., 1998; Hesteness, 1992) have identified model building as an higher level mental process skill. They focus on the process of constructing predictive conceptual models and point out that model building can be a formative pedagogical activity, since it allows pupils to better understand many content areas, enabling them to see similarities and differences among apparently different phenomena. As a consequence, it appears correct to say that a teaching approach focusing on modelling procedures can contribute to construct a unitary view of Physics as well as to unify the scientific approach to many problems.

In the last years the science education community has shown a great interest in fostering model based reasoning at all level of schooling: research projects have been developed recommending to shift the focus of science education from traditional subject matter contents to overarching themes and pupils' competencies development and to give an increasing relevance to modelling activities in teaching and learning of scientific disciplines (Clement, 2000; Gilbert et al., 1998; National Research Council, 1996). Although the "modelling approach" statement covers quite different perspectives, agendas and standards, the most of them agree on the general meaning of the "modelling" term. Modelling is intended as the process of developing and using scientific models to describe and explain observed phenomena; a model based teaching/learning sequence should, then, take into account the need to make pupils develop modelling procedures in making sense of their own physical experiences and in evaluating information gained by themselves and/or reported by others. Unfortunately, scientific models are very often different from the common man personal views of the world, deeply rooted in mind because developed in years of real life experience, the so-called spontaneous models (Gentner and Stevens, 1983). When dealing with interpretation of natural phenomena, pupils are other than "tabula rasa", bringing, instead, a complex set of representative and interpretative schemes of phenomena and trying to adapt new information gained at school to them, perceived as more familiar and adherent to real life evidence. In contrast, the targeted scientific concepts may seem incoherent and useless to the learner. For this reasons, pupil's knowledge frequently diverts from the scientific canons and become a personal interpretation based on alternative representations, i.e. spontaneous ideas about reality, often responsible of mechanisms of resistance or conflict against scientific concepts learned, dealing with same real life situations.

Decades of research studies about psychology of learning processes made evident that learning is a process in which the learner increase his competence not only by simply accumulating new facts and skills directly communicated by a teacher, but by reconfiguring his knowledge structures, adapting novelties to his pre-existent mental models, automating procedures and chunking information to reduce memory loads, and by developing strategies and models that tell him when and how facts and skills are relevant (Mislevy, 1993).

For these reasons an approach to physics teaching not taking into account the conflicts between scientific and spontaneous models may result in pupils (Gilbert et al., 1982):

- not changing at all their personal interpretation of natural phenomena;
- mis-interpreting learned concepts, using them to substantially confirm their spontaneous models;

- developing ideas resulting from the mixing of scientific ideas and spontaneous models, with not resolved internal contradictions;
- accepting the taught contents just in scholastic situations and only to gain good marks in assessment activities.

4. The Physics to be taught and the Pedagogical Content Knowledge

In order to get over the problem sketched above, some transformations of scientific models are necessary, aimed to really adapt pupils' conceptions to scientific model. This approach involves a construction of the physics content structure to be taught not mainly, or even solely, oriented to physics issues but including educational issues and pupils' conceptions, as well. This framework has been adopted in research studies based on constructivist epistemology (von Glasersfeld, 1993) and concerning the experimentation in classroom of new teaching approaches (Duit and Komorek, 1997; Linn and Songer, 1991; Viennot, 1996). These studies are based on the main assumption that there is not a single content structure in a particular content area, but different content structures can be performed, according to the specific aims the authors, explicitly or implicitly, hold. Moreover, the process of interpretation performed by each student is influenced by concepts and models he already holds. These two issues, students spontaneous models and statements of the scientific knowledge, are therefore accepted to be of the same relevance and treated as resources for physics education. In this way the physics content to be taught is reconstructed in order to realize the main goal: to allow students to gain a fruitful knowledge of the outer - in our case physical - world. For these reasons we use the name first adopted by Duit and Komorek (1996) and call this teaching/learning approach *Educational Reconstruction*.

In order to be effective, Educational Reconstruction involves substantial modifications in the structure of learning sequences, and, more generally, in the teacher's role and teaching methods. The teacher has to transform himself /herself from being a 'dispenser' of knowledge to become a 'coach', managing the evolution of student skills, and a 'modeller' shaping and moulding learners' knowledge (Watts and Jofili, 1998). Teaching strategies to be implemented have to build new knowledge on pupil spontaneous models and need to provide learning environments explicitly promoting an appropriate epistemology of science, that has to become the content of instruction and has to be embedded in instructional methods.

But what are the requested teacher's competencies in facing these challenging requests? It can be argued that teachers need to have a deep knowledge of the nature of physics models and their functioning in the development of the discipline, as well as an awareness of the pupils' spontaneous models in the different content areas.

Zeidler (2002) suggested that a centrepiece of educational reform within the circles of science teacher education has been largely a "*tripartite structure with the anchoring points being teachers Subject Matter Knowledge (SMK), Pedagogical Knowledge (PK) and Pedagogical Content Knowledge (PCK)*". The idea of a tripartite structure, that seems to capture the fundamental attributes of the teaching entity, is described in details in some papers (Shulman, 1986a; 1986b; 1987 , Shulman and Sparks, 1992), where authors advance the importance and distinction between SMK, PK and PCK, viewing these domains of knowledge as separate but strictly interacting.

Although this reduction of an entity (teacher) or activity (teaching) to principle components may seem to be quite reductive of the complexity of the level of analysis, it can provide helps in characterising the different aspects of the knowledge, expertises and competencies involved in teaching and consequently in teacher education. SMK refers to a teacher's quantity, quality and organization of information, conceptualisations and underlying constructs in a given field of science (e.g., Physics). PK pertains to a teacher's knowledge of generic instructional variables, such as classroom management, communicating and questioning strategies, assessment,… , PCK represents a teacher ability to convey the relevant constructs of the content knowledge in a manner that makes it accessible to their students (Zeidler, 2002). This type of knowledge has been originally characterised as :

> *the most regularly taught topics in one's subject area, the most useful forms of representation of those ideas, the most powerful analogies, illustrations, examples, explanations, and*

> *demonstrations … including an understanding of what makes the learning of specific concepts easy or difficult: the conceptions and preconceptions that students of different ages and backgrounds bring with them to the learning.* (Shulman, 1986b, p. 9).

Shulman (1987) hypothesized a process of teacher education based on a form of transformation whereby the teachers' SMK is converted into the form appropriate for teaching, the PCK. The interface between SMK and PCK is central on the Shulman transformation process and it raises several interesting questions mainly concerning the relationship between the quality of teachers' understanding of subject matter and the consequence of their understandings and beliefs for their subsequent pedagogy (PCK).

Other researchers have identified as a transformation process the transition from a SMK to PCK. In particular, "the transformation of several types of knowledge for teaching" (Magnusson, et al., 1999, p. 95) including subject matter knowledge, pedagogical knowledge (classroom management, educational aims,…), and knowledge about context (school, students).

Building upon the cited work of Magnusson et al. (1999), we report here a conceptualisation of pedagogical content knowledge for science teaching as consisting of five main components:

- orientations toward science teaching;
- knowledge and beliefs about science curriculum;
- knowledge and beliefs about students' understanding of specific science topics;
- knowledge and beliefs about assessment in science;
- knowledge and beliefs about instructional strategies for teaching sciences.

4.1. Orientations toward teaching Science

This PCK component is related to teacher's knowledge and beliefs about the goals and general aims of teaching science in a particular grade. Grossman (1990) designated this component as consisting of knowledge of the purpose of teaching a subject at a particular level or the "overarching conceptions" of teaching a particular subject. Other authors (Anderson and Smith, 1987) refer to this component as "orientations toward science teaching and learning". i.e. general ways of viewing and conceptualising science teaching. According this idea, knowledge and beliefs serve as a "conceptual map" guiding instructional decisions about teaching (daily objectives, the subject content of lessons, the use of curricular materials, the evaluation of students' learning, etc.)

4.2. Knowledge of science curriculum

This component of PCK can be seen as consisting of two categories: knowledge of goals and objectives of teaching and knowledge of specific curricular programs. Although Shulman originally considered curricular knowledge as a separate domain of the knowledge base for teaching, we consider it as part of PCK because it represents a knowledge kind deeply distinguishing the content specialist from the pedagogue.

4.2.1. Knowledge of goals and objectives

This category includes teachers' knowledge of the goals and objectives for students in the subjects they are teaching, as well as the articulation of those guidelines across topics addressed during the school year. It also includes the knowledge teachers have about the vertical curriculum in their subject; that is, what students have learned in previous years and what they are expected to learn in later years (Grossman, 1990)

4.2.2. Knowledge of specific curricular programs

This category of teachers' knowledge of science curriculum consists of knowledge of the programs and materials that are relevant to teaching a particular domain of science and specific topics within the domain. Also, it includes knowledge of general learning goals of the curriculum as well as the activities and materials to be used in meeting those goals.

4.3. Knowledge of students' understanding of science

This component of PCK refers to the knowledge a teacher must have about students in order to help them develop specific scientific knowledge. It includes two categories of knowledge: requirements for learning specific concepts and areas of science that students find difficult.

4.3.1. Knowledge of requirements for learning

It consists of teachers' knowledge and beliefs about prerequisite knowledge for learning specific scientific topics, as well as their understanding of different students' approaches to learning as they relate to the development of knowledge within specific topic areas. Knowledge of the subject contents, abilities and skills that students may need is an example of the first point. Knowledge of the approaches students of differing developmental or ability levels or learning styles may apply in relation to developing specific understandings is an example of the second point.

4.3.2. Knowledge of areas of student difficulty

This category refers to teachers' knowledge of the science concepts or topics that students find challenging to learn. There are several reasons why students find learning difficult in science and teachers should know at least about the fundamental difficulty types. For some science topics, learning is difficult because the concepts are very abstract and lack any connection to students' common experiences. Other topics are difficult because instruction centres on problem solving and plan strategies to find solutions. A third, important type of difficulty students encounter when learning sciences involves topic areas in which their prior knowledge is contrary to the targeted scientific concepts. Knowledge of this type is commonly referred as misconceptions or spontaneous models and it is a common feature of science learning problems. In section 2. we have already discussed of the problems that may arise when teaching are not taking into account the spontaneous models (sometimes called misconceptions). Several researchers (Magnusson, Templin and Boyle, 1997; Smith, diSessa and Roschele, 1993; Hammer, 1996) affirm that the view of spontaneous models as interfering agents that must be removed and replaced ignores the constructivist basis of learning. Spontaneous models are the product of reasonable, personal sense-making and they can continue to evolve and to change if the teacher organises his/her teaching strategies taking them into account and using them as the starting point to develop the desired scientific knowledge.

4.4. Knowledge of assessment in science

Tamir (1988) originally proposed this component of PCK. It can be considered as consisting of two main categories: knowledge of the dimension of science learning that are important to assess and knowledge of the methods by which that learning can be assessed.

4.4.1. Knowledge of the dimension of science learning that are important to assess

This category refers to teachers' knowledge of the aspects of students' learning that are important to assess within a particular unit of study. One example of a view of the possible dimensions of science learning important to assess is the framework for the science component of the 1990 National Assessment of Educational Progress (NAEP). It identifies conceptual understanding, interdisciplinary themes, nature of science, scientific investigation and practical reasoning as important dimensions of science learning to assess (Champagne, 1989)

4.4.2. Knowledge of methods of assessment

Another aspect teachers should clearly master concerns the ways that might be employed to assess the specific aspects of student learning, important to a particular unit of study. There are a number of methods of assessment, some of which are more appropriate for assessing some aspects of student learning than others. For example, students' conceptual understanding may be adequately assessed by written open tests, whereas their understanding of scientific investigation may require assessment through a laboratory practical examination or laboratory notebook (Lunetta, Hofstein and Giddings, 1981). In general, teachers' knowledge of methods of assessment includes knowledge of specific instruments and procedures, approaches or activities that can be used during a particular unit of study to assess important dimensions of science learning, as well as the advantages and disadvantages associated with employing a particular assessment device or technique.

4.5. Knowledge of instructional strategies

Two categories comprise teachers’ knowledge of the instructional strategies component of PCK: knowledge of subject-specific strategies and knowledge of topic-specific strategies.

4.5.1. Knowledge of subject-specific strategies

Subject-specific strategies are specific to teaching sciences as opposed to other subjects. They represent general approaches to or overall schemes for enacting science instruction. Teachers’ knowledge of subject-specific strategies is related to the “orientations to teaching science” component of PCK in that there are general approaches to science instruction that are consistent with the goals of particular orientations.

A number of subject-specific strategies have been developed in science education, many of them consisting of a three - or four - phase instructional sequence. A typical subject-specific strategies is the “Prevision-Experiment-Comparison Learning Cycle” (the PEC cycle) (Lombardi et al., 2002), a three phase instructional strategy based on a peer-to-peer learning method where students are made working in small groups, using a worksheet where they are requested to make previsions for some particular situation, conduct experiments regarding that specific situation, compare their results with previsions and, if necessary, return to the prevision phase, repeating the cycle. The knowledge is built by alternating small group activities with discussions involving all the students and by developing descriptive and/or interpretative model on the basis of PEC cycles and subsequent discussions.

An interesting aspect to point out is the evidence that teachers’ use of strategies is influenced by their beliefs. Research has documented that some teachers resisted changing their practices to match those of an innovative approach because their beliefs differed from the premises of the new approach (Mitchener and Anderson, 1989; Cronin-Jones. 1991). These findings indicate that the transformation of general knowledge into pedagogical content knowledge is not a straightforward matter of having knowledge; it is also an intentional act in which teachers choose to reconstruct their understanding to fit a situation.

4.5.2. Knowledge of topic-specific strategies.

This category of PCK refers to teachers’ knowledge of specific strategies that can be useful for helping students comprehend specific science concepts. In particular, we can distinguish between topic-specific representations and topic-specific activities. The first refer to teachers’ knowledge of ways to represent specific concepts or principles in order to facilitate student learning, as well as knowledge of the relative strengths and weaknesses of particular representations. We can also include here teachers’ ability to invent representations to aid students in developing understanding of specific concepts or relationships. Topic-specific activities refer to teachers’ knowledge of the activities that can be used to help students comprehend specific concepts or relationships. For example, problems, demonstrations, simulations, investigations or experiments.. Pedagogical content knowledge of this type also includes teachers’ knowledge of the conceptual power of a particular activity; that is, the extent to which an activity presents, signals or clarifies important information about a specific concept or relationship.

5. PCK in the new teacher role and the general University formation

Usually, physics courses, at high school as well as at university level, use a teaching approach based on a lecture format of the classes and few laboratory activities restricted to a mere verification of some physical laws. It has been shown that the direct learning experience as university students functions as the best training in teaching methodology. In fact, very soon teachers transfer perceived methods and learned contents in their classrooms, simplifying the approaches, usually through the teaching models reported in textbooks (Sprinthall, 1995). To add troubles to this unlucky situation, some research papers (Ball and McDiarmid, 1990; Grossman, Wilson and Shulman, 1989) evidence that pre-service teachers frequently do not possess a well articulated understanding of underlying connections among topics in their discipline. Additional exposure to traditionally presented SMK does little to better integrate their knowledge base into the “integrated wholes” in the absence of opportunities to develop a more pertinent PCK. In accord with Zeidler (2002), we do not want to suggest that a deeper SMK has no role in teacher education but that the evidence suggests that the quality of student learning increases when teachers pay attention to PK factors such as relating new information to students’ prior knowledge and PCK factors such as organizing and sequencing of content and activities in a manner that allows students to better discover relationships inherent in the discipline.

Teacher training usually consists in scientific courses and courses about education based on a lecture format of the classes. Moreover, the courses in education are totally separated from the instruction in physics content and teachers have to necessarily synthesize by themselves in order to solve their specific teaching and learning problems. The construction of the PCK is, then, usually assigned to the self-learning and self-forming of prospective teachers.

6. Discussion and conclusions

In this paper it has been argued that a new model of pre-service physics teacher formation has to be thought, based on the need to make prospective teachers understand the importance of modifying the high school physics teaching approach from a procedure of transmission of consolidated knowledge to the implementation of teaching/learning environments where teachers manage and support the pupil processes of knowledge construction. This objective is a big one, and involves a deep modification of the structure of the teacher training courses. Substantial modifications of teaching methodology and approaches cannot be transferred to teachers only by using theoretical courses outlining the methodological underpinnings, but by making teachers experience the same teaching/learning environments we think they have to provide to their pupils. In order to communicate new knowledge and new behaviours, we need teachers' training strategies that build the new knowledge on the previous one: there is a close parallelism between how the change occurs in pupils' scientific conceptions and how a change in the conception of teaching can occur (Sprinthall, 1995). Teachers who learn in a different way may be oriented to teach in a different way; in fact it has been shown that a well founded change in teachers' didactic activity involves also a conceptual change (Posner et al., 1982). Our main idea is that an educational reconstruction of the physics content to be taught needs a parallel reconstruction of teacher education.

Moreover, many new approach to physics teaching use innovative teaching/learning environments based on computational tools in order to support student activities concerning exploration, experimentation and modelling. Computational tools does not simply offer the same content in new clothing: areas of content have to be recast and new ways of teaching concepts are possible, allowing learners to explore concepts in a different way as well as concepts that were previously inaccessible. These new approaches and the effective use of computational tools the teacher has to make in his classroom activities again show that a substantial modification of teacher role and teaching methods is needed.

Many researchers have focused on metacognitive processes that facilitate knowledge construction as a way to get students to learn with greater understanding (Flavell, 1979; Schoenfeld, 1987). This line of research has yielded very interesting instructional programs that elaborate, make visible, support, and help students to reflect upon metacognitive processes (sometimes called *metareflection*) that are conducive to the construction of knowledge. A number of these programs have been demonstrated to be very effective in actual classrooms (Scardamalia et al., 1996; White et al., 1999).

For metareflection we mean the activation of those procedures that direct and steer the information processing-flow of learning, in order to make them explicit, recognizable and reproducible (Simons 1995). In particular, we intend the meta-learning development of Schön's reflective practice (1988) that has already been successfully applied in various contexts of science teaching and tutoring (Linder et al., 1997; McKinnon and Erikson, 1988). Schön (1988) argues that all aspects of teaching-practice supervision should be characterized by fundamentals of "coaching" where:

> *through advice, criticism, description, demonstration, and questioning, one person helps another to learn practice reflective teaching in the context of doing. And one does so through a*

Hall-of-Mirrors: demonstrating reflective teaching in the very process of trying to help the other learn to do it.

Schön defines the learning activity as the process of "making sense of complexity" or 'reflection-in-action', and introduces a second reflective domain relevant for the objective of learning to teach: the 'reflection-on-action', i.e. the thought used to review sense-making of complexity.

As we share the hypothesis that a focus on metareflection is the key to getting students to learn with greater understanding, the structure and content of pre-service teacher preparation courses have to be organised to take into account this point and to prepare teachers to carry out the teaching tasks required from teaching/learning approaches based on the knowledge of their own difficulties in learning and focused on modelling procedures. A possible hypothesis for a research aimed at improving prospective teacher education courses concerns the teaching methods to be implemented in the courses in order to make the prospective teachers aware of the strategies to put into action in filling the gap between the physics content to be taught and the pupils' knowledge relevant to find explanations for the involved natural phenomena.

In conclusion, we propose here some basic principles for a teaching method for prospective Physics teacher education, that include:

- to have prospective teachers attend education courses realising and experiencing the same learning environments they are supposed to realise and use in their future classrooms;
- to supply prospective teachers with appropriate pedagogical tools helping them in conceptualising physics models and in gaining the abilities connected with modelling procedures;
- to involve prospective teachers in activities aimed at stimulating hands-on learning and metareflection.

More specifically, a new model of pre-service teacher education should include activities aimed at

- projecting and experimenting "Teaching/Learning Pathways" (TLPs) constituting the framework of "Pedagogical Physics Laboratory" courses. These courses should be thought to be learning environments where prospective teachers develop new teaching approaches and strategies by performing a synthesis between scientific and pedagogic competences and by enabling conditions for collaborative inquire in model building procedures. Each TLP can be finalized to the development of a general argument (for example, thermal processes, mechanical waves propagation, etc.) and can be divided in smaller, handier parts, meant for the pedagogical development of specific aspects of the general argument, sometimes referred in literature as "Teaching/Learning Sequences" (TLSs);
- investigating the correlations between the characteristics of the proposed teaching/learning environment and the competencies developed by TTs, in the aim of developing and fully appreciating the interplay among SMK, PK and PCK and their role in teaching and learning.

These suggestions are, clearly, not the only one it is possible to give in order to design an effective pre-service teacher education system. They should be included in a wider educative program, dealing with more general pedagogy, sociology and communication arguments, in-deep studies of specific disciplinary subjects and, most important, apprenticeship activities in real school contexts. But a discussion on a general model of pre-service teacher education would request another whole paper, to be only superficially discussed…

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