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**EDUCATIONAL RECONSTRUCTION OF THE PHYSICS
CONTENT TO BE TAUGHT AND PEDAGOGICAL
CONTENT KNOWLEDGE IMPLEMENTATION BY USING
INFORMATION AND COMMUNICATION
TECHNOLOGIES**

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Abstract

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There is a growing interest among educational researchers on how to develop prospective teachers' knowledge and competencies adequate to the work they have to develop with their pupils, including the ability to actually convey the relevant constructs of their content knowledge in a manner that makes it accessible to their students. This means merging the “subject matter knowledge”, that refers to the teacher's ability to retain and organize information, to conceptualise underlying constructs in a given field of science (as physics), with a “pedagogical knowledge”, pertaining to the teacher's knowledge of generic instructional variables, such as classroom management, communicating and questioning strategies, and acquire what is called in science teacher education literature (Shulman, 1986a; 1986b; 1987) a “Pedagogical Content Knowledge” (PCK).

This dissertation deals on building a PCK in Physics Trainee Teachers (TTs) attending the Italian Graduate School for Secondary Teacher education by using the Information and Communication Technologies. In particular, Teaching/Learning Sequences based on Real Time Laboratory and Simulation Environments use, within the domain of modelling thermal physical phenomena, are described, and their experimentation results reported, aimed:

- to the development in TTs of general cognitive strategies to interpret real-life phenomena and build descriptive and interpretative models of them;

- to the activation in TTs of the knowledge transformation process needed to shift explanations from the ones commonly retained as a remembrance of their attended university Physics courses to a well organised compendium of competencies profitably useable in real classroom pedagogical activities projects.

This study investigates the development of PCK within two separate groups of pre-service physics teachers during the first semester of their two-year post-graduate teacher education program, in academic years 2000/2001 and 2002/2003. It focuses on the central issue of the relationships between observable phenomena, like macroscopic thermal properties of matter and their interpretation and/or explanation in terms of corpuscular characteristics and/or thermodynamics theory. The strategy is based on the consideration that knowledge transformation is not a one-way process from subject matter knowledge to pedagogical content knowledge, as literature suggests, but a bi-directional process involving deepening of subject matter knowledge and awareness of pedagogical issues.

The methodology used for this study conforms to the ‘case study’ approach in educational research (Stake, 1995, 2000). Then, it is naturalistic and interpretative and seeks to examine meaning in a given context. Our ‘case’ is the sociological and organizational unit of our teaching/learning settings, with the intent of assembling its comprehensive description in terms of a discrete number of research objectives.

Experimentation data were mainly analysed using a phenomenographic approach (Marton, 1988; Marton and Both, 1997) in order to reveal the different ways in which some classroom learning episodes were experienced by our TTs. Data were usually triangulated in order to present a comprehensive analysis of TTs’ participation in the work from several perspectives and to enhance the internal validity or credibility. The aim was to present a detailed contextual analysis of a limited number of events or conditions, with the goal of seeking to understand how the prospective teachers’ behaviours might change or be influenced in response to the pedagogical environment designed by the authors.

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1. Introduction

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 pre-service Physics teacher formation have to be thought and experimented to transform and deepen prospective teachers' understanding of subject matter and to redirect their habitual ways of thinking about subject matter for teaching.

This dissertation describes and discusses some pedagogical material dedicated to pre-service Physics teacher preparation and the related experimental results, developed by the Research Group in Teaching/Learning Physics (G.R.I.A.F.) of the University of Palermo, in the framework of an ongoing Research Project, FORM (Physics Education Pathways and Formation), supported by the Italian Ministry of Research and Education, involving eight research groups of different Italian Universities. The focus of the project is on finding out components of teaching and learning that are essential to a cultural transmission in scientific areas (in particular, Physics and Mathematics) and on supporting both planes of understanding and motivation to understanding.

Section 1.1 of this chapter outlines 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 science teacher formation.

Section 1.2 outlines the context of existing research in which FORM project has been developed. Section 1.3 identifies the aims of the research and describes the organization of the remainder of this dissertation.

1.1 See the need

1.1.1 The need for a new approach to physics education and teacher formation

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 one have to certainly 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 to guide 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 lacking of a noticeable evolution in scientific teaching (from programs to texts to methodologies) facing the general cultural and scientific progress.

This situation is even worse for 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 soon results in the need for new pedagogical models of physics teacher preparation.

1.1.2 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' formations 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 possess and improve to help their future pupils to develop an effective scientific culture. This has been shown in many fields 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 *subject matter for teaching*.

1.2 Deeper into the need

1.2.1 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.

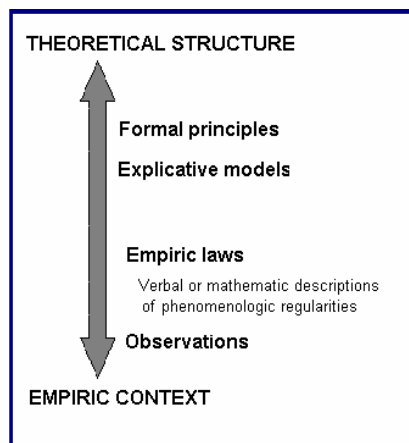


Figure 1.1. a schema of the knowledge used to build a scientific explanation of some empiric content.

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 1.1 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 play 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 1.2 shows a generalization of the cyclic process of building a real world system's model and of the subsequent empirical evaluation of the model.

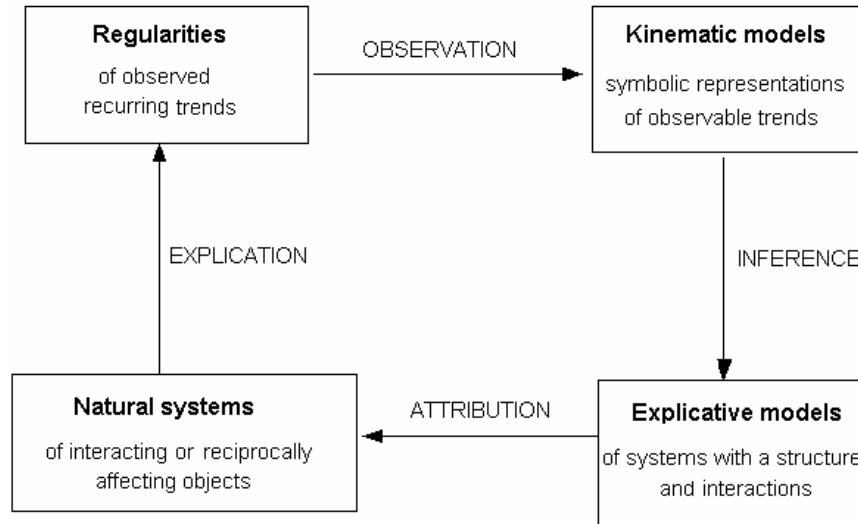


Figure 1.2. The cyclic process of building a model and empirically evaluating it

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 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 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, actually, 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 (NRC), 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 soon 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 about 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 very soon diverts from the scientific

canons and became 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 very soon 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.

1.2.2 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 other 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 call this teaching/learning approach Educational Reconstruction, using the name first adopted by Duit and Komorek (1996). It involves substantial modifications in learning sequences as well as in the teacher's role and teaching methods.

The teacher has to transform himself or 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 fronting these somehow 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 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.

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 to 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.)

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.

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)

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.

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*.

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.

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 1.2.1 we have already discussed of the problems that may arise when teaching not taking into account the spontaneous models. We will discuss again of this point in section 2.4.1, where we will treat pupils' spontaneous models in a different, non-negative prospective (after all, the use of the "misconception" term somehow hides the idea that spontaneous conceptions are wrong, and that the teachers' real task is to substitute them with the correct, "scientific" views of the world); several researchers (Magnusson, Templin and Boyle, 1997; Smith, diSessa and Roschele, 1993; Hammer, 1996) affirm that the view of

misconceptions as interfering agents that must be removed and replaced ignores the constructivist basis of learning. Misconceptions 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.

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*.

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)

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.

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*.

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. This point is developed in some more aspects in section 2.4.2, where L. Viennot's idea of the decisive role of teachers as "proposal transformers" is described.

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.

1.2.3 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 very soon 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.

1.3 Meet the need

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).

In the current research, we share the hypothesis that a focus on metareflection is key to getting students to learn with greater understanding. The structure and content of pre-service teacher preparation courses have to be organised to prepare teachers to carry out the teaching tasks required from the proposed teaching/learning approach focused on modelling procedures. Our research hypotheses concern 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.

The basic principles of our teaching method are the following:

- to make experience to prospective teachers attending our courses, from now on called Trainee Teachers (TTs), the same learning environments they are supposed to realise in their future classrooms;
- to supply TTs with appropriate pedagogical tools helping them in conceptualising physics models and in gaining the abilities connected with modelling procedures;
- to involve TTs in activities aimed at stimulating hands-on learning and metareflection.

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 (1988) 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.

With this in mind, the following interrelated goals were set for the model of pre-service teacher formation we want to discuss here.

- To project "Teaching/Learning Pathways" (TLPs) constituting the framework of "Pedagogical Physics Laboratory" courses of the Italian Graduate School for Pre-service Teachers Preparation (S.S.I.S.). These courses are thought to be *learning environments* where TTs 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 is 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).
- To investigate 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.

In Chapter 2 the general idea of TLP is described and the research frameworks behind the design of effective TLPs and associated TLSs are presented in some details. Chapter 3 contains a review of methods used in our research: the debate between the quantitative and the qualitative research methods is presented, then the important methodology of Case Study and the Phenomenographic approach to data analysis are described. In Chapter 4, some important previous research results on pupils views and spontaneous ideas, central in projecting effective pedagogical pathways in the field upon which the research described in this dissertation is based (thermal processes), are discussed. The actual design of a TLP about thermal processes and the research questions involved with it are discussed in Chapter 5. Some significant component TLSs are presented, and the phases of their experimentation in the S.S.I.S. workshops framework are discussed with regard to the related SMK and TTs competences. The analysis of data collected during the experimentation and a discussion of the research results are performed in Chapter 6. In Chapter 7 a summary of all the previous chapters is, finally, reported.

2. Teaching/learning pathways and sequences

This section describes the general ideas of Teaching/Learning Pathway (TLP) and of its components, the Teaching/Learning Sequences (TLSs). Some research trends in designing TLPs and, more specifically, TLSs are first presented and general theoretical frameworks in this field are, then, reviewed and discussed.

Contents here presented are inspired by presentations of the 2001-2003 Esera Conferences about TLSs design and on a subsequent paper due to Méheut e Psillos (2004), by the psycho-cognitive research studies done by Elby (2001), diSessa (1993), Hammer (1996, 2000) and colleagues and by other researches in Physics education such as the research works due to Viennot (2001, 2002, 2003a, 2003b).

2.1 About Teaching/Learning Pathways and Sequences

Several research-inspired pedagogic activities and approaches for improving students' understanding of scientific knowledge have been developed as a result of '70s and early '80s research studies eliciting students' conceptions regarding natural phenomena and concepts and to theoretical developments on teaching and learning as a constructive activity. An interesting line of inquiry involves the design and implementation of topic-oriented sequences for teaching physics, inserted in a more general context regarding a specific content to be developed. This trend can be inserted in the context of a science education research tradition by which teaching and learning are investigated at a micro (e.g. specific session) or medium level (e.g. single topic sequence) rather than at the macro level of a full year's or multi-year curriculum

A distinctive feature of these pedagogic activities and products is their dual character: both research and development, targeting a close linking of the teaching and learning of a particular topic, are involved. Actually, teaching sequences of that kind draw on the tradition of action research, being both research tools and innovations aiming at the handling of specific topic-related learning problems. Lijnse (1994, 1995) brought to the attention of the European research community questions and issues regarding the character of research into teaching sequences. It is argued that this sort of activity is a kind of "developmental research" involving the linking of design, development and

application of a teaching sequence on a specific topic, usually lasting a few weeks, in a cycling evolutionary process enlightened by rich research data. Kattman et al. (1995) have developed a framework for elaborating and improving the design of teaching learning sequences in terms of “Educational Reconstruction”. It is worth noting that in mathematics education, Artigue (1988) has already suggested a fruitful theoretical framework for developing teaching sequences drawing the attention to *a priori* epistemological analysis of the topic to be taught, an issue which is also fruitful for science education.

Though various terms have been used in the past, the term “Teaching/Learning Pathway” and the recently introduced “Teaching/Learning Sequence”, following recent international symposia, are now commonly used to connote the close linkage between proposed teaching and expected student learning as a distinguishing feature of a research-inspired topic-oriented sequence (Psillos and Méheut, 2001). A TLP and, more specifically, its component TLSs are both interventional research activities and products, like traditional curriculum unit packages, including well-searched teaching-learning activities empirically adapted to student reasoning. At times, teaching guidelines covering expected student reactions are also included. Considerations that in one way or another seem to influence the development of TLSs have included research into students’ conceptions, features of the specific scientific domain, epistemological assumptions, learning perspectives, current pedagogical approaches and features of the educational context.

A notable characteristic of a TLS is its inclusion in a gradual research-based evolutionary process aiming at linking the scientific and the student perspective and trying to fill the gap between scientific models and pupil’s alternative representations of natural phenomena. For this reason, a fundamental point in the design of a TLS is taking into account different aspects such as content analysis, epistemology, student’s conceptions and motivations, learning and pedagogical theories and other educational constraints.

2.2 A brief review of trends in designing Teaching/Learning Pathways and Sequences

2.2.1 A psycho-cognitive constructivist approach

During the '70s and early '80s a central subject in educational science research was the analysis of the so-called pupil's misconceptions, i.e. representations and spontaneous reasoning of the learner with respect to natural phenomena (see also section 1.2.1). Very soon researchers tried to find how to take the gathered information into account in order to improve science teaching and learning. One current, which resulted in research-based teaching approaches, was strongly "learner-centred", emphasizing the students' resources and the potentialities of confronting their ways of reasoning with data from the material world (Driver and Oldham, 1986). Comprehensive reviews of the considerable amount of research work developed in this perspective can be found for example in Scott, Asoko and Driver (1992) or in Duit (1999) .

Different approaches were worked out, ranging from radical constructivist to more moderate ones. In the radical approach, the main teacher's role is to establish a favourable climate for student discussions and activities; the students being left largely responsible for formulating and solving problems themselves. This point of view is expressed by von Glasersfeld: « *The teacher's art (...) resides in getting students to generate problems of their own that are conducive to the ways of thinking that are to be taught* » (von Glasersfeld 1992, p.37); a point that also appears in developmental research: « *In other words: preferably the students themselves should pose the problem to be further investigated (...) they themselves frame the questions that drive their learning processes* » (Kortland 2001, p.9-10). This type of model pays great attention to students and the role of the teacher is that of *facilitator* of student activities; a point worth of note in this approach is the fact that main choices underlying the design of the sequence are independent of the scientific domain of knowledge in concern.

In less radical approaches, the teacher (or researcher) is in charge of elaborating the problems to be solved; as we will see, this can lean more on psychological justification or epistemological argument (see section 2.2.2). Here, we consider one main approach that gives great importance to *contradictions*. A first set of research (see for instance Nussbaum and Novick, 1982; Driver and Erickson, 1983; Driver and Bell, 1986;

Nussbaum, 1989; Dewey and Dykstra, 1992; Ravanis and Papamichael, 1995) puts the accent on clarification of pupils' ideas when interpreting or predicting the results of experiments and "destabilisation" of these incorrect ideas when confronted with contradictory observation. Other authors use the word « conflict » to describe the contradictions between individual pupils' different thought processes (Stavy and Berkovitz, 1980; Rebmann and Bugeat, 1994). Another source of conflict can be found in the contradictions between the thought-processes of different pupils (Champagne, Gunstone and Klopfer, 1985).

Let us note that, restricting ourselves to the didactics of physics and chemistry, it is difficult to evaluate the advantages and limits of such "conflict" strategies. If some studies conclude to the effectiveness of such strategies (Guzetti et al., 1993), this conclusion is not fully shared. Nussbaum (1989) questions these teaching strategies stating that "the students maintain substantial elements of the old conceptions" (p. 538), while H. Schwedes and D. Schmidt (1992), P. Scott, H. Asoko and R. Driver (1992) go a step further, questioning the way in which pupils recognise these programmed "conflicts" and how they resolve them (Chin and Brewer, 1993). These researchers touch upon two important issues. The first is that what researchers consider "a conflict situation" is not necessarily such for the students, at least with regard to experiments. Examples from teaching electricity are illuminating in this respect (Psillos, Koumaras and Valassiades, 1987; Koumaras, Psillos, and Kariotoglou, 1997). The second issue is that, in a number of cases, the data gathered tends to assess the global effectiveness of a teaching sequence rather than permit precise analysis of the setting up and development of a specific conflict. Although the high expectations of conflict strategies were not fulfilled, appropriate embedding of conflict situations in a TLS may improve its effectiveness.

2.2.2 An epistemic constructivist approach

Different approaches to TLS design were more targeted to the scientific content to be developed rather than to students and teachers role in educative activities. Various aspects of scientific knowledge can be used as a driving force for the learning process. Some approaches make use of analogies between different fields of knowledge: such TLSs were developed in particular in the field of electro-kinetics, using hydraulic

(Schwedes and Schmidt, 1992; Schwedes and Dudeck, 1996) and thermal (Dupin and Johsua, 1993) analogies.

Others rest on analysis of pieces of knowledge as tools for solving problems. Such approaches focus on the relationships between the problems and the knowledge and competencies that have to be used to provide answers to them. Students are expected to develop, or at least make use of, new knowledge by solving well-designed problems, e.g. prediction problems, the underlying idea again being to highlight the limits of available thought-processes and to favour the elaboration or at least the appropriation of new knowledge.

It seems that such approaches did not lead to many international publications, which probably can explain why some authors consider that there is lack of attention to science content in contemporary research in science education (Lijnse, 1995, Fensham, 2001). So, we will here illustrate this approach with a few examples found in national and international literature originating from France. L. Tsoumpelis (1993) envisages building up the notion of molar concentration through prediction problems on difference in osmotic level by varying different factors. In mechanics, in a sequence studying free fall, G. Robardet (1995) asks for predictions relative to the falling movements of two objects of different mass; the rest of the sequence is structured by the search for a relationship between the speeds of the falling object at different moments in time. This type of problem (the search for a relationship between different concepts) has been studied by Weil-Barais and Lemeignan (1990) concerning the momentum concept. These same authors (Lemeignan and Weil-Barais, 1994) also propose training activities in the concept of energy by setting up energy transformation chains: making a bulb last longer and give a stronger light or a small car go faster and farther by the use of a battery, a hair-dryer, a pressure-cooker, the sun etc. Supplementing these action problems (production of such and such an effect) are representation activities aiming at describing the way the devices function in terms of energy-transfer.

So, alongside prediction problems - which are also at the heart of research into "cognitive conflicts" - other types of problems can be used as driving forces for learning: e.g. action problems on material systems (producing, modifying an effect), or more "theoretical" problems, such as how to establish a relationship between physical quantities, how to represent different phenomena in a unifying manner. Such approaches

can be linked to an instrumentalist view of science, the aims of scientific activity being not so much the verification (or refutation) of theory but rather the elaboration of ever more powerful models. From this modelling point of view, problems are useful not only to solve contradictions but also to develop models as simple and powerful as possible, in order to explain seemingly different phenomena in a unifying manner and to support action and prediction.

In such approaches the driving forces of learning are sought from the epistemic significance of knowledge. It is more or less implicitly supposed that such epistemic driving forces can act as forces driving learning.

2.2.3 A more integrated constructivist approach

The psycho-cognitive and the epistemological registers, were already apparent in the early 1980s. In such early approaches, the choice of experiments (and of questions) is based on analysis of the pupils' preliminary knowledge. The aims of instruction are purposely limited; the "notions" taught are placed in relation to the scientific concepts they prefigure. This double reference, to the pupils' knowledge and their conceptions about the physical world on the one hand and to scientific knowledge on the other, allows researchers to propose original steps in the conceptualisation of the phenomena, which at times may not coincide with those often included in textbooks or curricula. For example, in a study on teaching notions of temperature and heat, Tiberghien and Barboux (1983), amongst others, propose manipulations to lead the pupils to establish a "link between the temperature of a substance and the thermal balance of its environment" (p.7) and to generalise to all substances "the increase in temperature when heated (excepting change of state)" (p.7). The knowledge to be attained here, very simple at first sight, in reality represents a major step for the pupils in relation to their prior conceptions: in fact, it seems that pupils, before being taught this, think that the temperature of certain substances (ice and sand, for example) is not subject to variation. Similarly, M.G. Séré and A. Chomat (1983) questioned their representation of a gaseous state and suggested learning situations in which the objectives are that pupils give certain substance properties to the gases ; particularly concerning weight and conservation of quantity during different transformations.

Such studies marked an important step in the conception of teaching-learning sequences: the initial cognitive state of students being defined as far as is covered by current research, and the desired final cognitive state being defined according to scientific knowledge, which is transformed as to adapt to students reasoning. While this gave only a partial reply to the characterisation of the pedagogical process towards achievement of this final state, we may nevertheless note the importance given to the setting up of manipulations "favourable to the pupils' expression of conceptions and their evolution" (Tiberghien and Barboux, 1983, p. 5).

We find a similar approach in more recent work, where the attention is focused both on the pupil and on characterisation of the knowledge in question. In these studies the scientific content is considered as problematic and is handled by the researchers so as to give rise to innovative representations of scientific concepts and their relations according to the perceived aims of instruction by the researcher.

Thus the notion of pressure at junior high school level is introduced as a primary concept in a constructivist sequence on fluids. Force is introduced later on and the pupils are expected to establish the relation force –pressure after differentiating force with pressure (Kariotoglou, Koumaras and Psillos, 1995; Psillos and Kariotoglou, 1999). In another study voltage is introduced as primary concept in a sequence on electric circuits at junior high school level whereas in usual curricula current intensity is the introductory primary concept (Psillos, Koumaras and Tiberghien, 1988; Tiberghien, Psillos and Koumaras, 1995). The differentiation of concepts of intensity, tension and energy is a prominent objective of this sequence in which the experimental field includes the duration of a battery whereas usually only the brightness is handled. In another sequence on introductory electricity Barbas and Psillos used transient states of electrical circuits in order to make up for the observed dissociation of electrostatic and electrokinetic phenomena by the students taking into account their causal thinking as well (Barbas and Psillos, 1997)

Several other examples may be also cited concerning traditional topics such as optics (Kaminski, 1991; Chauvet, 1996; Galili, 1996)) at junior high school, energy (Trumper, 1990), structure of matter and particle models (Méheut and Chomat, 1990; Scott, 1992, Méheut, 1997; Vollebreght 1998) or more recently, superposition principle (Viennot and Rainson, 1999) and modern topics like non-linear physics in upper physics classes

(Komorek, Stavrou and Duit, 2001), fuzzy topics like the introductory treatment of errors at university level (Evangelinos, Psillos and Valassiades, 2003) or cross discipline ones like tides (Viri and Heikki, 2004). We may observe that some of these approaches give a significant role to contradiction as a source of motivation for learning, while others are more explicitly modelling-oriented (Gilbert and Boulter, 1998). We can see here an expression of different epistemological points of view, the former more logical, the latter more instrumentalist.

Among the numerous studies on the use of analogies (see for example Arnold and Millar, 1996), we find some that are mainly knowledge-centred, resting on an analysis of similarities between domains, and others that are more integrated, taking into account both psycho-cognitive data about the students and epistemic analysis about the analogical structures of the knowledge in question. Bridging analogy strategies can also be considered as belonging to this type of integrated constructivist approach (Brown, 1994). Such approaches link considerations about the students, their relation to material world, and epistemic points of view.

One important remark about these and the previous studies is that they are paying few attention to the teachers role. Let us notice that recent research works referring to a Vygotskian approach, plead for giving more attention to this point (Dumas-Carré and Weil-Barais, 1998; Leach and Scott, 2002).

2.3 General frameworks in designing TLPs and TLSs

An important development in the field of projecting a TLP and the associate TLSs is the elaboration of general frameworks focusing on the factors taken into account and on processes involved in designing sequences as a research activity. In this section we outline some of these general frameworks, which probably reflect different research traditions and educational contexts, in order to illustrate their specific contributions in the discussion on TLSs, as well as their possible common points or differences.

2.3.1 “Developmental Research”

Piet Lijnse’s papers on “developmental research” (Lijnse, 1994, 1995) brought to the fore in European physics education area general issues concerning the place of teaching-

learning sequences in science education research. He complains about an “*almost complete lack of attention to science content*” in contemporary research in science education, maybe unaware of some new research currents coming to general attention in those years, like “Educational reconstruction”. Moreover, he poses the question whether general learning or pedagogical theories may prove useful when one comes to the level of specific topic oriented designs. In order to “*fill the gap between theory and practice*”, Lijnse proposes a general schema for developing “didactical structures”. In his proposal, great importance is given to the freedom of students to follow their own elaborations and he doubts if “conceptual change” and particularly “cognitive-conflict” strategies can effectively give students this opportunity. The problem is then formulated as “*to conceive teaching situations to lead students to build freely the ideas we want to teach them*”.

He proposes some guidelines, for designing such teaching-learning situations, where great attention is paid to motivational and metacognitive dimensions and to the learning on the part of the teachers that such an approach makes necessary. Some general indications concerning conceptual development are given, with the proposition of three levels: selection of attention, transition to a descriptive level and, if necessary, transition to a theoretical level. Referring to this framework, J. Kortland (2001) proposes to deconstruct the teaching-learning process into five phases: motivation, question, investigation, application and reflection.

Lijnse gives great importance to empiric regulation in the process of elaborating “didactical structures”. Such regulation starts from a scenario describing and justifying (*a priori*) the design of teaching-learning activities and the expected teaching-learning processes. The teacher can use such a scenario when preparing the classroom trial; and it is also a guide for classroom observations, in the perspective of producing didactical structures “good enough for teaching practice”.

2.3.2 “Educational Reconstruction”

The model of “educational reconstruction”, developed by Kattmann et al. (1995), provides a framework for designing and validating teaching-learning sequences that draws on planning instruction models that were developed in the German pedagogical tradition. The model attempts to combine the German hermeneutic tradition on scientific

content with constructivist approaches to teaching and learning. It holds that clarification of science subject matter is a key issue if instruction in particular science content is to be developed. This is a process called “elementarisation”, which leads to constructing the core (‘elementary’) ideas of the content to be taught. Often this clarification process is primarily or solely informed by issues coming from the structure of the referent science content. Educational issues then are regarded only after the science subject matter has been clarified. The significant feature of the educational reconstruction approach is that its analysis of science content takes into account not only epistemic dimensions (genesis, function and meaning of the concepts) but also context, applications and ethical and social implications.

The educational reconstruction model closely links considerations on the science concept structure with analyses of the educational significance of the content in question and with empirical studies on students' learning processes and interests. Students' conceptions are taken into account in a constructive perspective in reconstructing science content structure by providing answers to questions like “Which are the most relevant elements of the students’ conceptual framework to be respected? Which opportunities are opened by certain elements of students’ conceptions or perspectives? Which conceptions of students correspond with scientific concepts in such a way that they can be used for a more adequate and fruitful learning?” (Kattmann et al., 1995).

The model is based on an integrated constructivist view. On the one hand, the knowledge acquisition process is seen as an active individual construction process within a certain social and material setting, while science knowledge, on the other hand, is viewed as a tentative human construction. Results of the analysis of content structure (linking clarification of the core concepts and analysis of the educational significance) and preliminary ideas about the construction of instruction play an important role in planning empirical studies on teaching and learning. The results of empirical studies influence the processes of educational analysis, elementarisation, and even the setting of detailed goals and objectives. This procedure is rather unusual for educational research, yet it fits the situation that a particular content structure for instruction has to be developed according to the students’ point of view, especially according to their pre-instructional conceptions and their learning paths. The science content structure and the students’ conceptions and frames of interpretation are seen as being equally important

parameters in the process of educational reconstruction and are necessary to attain the goals of science teaching. A special characteristic of the model is that knowledge gained in one of the components influences the activities and the interpretation of the results of the other components in a dynamic process

2.3.3 “Ingénierie Didactique”

Another framework, developed in mathematics education research is, as we mentioned in section 2.1, also useful for science education. This framework proposed guidelines for both designing and validating a sequence. In this general framework, Artigue (1988) suggested three main dimensions for *a priori* analyses:

- an “epistemological” one: analysing the contents to be taught, the problems they answer, their historical genesis
- a “psycho-cognitive” one: analysing the students’ cognitive characteristics
- a “didactic” one : analysing the functioning of the teaching institution

This general framework rests on a strong model of learning by problem solving. Thus, the *a priori* analyses are linked up in order to accurately define “problems” to be managed by students and to anticipate the elaboration of knowledge by students through these “problems”. The comparison of the cognitive itineraries actually observed with those predicted can validate or challenge the hypotheses involved in the building up of learning situations.

2.4 Other researches about frameworks in designing TLPs and TLSs

2.4.1 “Student’s resources knowledge” and the “p-prims” concept

As we have seen previously, remarkable resources have been engaged, in the field of research in Physics education, to the studies on students’ misconceptions and difficulties. Both are concerned with understanding aspects of students’ knowledge and reasoning representing obstacles to learning. Surely, this work has been and continues to be very useful in order to orient the development of scholastic curricula as well as for motivating researchers and teacher to examine and reconsider conventional methods of instruction.

However, as views of student knowledge and reasoning, misconceptions and difficulties of the students are limited in two respects. First, they do not supply explanations on the productive resources that the students can use in order to activate their understanding; second, descriptions of student difficulties provide no analysis of the underlying mechanism, while the perspective of the misconceptions cannot explain the dependency of the reasoning of the students from the context (Hammer, 1996; Smith, diSessa and Roschelle, 1993), such as the empirical fact that substantively equivalent questions, posed in different ways, can induce different answers in the same student (Steinberg and Sabella, 1997).

In this sub-section we will review some of the current ideas for thinking about students in terms of the “resources” they put into action in order to learn. The perception of these resources is not complementary to the view of difficulties, as an account of students resources should provide a theoretical support for the understanding of difficulties.

When presented with a not sufficiently familiar problem, a person, normally, invokes his own knowledge and experience, putting to comparison various thinking lines and choosing the one that best fits, in its opinion, to the situation that must be faced. The person tries to apply its cognitive resources to the situation in order to find the solution to the problem but it can sometimes happen that the used resource does not reveal profitable for the problem resolution, being, instead, an obstacle.

As an first example, consider the classic question, posed by Elby (2001) to some students, in the framework of a research about students’ resources:

a truck hits one parked car, which has half the mass of the van. Intuitively, which is larger during the collision: the force exerted by the truck on the car or the force exerted by the car on the truck?

It is easy to imagine that the typical answer can have been that the truck exerts a larger force on the car than the car on the truck, this is a typical situation of “misconception” where intuition is in discordance with laws of dynamics. A second question was, then posed by Elby to his students:

Suppose the truck has mass 1000 kg and the car has mass 500 kg. During the collision, suppose the truck loses 5 m/s of speed. Keeping in mind that the car is half as heavy as the

truck, how much speed does the car gain during the collision? Visualize the situation, and trust your instincts.

This time, most of the students answered correctly; and by working through follow-up questions, they came to the conclusion that their "instincts" this time do agree with Newton's Third Law. Elby identified the notion that "the car reacts twice as much" as a resource from which students could build their understanding. Depending on how they used this resource, the idea could contribute to a Newtonian understanding or it could pose a difficulty for that understanding.

A second example of analysis on the existence of productive resources in students' understanding can be found in the work of Clement, Brown and Zeitsman (1989). The authors noted that "not all preconceptions are misconceptions" and described "anchoring conceptions" in which student understanding typically aligns well with physicists' and how these may serve as targets of "bridging analogies" to help students apply that understanding in other contexts. A core example of this is Minstrell's (1982) strategy for helping students understand the Newtonian idea of a *passive force*, such as the force exerted upward by a table on a book. Students generally have difficulty with the idea that the table can exert a force. Asked, for example, to draw a free-body diagram for the book, students often draw a downward gravitational force but omit the upward contact force exerted by the table. Many explicitly contend that a table cannot exert a force, but rather, "gets in the way" or "blocks" the book from falling. In other words, students have difficulty understanding the table as having a causal role in the interaction, because the table seems to be an inherently passive object: how can a table "exert"?

Students do not, however, typically have that difficulty when thinking about a spring. They readily see a compressed spring as "exerting" force against its compression; they can "see" it pushing. Minstrell's (1982) strategy uses students' understanding of springs as a productive resource, the anchoring conception (Clement, Brown and Zeitsman, 1989) from which to build an understanding of passive forces. Specifically, he uses a series of bridging analogies to help students learn to see a table as an extremely stiff spring.

In sum, students possess resources for reasoning that, activated and properly used, are productive for building interpretative models of observed phenomena aligned to physicists' understanding. The task of the instructor is, then, to design teaching/learning strategies to help bring about that activation.

Conceptual and “raw” resources

Almost all teachers know, at least tacitly, that students possess resources. As a matter of fact, much of naïve instructional practice is characterized by inappropriate presumptions regarding the resources students possess. Great emphasis in much of the current physics education research literature on difficulties and misconceptions is given to design, address and debunk these presumptions; it is now clear that students do not have well-formed, prerequisite conceptions, such as of "mass," "air," "force," and "velocity," as instructors often unknowingly assume. Nor, as we have already noted, are students "tabula rasa" on which instructors can inscribe correct ideas.

However, the productive resources shortage in students, in the form naïve instructors presume, does not mean that they entirely lack productive resources. There is broad consensus in the physics education community that students "construct" new knowledge from prior knowledge; this obviously implies that students have in their prior knowledge the raw material for that construction. Nevertheless, in its emphasis on difficulties and misconceptions, physics education research has mostly overlooked the task of studying and describing this raw material.

It is to the interest both of progressing toward a theory of physics learning and of designing and implementing effective TLSs that physics education researchers come to understand the resources students bring to learning physics. Because effective instructors already have a rich, tacit sense of these resources, there is much to be gained from mining for insights embedded in their practices.

In his case study about forces and velocity variations during collisions, Elby identified students' correct answer to the second question as reflecting their "raw intuition" that "the car reacts twice as much during the collision". This raw intuition provided the material for students in building their understanding; the intuition itself is neither right or wrong: it becomes correct or incorrect in its use.

Elby's instructional strategy lead students to the idea that they can “refine” their raw intuition in one of two ways. If they apply their "car reacts twice as much" intuition to the concept of force, their reasoning leads to a contradiction with Newton's Third Law; if they apply it to the concept of velocity change, i.e. to acceleration, their reasoning is consistent with Newton's Laws.

It is well worth noting that, in this approach, the account of student cognitive and reasoning resources does not disregard knowledge of difficulties or phenomena associated with misconceptions; rather, the difficulties are classified as the tendency to misapply resources and misconceptions represent robust patterns of misapplication.

A similar view of student knowledge motivated Minstrell (1989, 1992) to coin the term "facet"; Elby's raw intuition here would constitute a facet of student understanding that students could apply productively or counter-productively. Understanding students knowledge in this way, the task for instruction becomes, in Minstrell's metaphor (1989), helping students "unravel" and "reweave" the strands of their knowledge and understanding rather than removing or replacing (mis)conceptions.

Toward a more precise model of conceptual resources

Minstrell and Elby "facet" and "raw intuition" definitions were thought to make the general notion of students' resource accessible to a broad audience, including researchers and trainee teachers. Of course, developing a model of physics knowledge and learning eventually require more precise ideas and terminology.

In 1993 diSessa presented a technically more precise model, beginning with his account of "phenomenological primitives," or "*p-prims*," as a form of cognitive structure. Following researches on artificial intelligence, attributing mental phenomena to the action of many "agents" (Minsky, 1986) acting in parallel and the metaphor of the mind as a computer, diSessa conjectured *p-prims* as one form of primitive cognitive structure, in a very similar way to the "primitives" of a given computer language called by routines and subroutines used to build a program.

To make an example, let's think about why it is hotter in the summer than in the winter. In an actual research, (Sadler, Schneps and Woll, 1989) many students answered that it is because during summer the Earth is closer to the sun. An usual interpretation attributes this response to the pupils' conception of the Earth moving in a highly eccentric ellipse around the Sun, and in some cases this may be the case. An alternative interpretation, however, is that some students do not activate the conception of the Earth orbital motion as a cause of seasons but generate the answer on the spot. Asked the question, they quickly search in their knowledge and reasoning baggage for a way to

think about it. One of the first resources they identify is the general notion that getting closer to a source increases the intensity of its effect: *Closer means stronger*.

Closer means stronger is a primary resource that can be productively activated to understand a number of phenomena: the light is more intense closer to the bulb; music is louder closer to the speaker; an odour is more intense closer to its source. Students' tendency to explain seasons in terms of proximity to the sun may be seen as a faulty activation of this resource, rather than as reflecting a faulty, previously existing conception.

diSessa's p-prims idea can give a more accurately account of Clement and Minstrell's bridging analogy. The situation of the book on the table tends to activate the primitive *Blocking*: the table blocks the book from falling. As a primitive element of student reasoning, *Blocking* needs no explanation, and its activation in this context represents a difficulty. Meanwhile, springs tend to activate *Springiness*, a primitive notion of a restoring agency acting in response to a deformation. The bridging analogy helps to activate *Springiness* to the situation of the book on the table; that activation can be reinforced by a demonstration to show the table's deformation (Minstrell, 1992). *Springiness* would cue other primitives as well, including *Maintaining Agency*, by which the students understand the deformation of the table as causing and maintaining an upward force on the book, and *Balancing* by which students see an equilibrium between the weight of the book downward and the upward force by the table. As important, these activations would tend to deactivate *Blocking*, and students have arrived at a new understanding of the book on the table.

2.4.2 “Critical Details Account”

Another interesting research line about designing TLSs can be find in some recent papers and books of Laurence Viennot (2001, 2002, 2003a, 2003b), where conditions for an effective linkage of research to pedagogic practice are extensively illustrated and discussed. Viennot's aim is to go beyond the ascertainment of the existing gap between what research recommends and the common teaching practice and to examine the ingredients of research-based sequences and some elements used to evaluate their impact on teaching practice. At each step of the process, preliminary investigations, design of a sequence, implementation and evaluation, it is argued that fine-grained analysis is

needed, with close attention to apparently small aspects of the content, the so-called “critical details”, of the students ideas and of the teaching strategies. Viennot recommends a multidimensional approach, jointly with the use of some organising tools, in particular the “lines of analysis” for the design of the sequence and the “profiles” of understanding for the evaluation. Regarding the former, several examples are given in the domain of elementary optics and mechanics to illustrate the relevance of “the spotlighting of a content”, the impact of images and experiments and analyse critically the common idea that “to see is enough to understand”. Another line of attention, i.e. to avoid fragmentation in teaching concepts and to favour various types of linkages, is especially illustrated by a sequence about “Doppler and Römer” (Viennot, 2003b). In the proposed sequence, a combined use of physical and mathematical tools of analysis is applied; the physical meaning of some characteristics of linear graphs x/t – change of origin and slope – play an essential role in simplifying the analysis of the Doppler effect, and in focusing on the relevant factors. In this way, a benefit can be expected on both grounds, mathematic and physic. Another linkage shows his benefit, facilitating the chosen approach; two phenomena, usually disconnected, come close to each other: Doppler effect and Römer’s discovery of the finite value of the speed of light. This and other examples, including a sequence about the superposition of electric fields (Viennot, 2002), suggest that, whereas is difficult to evaluate separately the impact of a given critical detail, it is likely that a “critical mass” of critical details (Viennot, 2002), necessary to really change the outcome of teaching, may have an important outcome in the developing of a TLS.

2.4.3 The role of teachers

Another aspect put in evidence by Viennot is the decisive role of teachers as “proposal transformers”. Exactly as students are not passive receivers of what they are taught, teachers are not simply passive transmitters of pedagogic intentions defined by research. Global adhesion to theories or general principles, or even strong motivation for implementing a given sequence, are not enough. More or less subtle transformations of the planned strategies, more or less explicit disregard of critical details of the sequence are likely to have decisive effects on the student’s learning. What is important is students’ conceptual progress but a research-based sequence is not a remedy sent by post and

administered by the teacher. Teachers are actors in the teaching process, their global and micro-decisions are essential factors of what happens in class. If, as Viennot argues, the aimed effects of a sequence occurs only by bringing to bear a critical mass of critical details of practice, coherently organised by a global rationale, a resonant implementation means that the teacher's role is fundamental in giving the right attention to these "details" (Viennot et al., 1999).

2.5 Designing and validating teaching-learning sequences

2.5.1 Structure and design

In the framework of "Student's Resources Knowledge" (Hammer, 2000; diSessa, 1993), difficulties generally attributed to stable beliefs may be understood in terms of counter-productive resource activations. Rather than think in terms of confronting misbeliefs, an instructor could think in terms of modifying the resources students activate. A core difference between conventional and reformed physics instruction may be in the epistemological resources the different instructional contexts tend to activate. Encouraging debates in science class for example, certainly not a new practice, may be understood as a means of helping students activate a set of epistemological resources they have available for understanding argumentation and differing points-of-view. The class may become a context in which students understand it as important to explore a variety of perspectives, as opposed to looking for the "one right way" of thinking about the issue at hand. These are resources they activate (or should!) in the contexts of debates about, e.g. politics and history, and they may be productively activated in physics as well.

Much of the benefit of innovative pedagogical approaches can be understood in these terms: They change the context in such a way as to invoke productive epistemological resources. Another example is engaging students in activities of design and construction, such as building gadgets or writing computer programs that accomplish some task. Students have resources for understanding these sorts of activities, of what it means to make something, try it, and adjust it to improve performance (Harel and Papert, 1991). That understanding may also be used to activate resources productive for learning.

In "Developmental Research", Lijnse (1994, 1995) focuses mainly on students and

secondarily on the role of the teacher; the epistemic dimensions of the knowledge to be taught are not evoked as playing a determining part in planning the didactical structure: problems are to be formulated by students, with the help of the teacher; only general indications about a progression are given by the researchers.

Both “Ingénierie Didactique” (Artigue, 1988), “Educational Reconstruction” (Kattmann et al. 1995) and “Critical Details Account” (Viennot, 2001, 2002, 2003a, 2003b) suggest precise guidelines with regard to the epistemic dimension. In “Ingénierie Didactique”, the elaboration of problems to be treated is the responsibility of the researchers, and is strongly linked to content analysis. As mentioned above, Artigue focuses on *a priori* analyses: epistemological, psycho-cognitive (conceptions and reasoning), and “didactic” (educational constraints), while little is said about psycho-affective and social aspects of teaching-learning processes. In “Educational Reconstruction” we can find also content and psycho-cognitive analysis as well as much about motivation and the social and ethic implications of the knowledge to be taught, but little discussion of educational constraints. In “Critical Details Account”, Viennot stresses the role of lines of attention to develop and of apparently small aspects of the content (“critical details”) to be taught deeply influencing the result of a TLS;. She brings also to light the importance of teachers, seen as “proposal transformers”, responsible of the “staging” of contents to develop with pupils and of the selection-emphasis made for teaching – the French “transposition didactique” (Chevallard, 1985). Great relevance is given by Viennot to teacher’s role in reaching, during pedagogic activities, a “critical mass” of critical details that can “activate” a teaching strategy, transforming it from being inactive in the direction of the designers’ expectation to effectively reaching pupils’ understanding level .

The “Developmental Research” framework appears to be more psychologically based, and the design of activities student-centred, whereas in “Ingénierie Didactique” epistemic points of view appear more explicit. “Educational Reconstruction”, “Student’s Resources Knowledge” and “Critical Details Account” can appear as taking into account quite explicitly psychosocial points of view and epistemic analyses and their interactions. We note that our remarks reflect what the authors say about the relative emphases in their frameworks, and do not imply that other aspects are ignored.

We may note that one feature that is common to all the theoretical proposals and empirical studies is on the one hand the treatment of usual scientific content as problematic in relation to the aims of instruction as perceived by the designers; on the other hand the dynamic character of developing a TLS, the features of which are further discussed in the next section. This means that designing a TLS is not a “one-shot” activity but a long-term endeavour, one product of which is often an innovative content representation, which is different from those appearing in several textbooks and curricula worldwide..

With regard to empirical works, we note that some factors could or should be more explicitly taken into consideration in the design of TLS. This is the case for educational constraints, which are rarely explicitly managed or, at least reported, (Tiberghien, 1996). In other words, we argue that researchers should make public the craft handling of contextual factors and particularly educational constraints. We believe that this is a difficult endeavour bearing on the feasibility of TLS beyond small scale innovation. Besides, this is also the case for managing social interactions in the classrooms a factor that only recently has started to be taken into account explicitly in the design of TLS (Dumas-Carré and Weil-Barais 1998, Leach and Scott 2002).

2.5.2 Validation: some trends

Various kinds of validation appear to be possible when utilising a sequence as a teaching and/or research tool,. Some methodological approaches aim at evaluating the effectiveness of a sequence by comparing the students’ cognitive “ final state ” to their cognitive “ initial state ”. Other methodological approaches illuminate students’ cognitive pathways all through the teaching-learning process.

Pre-test/ Post-test procedures

The methodology often adopted tends to prove the effectiveness of a teaching "package" in relation to specific learning objectives. Data can be collected in form of "tests" after the sequence. The effectiveness of such an approach can be found in comparing these results with those obtained by the same pupils before the sequence (sometimes called "internal" evaluation) or by those of a group of pupils judged to be of the same level and who have not attended the same sequence (sometimes called "external" evaluation). The first objectives of internal evaluations are to test the

effectiveness of the sequence in relation to the initial objectives (cf. for example Thiis 1992; Mortimer 1993; Andersson and Bach 1996; Asoko 1996; Boohan 1996). The “external” evaluations let us ascertain that, in relation to our objectives, work done together with the pupils is more effective than other types of teaching taken as reference (cf. for example Minstrell, 1992; Nikolopoulou, 1993; Ravanis and Papamichael, 1995; Kariotoglou, Koumaras and Psillos 1995; Psillos, 1998; Chang and Barufaldi, 1999).

Internal or external evaluations have also been used to characterise the relative "difficulty" of a given objective. Thus, Tiberghien and Barboux (1983) concluded, after a sequence, that the notion of thermal equilibrium proves difficult to acquire in the junior secondary school years, although the fact that the temperature does not vary when there is a change of state proves to be less of a problem. Later, F. Chauvet tried to characterise the "obstacles and persistent difficulties" at the end of a teaching sequence on colour, "persistence of the common conception of colour as matter" and "fragility of the conceptualisation of coloured light" (Chauvet 1994, p. 179). Conceptual profiles can be considered as fruitful evaluation tools in this perspective (Viennot and Ranson, 1999).

Such types of evaluation lead to the following questions:

- Some cognitive objectives prove to be easy or difficult to reach, but can such results be considered as general and independent of the conditions in which they have been obtained?
- Which choices in the design of the learning situations are determinant for the effectiveness of the learning-process? What actually “makes the difference” in the gap between usual types of teaching and experimental teaching.?

Here we encounter problems relating to the control of variables and the reproducibility of experimental teaching. If these questions have been the object of pedagogic studies in mathematics (Brousseau 1981; Artigue 1988), it seems that they are latent in physics and chemistry education. In the last few years they have appeared in declarative rather than operational form in international publications in physics education. Thus, Hewson and Thorley (1989) remark that if the model of "conceptual change" has been set in motion in numerous teaching sequences, the data thus gathered was not sufficient to discuss the role played by the specific factors considered as essential in putting into effect this model. The precautions taken by certain authors in presenting their conclusions show that they share these preoccupations. Thus S. Johsua and J.J. Dupin bet on the reproducibility of

their observations (Johsua and Dupin 1989, p. 201), whereas S. Rainson leaves the issue open (Rainson 1995, p. 152). B. Andersson and F. Bach (1996) formulate the problem clearly in relation to their own experiments: "There is, however, one question that the improved design does not answer. Which aspects of the teaching were particularly important, and which were less important, with reference to achieving the observed result?" (p. 18).

Studying learning pathways

Another type of approach that has gained prominence in science education research consists in observing pupils all throughout the learning process. This seems indispensable if we want the study of the learning processes to be focused and to test the choices made in the elaboration of specific teaching-learning situations.

We can find this preoccupation in some early studies (see, for example, Méheut 1982; Tiberghien and Barboux 1983, Séré 1985) which included observations, collected as manipulation memos and written answers to teachers' questions or tests. Such an initial preoccupation is further elaborated in more recent works in terms of the description of cognitive itineraries, conceptual pathways or learning pathways (see for example Duit, Goldberg and Niedderer 1992 (Part 3); Arnold and Millar 1996; Petri and Niedderer 1998; Welzel 1998; Aufschnaiter and Welzel 1999; Psillos and Kariotoglou 1999; Galili, 1996, Niedderer, 1997)

In addition to the overall evaluation of a sequence, detailed analyses of students' learning pathways can be used to discuss the effectiveness of a specific learning situation, to test hypotheses underlying the design of the learning situations and to improve them. For example, a detailed analysis of a student's learning pathway allows Schwedes and Schmidt (1992) to discuss the reality of expected cognitive conflicts and to bring to light some unexpected difficulties encountered in developing an analogy between hydraulic and electric circuits; Psillos and Kariotoglou (1999) traced the various learning pathways of students who were engaged in a teaching sequence in fluids, and thus accounted for their differential reaction to a conflict situation. We find similar kinds of results in Arnold and Millar (1996), regarding the use of an analogy in the teaching of heat, temperature and thermal equilibrium, and in Duit et al. (1998), regarding the use of an analogy in a unit on chaotic systems. Such research works present some characteristics of what Lijnse (1994) defined as "developmental research": data analysis makes it possible to

discuss and improve the effectiveness of teaching-learning strategies (see for instance the evolution of strategies between Schwedes and Schmidt 1992 and Schwedes and Dudeck 1996).

Interview analysis

Another way to test hypotheses underlying the design of the learning situations, to improve them and to validate a teaching/learning pathway is to study its effectiveness by interviews with students actually participating to the various TLP's phases. According to Marton (1981), a way to approach questions about learning is to analyse people's ideas or experiences of the world. We will discuss this methodology in section 3.3, where we will take into account the Phenomenographic approach to study the different ways in which people experience, interpret, understand, perceive or conceptualise a phenomenon or experienced activities, as the participation to the various phases of a TLP .

3. Research methods

Our research, that will be discussed in details in chapters 5 and 6, adopts qualitative as well as quantitative research methods. It is based on the ‘Case Study’ approach (Stake, 1995, 2000) and data are mainly analysed using a phenomenographic approach (Marton, 1981, 1986, 1988; Marton and Both, 1997).

This chapter reports some literature review based on well known scientific papers, widely available also on the world wide web, due to James Neill¹, Winston Tellis², Donna M. Zucker³ and MaryKay Orgill⁴. First, the main aspects of qualitative and quantitative research methods are discussed and their main characteristics, differences and similarities are analysed. Then, the Case Study method is described and the meaning of the phenomenographic approach to qualitative research is discussed by evidencing points of strength and also some criticisms .

3.1 Qualitative and quantitative research

Research in behavioural sciences can be roughly divided in two categories, related to two different paradigms in social research: the positivistic (or neo-positivistic) and the interpretative one. The quantitative research approach can be considered representative of the first category: its main hypotheses are that social facts have an objective reality and variables influencing them can be identified and relationships measured. Qualitative research methods, on the other hand, are representative of the second category, and their assumptions are that reality is socially constructed and variables describing it are complex, interwoven, and difficult to measure.

Qualitative researchers are mainly concerned with the description of a process in a context. No attempt is made to assign frequencies to the features which are identified in the data, and rare phenomena receives the same amount of attention as more frequent phenomena. Qualitative analysis allows to draw fine distinctions because it is not

¹ <http://www.wilderdom.com/research/QualitativeVersusQuantitativeResearch.html>

² <http://www.nova.edu/ssss/QR/QR3-2/tellis1.html>

³ <http://www.nova.edu/ssss/QR/QR6-2/zucker.html>

⁴ <http://chemed.chem.purdue.edu/chemed/bodnergroup/frameworks/phenography.htm>

necessary to shoehorn the data into a finite number of classifications. Ambiguities, which are inherent in human language, can be recognised in the analysis.

The main disadvantage of qualitative approaches to data analysis is that their findings can not be extended to wider populations with the same degree of certainty that quantitative analyses can. This is because the findings of the research are not tested to discover whether they are statistically significant or due to chance.

In quantitative research we classify features, count them, and even construct more complex statistical models in an attempt to explain what is observed. Findings can be generalised to a larger population, and direct comparisons can be made between two data sets, so long as valid sampling and significance techniques have been used. Thus, quantitative analysis allows us to discover which phenomena are likely to be genuine reflections of a variety of behaviours, and which are merely chance occurrences. The more basic task of just looking at a variety allows one to get a precise picture of the frequency and rarity of particular phenomena, and thus their relative normality or abnormality.

The picture of the data which emerges from quantitative analysis is less rich than that obtained from qualitative analysis. For statistical purposes, classifications have to be of the hard-and-fast (so-called "Aristotelian" type). An item either belongs to class x or it doesn't. Quantitative analysis is therefore an *idealisation* of the data in some cases. Also, quantitative analysis tends to sideline rare occurrences. To ensure that certain statistical tests (such as chi-squared) provide reliable results, it is essential that minimum frequencies are obtained - meaning that categories may have to be collapsed into one another resulting in a loss of data richness.

Moreover, another issue in quantitative research is the problem of the *validity* of methods used in it, i.e. the question of whether the researcher is actually measuring what he/she says he/she wants and the problem of the *reliability*, a value indicating the internal consistency of a measure or the repeatability of a measure or finding, the extent to which a result or measurement will be the same value every time it is measured.

We can distinguish some different types of validation of tests and/or research methods, amongst which we recall:

- *Content validity*, also called *logical validity*. It is an estimate of how representative the test items are of the content of related subject matter. The

implicit assumption (and the main difficulty of this validation) stay in the fact that content experts are the one deputed to judge whether or not the test is measuring that which it purports to measure.

- *Construct validity.* It is a measure of argument-relevant characteristic (e.g., reasoning ability) and the extent to which a test measures the hypothetical trait (construct) it is intended to measure. Methods for establishing construct validity include correlating test scores with scores on measures that do and do not measure the same trait; conducting a factor analysis to assess the test’s factorial validity; determining if changes in test scores reflect expected developmental changes; and seeing if experimental manipulations have the expected impact on test scores.

Table 3.1 resumes some fundamental features of qualitative and quantitative research:

Table 3.1
Fundamental features of qualitative and quantitative research

Qualitative	Quantitative
"All research ultimately has a qualitative grounding". - Donald T. Campbell (*)	"There's no such thing as qualitative data. Everything is either 1 or 0". - Fred Kerlinger (*)
The aim of qualitative analysis is a complete, detailed description.	In quantitative research we classify features, count them, and construct statistical models in an attempt to explain what is observed.
Recommended during earlier phases of research projects.	Recommended during latter phases of research projects.
Researcher may only know roughly in advance what he/she is looking for.	Researcher knows clearly in advance what he/she is looking for.
The design emerges as the study unfolds.	All aspects of the study are carefully designed before data is collected.
Researcher is the data gathering instrument.	Researcher uses tools, such as questionnaires or equipment to collect numerical data.
Data is in the form of words, pictures or objects.	Data is in the form of numbers and statistics.
Qualitative data is more “rich”, time consuming, and less able to be generalized.	Quantitative data is more efficient, able to test hypotheses, but may miss contextual detail.

Researcher tends to become subjectively immersed in the subject matter.	Researcher tends to remain objectively separated from the subject matter.
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(*) Quotes are from Miles and Huberman (1994, p. 40). *Qualitative Data Analysis*

Miles and Huberman's book quotation of Kerlinger's and Campbell's positions about qualitative and quantitative research is followed by the consideration that this back and forth banter among qualitative and quantitative researchers is "essentially unproductive". They and many other researchers agree that these two research methods need each other more often than not. However, because typically qualitative data involves words and behaviours and quantitative data involves numbers, there are some researchers who feel that one is better (or more scientific) than the other. Another major difference between the two is that qualitative research is inductive and quantitative research is deductive. In qualitative research, a hypothesis is not needed to begin research. However, all quantitative research requires a hypothesis before research can begin.

However, the main difference between qualitative and quantitative research is the underlying assumptions about the role of the researcher. In quantitative research, the researcher is ideally an objective observer that neither participates in nor influences what is being studied. In qualitative research it is thought that the researcher can learn the most about a situation by participating and/or being immersed in it. These basic underlying assumptions of both methodologies guide and sequence the types of data collection methods employed.

Some researchers believe that qualitative and quantitative methodologies cannot be combined because the assumptions underlying each tradition are so vastly different. Other researchers think they can be used in combination only by alternating between methods: qualitative research is appropriate to answer certain kinds of questions in certain conditions and quantitative is right for others. More, some researchers think that both qualitative and quantitative methods can be used simultaneously to answer a research question.

To a certain extent, researchers on all sides of the debate are correct: each approach has its drawbacks. Quantitative research often "forces" responses or people into categories that might not "fit" in order to make meaning. Qualitative research, on the other hand, sometimes focuses too closely on individual results and fails to make

connections to larger situations or possible causes of the results. Rather than discounting either approach for its drawbacks, though, researchers should find the most effective ways to incorporate elements of both to ensure that their studies are as accurate and thorough as possible. We mainly conform to this idea and we will actually use qualitative and quantitative methods to gain the most information and try to make sense of our data.

We believe that it is important for researchers to realize that qualitative and quantitative methods can be used in conjunction with each other. In a study of computer-assisted writing classrooms, Snyder (1995) employed both qualitative and quantitative approaches. The study was constructed according to guidelines for quantitative studies: the computer classroom was the "treatment" group and the traditional pen and paper classroom was the "control" group. Both classes contained subjects with the same characteristics from the population sampled. Both classes followed the same lesson plan and were taught by the same teacher in the same semester. The only variable used was the computers. Although Snyder set this study up as an "experiment," she used many qualitative approaches to supplement her findings. She observed both classrooms on a regular basis as a participant-observer and conducted several interviews with the teacher both during and after the semester. However, there were several problems in using this approach: the strict adherence to the same syllabus and lesson plans for both classes and the restricted access of the control group to the computers may have put some students at a disadvantage. Snyder also notes that in retrospect she should have used case studies of the students to further develop her findings. Although her study had certain flaws, Snyder insists that researchers can simultaneously employ qualitative and quantitative methods if studies are planned carefully and carried out conscientiously.

3.2 Using Case Study methodology in Research

The history of case study research is marked by periods of intense use and periods of disuse. The earliest use of this form of research can be traced to Europe, predominantly to France and the field of sociology was the most strongly associated with case study research methodology.

There are multiple definitions and understandings of the case study. According to Bromley (1990), it is a "*systematic inquiry into an event or a set of related events which*

aims to describe and explain the phenomenon of interest". The unit of analysis can vary from an individual to a corporation. While there is utility in applying this method retrospectively, it is most often used prospectively. Data come largely from documentation, archival records, interviews, direct observations, participant observation and physical artefacts (Yin, 1994).

Case studies often involve in-depth interviews with participants and other key personnel (for example, experienced people conducting activities regarding the study), review of the participants' produced materials (worksheets, personal writings, diaries), observation. Case studies have a practical function in that they can be immediately applicable to the participants' diagnosis or treatment.

According to Stake (1995) the case study researcher may be somewhat of a biographer focused on a phase or segment of the life of an individual. Various contemporary reports in psychology (Bromley, 1986), sociology (Yin, 1994), and education (Stake, 1995) have studied the individual as the unit of analysis, and have used the case study method to develop rich and comprehensive understandings about people.

The literature contains numerous examples of applications of the case study methodology. The earliest and most natural examples are to be found in the fields of Law and Medicine, where "cases" make up the large body of the student work. However, there are some areas that have used case study techniques extensively, particularly in government and in evaluative situations. The government studies were carried out to determine whether particular programs were efficient or if the goals of a particular program were being met. The evaluative applications were carried out to assess the effectiveness of educational initiatives. In both types of investigations, merely quantitative techniques tended to obscure some of the important information that the researchers needed to uncover.

The body of literature in case study research is "primitive and limited" (Yin, 1994), in comparison to that of experimental or quasi-experimental research. The requirements and inflexibility of the latter forms of research make case studies the only viable alternative in some instances. It is a fact that case studies do not need to have a minimum number of cases, or to randomly "select" cases. The researcher is called upon to work with the situation that presents itself in each case.

Case studies can be single or multiple-case designs, where a multiple design must follow a replication rather than sampling logic. When no other cases are available for replication, the researcher is limited to single-case designs. Yin (1994) pointed out that generalization of results, from either single or multiple designs, is made to theory and not to populations. Multiple cases strengthen the results by replicating the pattern-matching, thus increasing confidence in the robustness of the theory.

As a final, important, note, case study evaluations can include both quantitative and qualitative data and can, then, cover both process and outcomes.

3.2.1 Case Study types

There are several examples of the use of case methodology in the literature. Yin (1993) listed several examples along with the appropriate research design in each case. There were suggestions for a general approach to designing case studies, and also recommendations for *exploratory*, *explanatory*, and *descriptive* case studies. Each of those three approaches can be either single or multiple-case studies. There were also specific examples in education, where the method has been embraced for instructional use.

In *exploratory* case studies, fieldwork and data collection may be undertaken prior to definition of the research questions and hypotheses. This type of study has been considered as a prelude to some social research. However, the framework of the study must be created ahead of time. Pilot projects are very useful in determining the final protocols that will be used. Survey questions may be dropped or added based on the outcome of the pilot study.

Explanatory cases are suitable for doing causal studies. In very complex and multivariate cases, the analysis can make use of pattern-matching techniques. An explanatory study is described, for example, by Yin and Moore (1987), where the reasons why some research findings get into practical use are examined.

Descriptive cases require that the investigator begin with a descriptive theory, or face the possibility that problems will occur during the project. What is implied in this type of study is the formation of hypotheses of cause-effect relationships. Hence the descriptive theory must cover the depth and scope of the case under study. The selection of cases and the unit of analysis is developed in the same manner as the other types of case studies.

Case studies have been increasingly used in education. While law and medical schools have been using the technique for an extended period, the technique is being applied in a variety of instructional situations. Schools of business have been most aggressive in the implementation of case based learning, or "active learning" (Boisjoly and DeMichiell, 1994). Harvard University has been a leader in this area, and cases developed by the faculty have been published for use by other institutions. The School of Business at Fairfield University has revised the curriculum so that in place of the individual longitudinal courses in the areas of Management, Marketing, Operations, Finance, and Information Systems, students take one course. That course is designed around cases that encompass those disciplines, but are presented in an integrated manner. The students are therefore made aware of the interrelatedness of the various disciplines and begin to think in terms of wider problems and solutions. Later courses add the international dimension to the overall picture.

3.2.2 Case Study design and analysis

According to Yin (1994) the case study design should include five main components: the research question(s), its propositions, its unit(s) of analysis, a determination of how the data are linked to the propositions, and criteria to interpret the findings Yin concluded that operationally defining the unit of analysis assists with replication and efforts at comparison.

Stake (1995) emphasize that the number and type of case study depend upon the purpose of the inquiry: an instrumental case study is used to provide insight into an issue; an intrinsic case study is undertaken to gain a deeper understanding of the case; and the collective case study is the study of a number of cases in order to inquire into a particular phenomenon. Stake recognizes that there are many other types of case studies based on their specific purpose, such as the teaching case study or the biography. Feigin, Orum and Sjoberg (1991) state that irrespective of the purpose, unit of analysis, or design, rigor is a central concern. They suggest that while proponents of multiple case studies may argue for replication, using more than one case may dilute the importance and meaning of the single case.

Method and analysis occur simultaneously in case study research. Specifically, data collection and analysis occur as an iterative process, wherein the researcher moves

between the literature and field data and back to the literature again. Contributions to the case study literature coming from three major sources have informed this work. Yin (1994) offers a very straightforward protocol approach for case study, emphasizing field procedures, case study questions, and a guide for the final write up. Yin claims such steps are a major tactic in increasing the reliability of the research endeavour. Similarly Stake (1995) has proposed a series of necessary steps for completing the case method, including posing research questions, gathering data, data analysis and interpretation. A remarkable distinction is Stake's emphasis on a more naturalistic approach, the importance of the philosophical underpinnings of case method, and the importance of the description of contexts.

Guba and Lincoln (1981) emphasize that reporting of results and interpreting findings stem from purposeful activities that fit into a taxonomy of case study types. These types are factual, interpretative and evaluative. Each case study must outline the purpose, then depending on the type of case study and the actions proposed by the researcher, the researcher could determine the possible products of the study. For example, research undertaken to describe the experiences of men living with chronic diseases could be placed in both factual and interpretative categories. The researcher's actions include recording; constructing and presenting; producing a chronicle, a profile, or facts. Additionally the researcher is construing; synthesizing and clarifying; producing a history, meanings, and understandings. Such influences helped to form the following stages of this case study method.

3.3 The Phenomenographic approach to data analysis

Phenomenography is an empirical research tradition that was designed to answer questions about thinking and learning, especially in the context of educational research (Marton, 1986). It is concerned with the relationships that people have with the world around them. The word "phenomenography" has Greek etymological roots. It is derived from the words "phainomenon" (appearance) and "graphein" (description). Thus, phenomenography is a "description of appearances" (Hasselgren and Beach, 1997).

3.3.1 Aims of Phenomenographic Research

According to Marton (1981), a way to approach questions about learning is to take into account the analysis of people's ideas or experiences of the world. Phenomenography is this kind of approach. Its aim is to define the different ways in which people experience, interpret, understand, perceive or conceptualise a phenomenon, or certain aspect of reality.

Different people will not experience a given phenomenon in the same way. Rather, there will be a variety of ways in which different people experience or understand that phenomenon. "Phenomenographers" seek to identify the multiple conceptions, or meanings, that a particular group of people have for a particular phenomenon. As a consequence, the conceptions of the researcher for that phenomenon are not usually a focus of such a study. Instead, the researcher attempts, as much as possible, to act as a "neutral foil" for the ideas expressed by the participants of the study.

Marton (1981, 1994) believes that there are a limited number of qualitatively different ways in which different people experience a certain phenomenon. From this theoretical stance, it is irrelevant if those conceptions are considered "correct" or "incorrect" by current standards. The aim is simply to elucidate the different possible conceptions that people have for a given phenomenon.

The main results of phenomenographic research are "categories of description" of the various conceptions of a phenomenon. Phenomenographic research is more than simply reporting these different conceptions, however. It involves identifying the conceptions *and* looking for their underlying meanings and the relationship between them (Entwistle, 1997). Marton (1981) makes the following statement about this additional goal of phenomenography:

"Still, we are able to point not only to conceptions making up its constituents but also to relations between certain conceptions of one aspect of the world and certain conceptions of another aspect. What we have in mind is certainly not merely a listing of one conception after another. Some aspects are certainly more basic than others and different (and more or less fundamental) layers of the perceived world can be revealed." (p. 190) "

Marton (1994) also says that the different ways of experiencing different phenomena or concepts are representative of different capabilities for dealing with those phenomena

or concepts. Some ways of dealing with phenomena or concepts are more productive than others. Thus, the conceptions, or “ways of experiencing”, and their corresponding descriptive categories can not only be related, but also be hierarchically arranged. The ordered and related set of categories of description is called the “outcome space” of the concept being studied.”

Although phenomenography makes no assumption about the nature of reality, it does make assumptions about the nature of conceptions. The primary assumption is that conceptions are the product of an interaction between humans and their experiences with their external world. Specifically, conceptions results from a human being’s thinking about his or her external world. An assumption that is extremely important to phenomenographic research is that a person’s conceptions are accessible in different forms of actions, but particularly through language (Svensson, 1997).

3.3.2 Methods of Phenomenography and applicability in education

In order to discover the different ways in which people understand or experience certain natural or social phenomena, phenomenography uses particular methods, usually based in the social sciences research on open, deep interviews (Booth, 1997).

With respect to the interview method, “open” indicates that there is no definite structure to the interview itself; while researchers may have a list of questions or concerns that they wish to address during the interview, they are also prepared to follow any unexpected lines of reasoning that the interviewee might address as some of these departures may lead to fruitful new reflections that could not have been anticipated by the researcher. “Deep” indicates that the interview will follow a certain line of questioning until it is exhausted, until the participant has nothing else to say and until the researcher and participant have reached some kind of common understanding about the topics of discussion.

The aim of an interview is to have the participant reflect on his or her experiences and then relate those experiences to the interviewer in such a way that the two come to a mutual understanding about the meanings of the experiences (or of the account of the experiences).

In the field of education, analysis of open questionnaires and worksheets and records of peer to peer discussions during specific activities are also widely used. In this context,

data acquired using these methods can be useful to gain information about the different types of procedures used by people to make sense of real life experiences and to build models of explanation for them. In particular, in teacher education this kind of data may also help the researcher to explore about the acquired competencies in transforming the “theoretical” physics knowledge in a knowledge useful for teaching.

3.3.4 Data analysis

During data analysis, the researcher will identify qualitatively distinct *categories* that describe the ways in which different people experience a different concept. Phenomenographers believe that a limited number of categories are possible for each concept under study and that these categories can be discovered by immersion in the data, which, in most cases, are transcriptions of the interviews (Booth, 1997).

The researcher examines the transcripts of several participants’ interviews, looking both for similarities and differences among them. In this process, the researcher develops initial categories that describe different people’s experiences of the given phenomenon. If the interview has covered multiple topics or multiple aspects of a given phenomenon, the researcher will attempt to develop an “outcome space” for each topic. The only ground rules for category development are internal consistency and parsimony, or finding an “outcome space” that includes the minimum number of categories which explain all the variations in the data.

With these initial categories in mind, the researcher re-examines the interview transcripts to determine if the categories are sufficiently descriptive and indicative of the data. This second review of the data results in modification, addition, or deletion of the category descriptions and a third examination of the data for internal consistency of the categories of description. This process of modification and data review continues until the modified categories seem to be consistent with the interview data. Marton (1986) says that

“definitions for categories are tested against the data, adjusted, retested, and adjusted again.? There is, however, a decreasing rate of change, and eventually the whole system of meanings is stabilized” (p. 43).

Once a stable “outcome space” has been defined, the researcher attempts to develop as deep as possible an understanding of what has been said, or rather, what has been

meant (Marton, 1994, p. 4428). To do this, he needs to consider not only specific categories of description, but also how the individual categories relate to each other and how one person's conceptions compare across different topics.

3.3.5 Criticisms of Phenomenography

One of the criticisms of phenomenography is its tendency to equate students' experiences with their *accounts* of those experiences, as Marton (1994) evidences by stating that conceptions, the focus of phenomenographic studies, are "ways of experiencing". Saljo (1997) reports that, at times, there appears to be a discrepancy between what researchers observe of a participant's experience with a particular phenomenon and how the participant describes his experience with the phenomenon. Richardson (1999) claims that phenomenographers do not sceptically examine the effects of the interview environment or of socially accepted linguistic practices on what is reported by the students.

In order to avoid equating experiences with accounts of experiences, Saljo (1997) suggests that we refer to studying people's different "accounting practices" of phenomena, which are public and accessible to study, instead of referring to studying people's "experiences". We must keep in mind, however, that such accounting practices may be socially and environmentally influenced (i.e. the student might say what he thinks the interviewer wants to hear, etc.).

It may be true that people's accounts of their experiences with a particular phenomenon are not equivalent to the ways in which they experience the phenomenon. However, the only way we can begin to understand the ways in which people experience a given phenomenon is to ask each person to describe his or her experience. There is no physical way to examine a person's brain to obtain this data. We, as researchers, can make observations of what people experience, but those observations will not tell us *how* they experience a given particular phenomenon, especially if we accept the idea that conceptions, or ways of experiencing, are products of an interaction between the person and the phenomenon he experiences. Phenomenographic results may not be "truth", in that they may never accurately describe "ways of experiencing", but they may be useful. So, then, it may not matter if accounts are equivalent to experience.

One of Webb's (1997) main critiques of researchers using phenomenography is their assumption that they *can* be "neutral foils" while analysing research data. It is more reasonable to assume that researchers have had certain experiences and hold certain theoretical beliefs that will influence their data analysis and categorization. Webb calls for researchers to make their backgrounds and beliefs explicit, not because having these backgrounds and beliefs is "bad", but rather because the readers and users of phenomenographic research need to be informed about all variables that have potentially affected the study results. Our opinion is that such self-examination may lead to additional insights into the data and, to some extent, a more critical examination of how the researcher's own beliefs have affected the research and the results of this research.

Other researchers have questioned the reliability and repeatability of phenomenographic studies. On issues of reliability, Marton (1986) says that it *is* possible that two different researchers would discover different categories of description while working on the same data individually. However, once the categories have been found, they must be described in such a way that all researchers can understand and use them. Marton compares this process to botanists that discover a new plant species on an island. If the new species does not appear to fit into already existing category, the botanist must develop a new category of classification for it, and it is highly probable that a separate botanist would develop a qualitatively different category for that new species. However, once the botanist has developed and described a category, the category is now accessible and available for classifying plants that any botanist finds. Indeed, once the category is developed and described, it becomes useful to others who use the results of the study.

3.3.6 Potential educational benefits of Phenomenographic Research

There are certain benefits to using the results of phenomenographic research in a higher education institution. At this level of instruction, students are generally encouraged to develop conceptual understandings (Entwistle, 1997, Sperandeo-Mineo et al., in press). It is often the goal of teachers to help their students develop conceptions that are consistent with those held by recognized experts in various fields. However, students often have multiple different conceptions for a phenomenon that are not necessarily consistent with the conceptions held by experts. Marton (1986) claims that

“a careful account of the different ways people think about phenomena may help uncover conditions that facilitate the transition from one way of thinking to a qualitatively better perception of reality” (p. 33).

Thus, phenomenographic information about the different conceptions that students hold for a particular phenomenon may be useful to teachers who are developing ways of helping their students experience or understand a phenomenon from a given perspective. Another possible benefit of phenomenographic research is that students may become conscious of contradictions in their own reasoning and become more open to alternative ideas as they reflect on their perceptions and understandings of their world experiences (Marton, 1986).

4. Relevant points in previous research about Thermal Processes

Researches on learners' conceptions about thermal processes usually concentrate on heat and temperature concepts and study common interpretations of phenomena like heating, cooling, thermal contact and equilibrium. Arguments like these are familiar to people, as terms as heat, temperature, energy and the like are, in general, commonly used in our normal-life language. Yet, ideas really different from the scientifically accepted ones are easily found when exact definitions for these concepts and/or a clear difference between them are searched for.

A lot of research findings discuss about typical conceptions regarding thermal phenomena held by school pupils in grades varying from primary to secondary education, before, during or after teaching, with a particular stress, in the latter case, upon the difficulties that remain after teaching (see, for example, Erickson 1985; Tiberghien 1984, 1985). Here we report some of these ideas and conceptions that we find relevant for the development of a TLP on the subject of thermal processes aiming to secondary school teacher preparation.

4.1. The ideas of heat and temperature

One of the first researches in this field has been developed by Erickson (1979, 1980), who investigated the conceptions about heat and temperature nature in children in the six-thirteen years range. The research was developed by using a Piaget-style interview format and the common questions posed to children participating to the research were about:

- volume variation of a liquid in thin tubes placed in water at different temperatures;
- heating and cooling rates of objects made of different matters, initially at the same temperature;

- heat transmission through a conductive septum in a Plexiglas container and the prevision of the final temperature when the septum is removed;
- heat conduction mechanism in a solid body.

Typical responses gave evidence about confusion between heat and temperature resembling the caloric model and the idea that two types of heat do indeed exist: a hot and a cold one:

Heat is like a wave going forward in a road. It is like smoke

Hot substances contain smoke and, when cooling, this smoke gradually goes into air

There are two types of heat: hot and cold:

Cold heat is more powerful and can move faster than hot

Cold seems different from hot, but I cannot explain why

A body's temperature is based on the smoke quantity the body contains

An object cools down when some of its heat is given away as smoke

The great majority of pupils participating to the interviews showed personal models about heat and temperature connecting heat to something “hot” (smoke, in the pupils answers to interviews), making the temperature of other bodies grow when absorbing the “hot”. As Erickson (1985) wrote, this something is equated either with a kind of substance given off by a heat source or with a hot body.

Changing the age of pupils, in some aspects the situation did not change in a great extent. The following are class of responses obtained during a study concerning twelve–sixteen year-old pupils asked to "say in a couple of sentences what heat is" (Engels 1982):

"Heat is warm air";

"Heat is a warming fluid or solid... when you touch it, it feels hot-if anything has got the heat in it".

It is interesting to note that about 30% of the older pupils in this study still gave these types of responses, in contrast with the rest of them for which "heat" is defined in terms

of energy and transfer: "Heat is energy; when it heats something up it will transfer the heat energy to what is heating up."

According to Erickson (1985), "up to the age of 12-13, pupils are familiar with the term temperature and are able to use a thermometer to assess the temperature of objects, but they actually have a fairly limited concept of the term and rarely use it spontaneously to describe the condition of an object". And, taking into account the classic problem of the difference between heat and temperature, when students were asked directly about this point, "the most common type of response (accounting for more than 25% at all age levels) is that there is no difference between them". Other typical responses are reported (Engels 1982, Wisser and Amin, 2001) in which temperature seems to be either "a measurement of heat", the "degree of heat" or "the effect of heat" and heat seems to be a mysterious non-material entity, with the essential property of *hotness*, that can propagate in substances:

"Temperature is the amount of heat in that space...it tells you the hotness of the water"

"A hot plate on a warm setting emits less intense heat than a hot plate on a high settings"

(When asked to envision a piece of steel on a hot plate) *"Heat spreads through the steel piece because it is pushed by the incoming heat from the hot plate"* .

4.2. The analysis of thermal phenomena

Here, a common researchers' line is to focus attention on children's comments and predictions concerning phenomena involving heat and temperature, rather than on purely declarative aspects of knowledge. From a physicists' point of view, phenomena put into play in these studies can be classified in two types (Viennot, 1997) : a "restricted category", where a transfer of heat causes only the variation of mean particles kinetic energy, and changes of state, where a transfer of heat influences potential energy of particles and not necessarily gives a change of temperature .

4.2.1 "Restricted category" phenomena

In the "restricted category" the fundamental point is the experimental fact that all objects in prolonged contact reach the same final temperature. Notably, this idea, obvious to physicists, is not so obvious to pupils, even after specific pedagogic activities. Researchers report on some answers that seem to deny the existence of a thermodynamic equilibrium between the objects involved.

As an example, the spontaneous model about the existence of two different types of heat – hot and cold – is relatively common. A typical experiment to test this conception utilizes some objects, made of different substances (metal, wood, plastic, paper, polystyrene), in thermal equilibrium with an environment; it is asked to participants to touch the objects, say if they have the same temperature and, if not, try to give a rough estimate of the temperature difference between the warmest and the coolest object touched. Typical answers to this test proposed to ten-sixteen years old pupils (Tiberghien, 1984), individuate metals as the coolest objects in the group and differences between "the coolest" and "the warmest" object are easily set in a couple of degrees or more.

Even after teaching, when asked if a metal and a plastic plates, placed in the same room since a long time, are at the same temperature, most of pupils seem to believe that this is not the case (Engel-Clough and Driver 1985). Tiberghien (1985) also reports that "different materials (flour, nails, water) placed for several hours in an oven at 60° C are at different temperature for the majority of pupils. Typically, flour is at less than 60° C because "flour does not heat up very much", nails are at more than 60° C because "iron heats faster", and water is at 60° C because "it takes the temperature of the surroundings".

Similarly, it is not immediate for the pupils to clearly state that, normally, heating a substance will result in an increase of the substance's temperature. Thus, still quoting Tiberghien, "before teaching, only about a third of the pupils think that the temperature of sand, sugar and water increases when they are heated. Many of them predict that sand will not be hot "because sand cannot heat", whereas water can heat up. For them, the ability to be heated is a "*natural*" property of particular substances. After teaching, more than 50 per cent of the pupils recognized that the temperature of these three substances increases when they are heated, but it remains a difficult concept for them."

On the other hand, these difficulties are not evident if homogeneous mixtures of liquids are considered; in this case it is well understood by pupils that a unique final

temperature exists. However, the problem shifts on the qualitative or quantitative prediction about this final value. Various investigations were performed (Stavy and Berkovitz 1980, Driver and Russel 1981, Strauss 1981, Engels 1982), regarding mixing experiments with amounts of water at same or different initial temperature. In both cases, qualitative and quantitative predictions were asked. The case of identical initial temperatures are seen as easier to cope with, and quantitative questions are more difficult than qualitative ones. Strategies consisting of adding or subtracting the initial temperatures are still observed at the age of 16 (Engels 1982).

Some more questions arise on which materials are good for the thermal insulation of different objects. To produce a correct answer in this case, one needs to consider a property of a given material - being a good or a bad conductor - with a focus on the idea of transfer between two other systems. This idea of transfer unfortunately has to confront itself with the difficult (because hard-wired with common life experience) issue of tactile sensations produced by various materials at same temperature.

Not surprisingly, most of pupils' explanations for such problems rely on a property of the material. But in many of these, the property of the object is asymmetrically linked to one or the other of the categories "hot" or "cold", as if a particular situation had been used to ascribe an intrinsic link between the material and one particular end of the hot-cold continuum.

Most of these explanations seem to take into account the material under consideration and only one of the other involved systems: the body to be insulated or ambient air, with or without the mediation of "heat". Tiberghien (1985) quotes some examples of such explanations:

(to insulate a cold ball bearing), "*the aluminium keeps cold better*" (11 year-old);

(to insulate a hot drink), "*the glass wrapped in cloth will be hotter than the others since it is wrapped in cloth*" (11 year-old);

"*metal cools things, metal is cool*" (12 year-old);

"*I think that (metal) will keep (the ice) frozen most easily, because that (cotton) is hotter and keeps the heat better*" (12 year-old).

Indeed, these explanations are predominant before teaching and can be gradually replaced, after teaching, by others which suggest no asymmetry with respect to "hot" and "cold", such as (Tiberghien, *ibid.*): "The material transmits heat more or less quickly; heat propagates, moves in the material, more or less quickly.". Simply saying "the material is a conductor or an insulator" doesn't guarantee that the problem of transfer is properly understood. For instance, the following comment was given by a pupil who had chosen aluminium foil to keep a ball-bearing cold (Tiberghien, *ibid.*):

"because the metal keep the cold, the aluminium is a conductor..."

"Yes because it will take the temperature of the marble... and it will keep it for a long time." (12 year-old).

The question of symmetry of role between the interacting systems (the "hot" and the "cold" source) is one of the most critical, a point that needs a great attention when designing effective teaching-learning sequences.

Similar researches developed in Italy with participants in different age ranges, including a school teacher group (Sciarretta, Stilli, Vicentini, 1990), show that the Zero Law of Thermodynamics is commonly known by a very small percentage of students and by the majority – but not the all – of teachers. An interesting point about interpretation of the thermal equilibrium concept comes out from the analysis of answers to questions asking to explain about the body temperatures of living beings, namely a cat, a fish and the interviewed themselves. Even if all participants to the interviews initially declared to be aware that the human body temperature is constant at about 37 °C, this concept was only coherently found in 84 out of 261 interviews. For 18 participants, the body temperature of animals (and ours) is variable in relation to the environmental temperature. 106 participants made a difference between the fish temperature, considered equal or lower than the environmental one, and the temperature of a man or a cat. It is possible to hypothesize that such responses originated by the fact that, in Italian language, animals like mammals and birds are often called "warm blood animals" and fishes and reptiles "cold blood animals". The linguistic aspect can, then, be considered another point strongly influencing the way the common knowledge is built and developed to give sense to the real world phenomena and to answers given to posed questions and

problems. For this reason, then, the linguistic/semantic aspect must not be undervalued when designing a teaching-learning sequence aiming to build on aspects of science belonging to fields usually “shared” with common knowledge.

4.2.2 Changes of state

It appears that the stability of temperature during a change of state is not commonly known before teaching, and that it causes a real surprise when observed. After teaching, this point seems to be widely accepted, although such a stability over time is often considered as affected by the rate of heating, as shown in two studies (Driver and Russel, 1981, Andersson 1979).

Another interesting point is the fact that it also seems difficult for students to accept that, once the change of state is over, the new phase will behave normally, i.e. will have its temperature increased when heated. Tiberghien (1984, 1985) reports that, asked to explain why a piece of zinc placed in an oven at 1000°C had successive values of temperature 30° , 70° , 200° , 420° , 420° , 420° , about 20% of a group of pupils answered, after teaching about changes of state, that "*it is the highest possible temperature for zinc*". Concerning the values of temperature to be expected later on, 70% of the pupils said that "*the temperature always stays at 420°* ". Swedish students also often think that 100°C is "*the maximum temperature of water*" (Andersson, 1979).

Viennot (1997) tries to explain this by assuming that “ this reluctance to admit a normal behaviour for the phase resulting from a change of state may be phenomenon-dependent. In particular, children would probably admit that heating an ice cube results first in its melting, then in an increase of the temperature of the resulting water.”. Surely, very high and very low temperatures are difficult to imagine, so extreme values can not very easily be connected with ordinary personal experience, in our common life’s temperature ranges. Pupils, then, try to explain experimental data with models in evident contradiction even with the evidence, i.e. not in accord with a “scientific” reasoning: maybe something that could be explained with diSessa and Hammer’s idea that explanations of non familiar situations may be the result of “on the fly” cognitive constructions based on common life experience (see chapter 2.4.1 for more details).

It might also be due to a break in a reasoning line. The change of state forces one to leave aside the rule that holds in the "restricted category" of phenomena, i.e.: if a body is

heated, its temperature increases. This may seem arbitrary to children and discourage them from coming back to this rule when they consider the phase resulting after the change of state.

In the absence of any experimental support, it is not possible to say much more about these hypotheses. But, from a teaching-learning perspective, the last remark suggests that we take all the more seriously Erikson's plea (Erikson 1985) for presenting pupils with explanations - for instance concerning the boiling point of water:

"...This understanding would seem to require some explanation of what is happening to the liquid, at the molecular level, in order for temperature invariance to make sense."

4.2.3 Intensive and extensive variables

In 1980 Stavy and Berkovitz published the results of a research on the confusion between the concepts of intensive and extensive variables. It was based on a verbal aspect (qualitative), a numeric one (quantitative) as well as on the concept of intensive quantity and intermediate temperature. Researchers proposed to interviewed persons (77 students, all about 10 years old, in three classrooms where the understanding of conservation of mass was well consolidated) situations where cold or hot water were placed or mixed together in one or two containers according to figures 4.1, 4.2 and 4.3. Results to questions were collected as pre-tests (before instruction on the concepts involved) and as post-tests (after instruction).

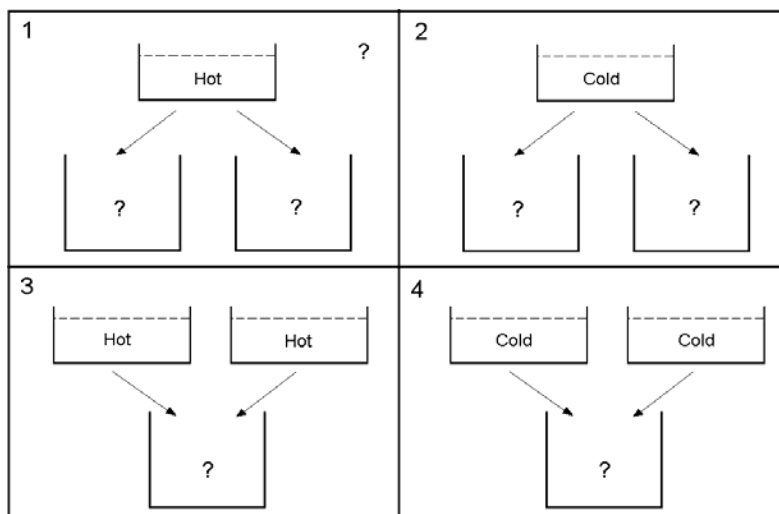


Figure 4.1 The qualitative questions on intensive quantity

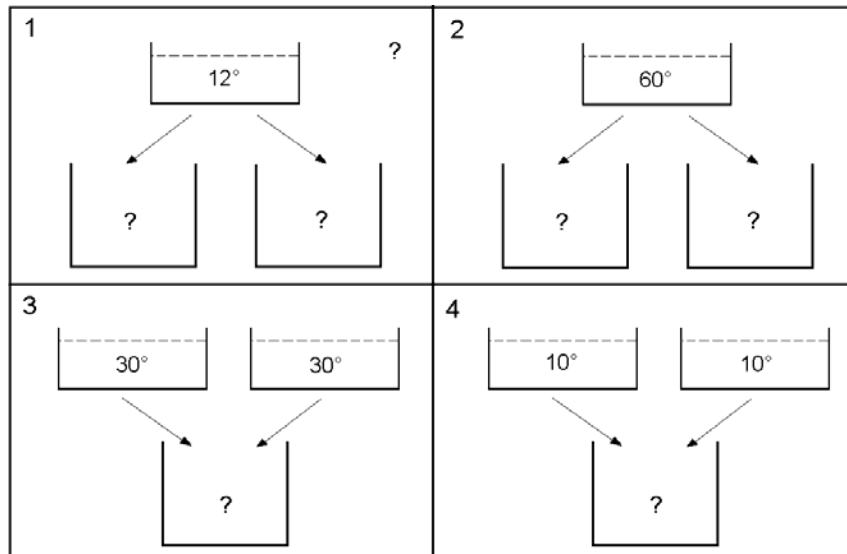


Figure 4.2 The quantitative questions on intensive quantity

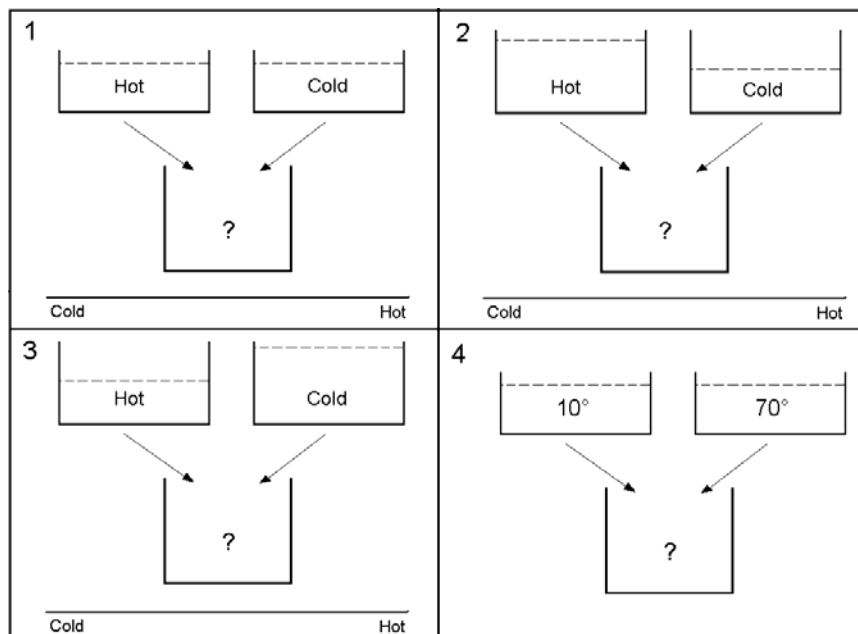


Figure 4.3 The qualitative questions and the quantitative one on the intermediate temperature

An high percentage of answers to the qualitative questions was correct: in the pre-tests, percentages for the correct answers regarding intensive quantity were from 60% to 80%; for intermediate temperature percentage were from 92% to 100%. Percentages in post-

tests were even higher. On the other hand, percentages of correct answers to quantitative questions were notably lower: from 20% obtained in questions dealing of intensive quantity to 4% relative to intermediate temperature. Percentages of correct answers were higher after instruction but still unsatisfactorily low (42% - 76% for the intensive quantity, 11% - 40% for the intermediate temperature)

Typical answers were:

In situation 2 of figure 4.2, “water, originally at 60°C , dividing in two containers will have a final temperature of 30°C ”

In situation 4 of figure 4.2, “two equal quantities of water, originally both at 10°C , combine together in water at 20°C ”

In situation 4 of figure 4.3:

“The final water temperature is the sum of the temperatures of the separate water quantities ($10^{\circ}\text{C} + 70^{\circ}\text{C} = 80^{\circ}\text{C}$)

The final water temperature is an intermediate one obtained by subtracting the lower temperature from the higher one ($70^{\circ}\text{C} - 10^{\circ}\text{C} = 60^{\circ}\text{C}$)

The final water temperature is the near the originally higher one”

The obvious conclusion one can give from these results is that, even after instruction, the intensive nature of temperature is hardly understood by pupils, as well as the fact that different quantities of water can give or absorb different quantities of energy, (i.e. the energy is an extensive quantity).

Thus, concerning simple heat transfers as well as changes of state or the surely harder to understand concepts like intensive or extensive quantities, simply "learning the facts" seems insufficient to reach a coherent understanding of the concepts involved.

5. Educational reconstruction of chosen Physics contents

This section presents our approach to the educational reconstruction to specific physics contents. A TLP, developed by the Research Group on Teaching/Learning Physics (G.R.I.A.F.) of the University of Palermo for the Italian School for Pre-Service Physics Teacher Education (S.S.I.S.) Pedagogical Physics Laboratories is described in details and the experimentation of some component TLSs in S.S.I.S. courses is discussed with regard to research questions, pedagogic strategies and assessment methods.

5.1 The framework in which TLP is experimented

The contents of the S.S.I.S. lab courses are organised according to ideas exposed in section 1.3. Educational activities are mainly structured in workshops covering 80% of the whole class time and workshops represent the core part of a TLP related to a specific physics subject. The TLP we describe and discuss in this chapter is related to the S.S.I.S. “Thermal Phenomena Laboratory” course, held by the author of this dissertation, and have been experimented during two academic years, 2000/2001 and 2002/2003. Section 5.2 describes our approach to the educational reconstruction of the chosen Physics contents and the TLP phases are discussed in details; some significant TLSs related to particular conceptual nodes found relevant (from the previous research results presented in Chapter 4 and our own experience) for the learning and the main characteristics of the related workshop are then discussed. Significant pedagogical material used in the TLP development, as well as pre-test and post-test proposed to TTs, are reported in Chapter 5 appendix.

Data analysis, results concerning TTs' learning and interest and conclusions are discussed in Chapter 6.

The structure and content of the workshops have been planned in order to prepare teachers to carry out the teaching tasks required from the proposed teaching/learning approach focused on modelling procedures. Our research hypotheses concern the teaching methods to be implemented in the course 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.

The workshops have been designed in order to implement some points of our teacher preparation process that have been considered relevant for the construction of a PCK appropriate for the assumed objectives of the physics teaching at high school level.

5.1.1 The goals

The aim of this study was twofold:

- to construct a teaching/learning environment for TTs, enabling conditions for collaborative inquire in model-building procedures;
- to investigate the correlations between the characteristics of the supplied teaching/learning environment and the competencies developed by TTs in the direction of the construction of a PCK.

The teaching/learning environment supplied by the workshops was organised on the basis of the following objectives:

- to allow TTs to make explicit their mental representations and to stimulate (when necessary) for different explanation-building processes through negotiation in collaborative inquiry;
- to make experience TTs the same learning environments they will be supposed to realise in their future classrooms;
- to supply TTs with appropriate pedagogical tools helping them in conceptualising physics models and in gaining the abilities connected with modelling procedures;
- to involve TTs in activities aimed at stimulating hands-on learning and metareflection.

The main research questions involved in this study were the following:

- Are the nature and level of the TTs' initial physics knowledge adequate to develop the disciplinary competencies required in performing teaching approaches focused on modelling of the natural world?
- Was the proposed learning environment able to stimulate modifications in the disciplinary as well as pedagogical competencies required?

- How have the characteristics of the proposed learning environment modified TTs' approach to modelling procedures?
- What kind of evidence have TTs shown about their ability to transfer knowledge and abilities to their pupils?

5.1.2 Participants

The TTs attending the workshops were graduated in engineering and mathematics and their university curricula included two (Mathematicians) of three (Engineers) annual physics courses. These consisted in lectures concerning the theory and applications aimed at the solution of quantitative problems without any laboratory activity. Few TTs had some teaching experience for limited periods of time.

Two experienced high school teachers participated, as tutors, to some phases of the workshops, working and discussing with TTs. They had already experimented some of the proposed experiments in their classrooms as well as modelling activities and evaluation materials.

Two researchers recorded questions and problems, posed by the TTs, concerning physics content and pedagogical tools (experimental set-up and/or software) during all the phases of the workshop. Almost all the class periods ended with small group discussions during which TTs were stimulated to make explicit the difficulties they met with and to reflect on their misunderstanding and/or lacking of appropriate knowledge of the physics content.

5.1.3 The redesigned teacher training course

In the TLP here discussed the relevant points of our teacher preparation process are:

- the thorough analysis of the physics content structure;
- the account for the pupil involved spontaneous models and cognitive resources (Hammer, 2000);
- the construction of pilot classroom instructional sequences based on thorough considerations on “critical details”, in relation with general principles, as well as with the content and the corresponding learners' common approaches (Viennot, 2001, 2003);
- the accurate metareflection on the involved learning requirements.

Our workshop organisation is based on a learning-by-scaffolding apprenticeship model: it provides structures and supports in order to undertake the mediation among “knower”, “known” and “to-be-known” (Simons 1993). According to Resnick (1987), apprenticeship is an “in-the job training” that, in contrast to the usual school and university systems, typically uses:

- 1) group learning instead of individual learning,
- 2) learning with tools instead of learning without tools,
- 3) domain-specific learning instead of widely usable knowledge and skills and,
- 4) object-manipulation instead of theoretical accounts.

Following Resnick's idea, we modified *apprenticeship* in *cognitive apprenticeship*, in order to train teachers on how to use constructive learning environments. By taking into account the apprenticeship model as well as the modelling approach to the physics content, we organised the workshop according to a general template, composed by five operative phases plus a pre-test and a post-test:

- In the pre-test (reported in the appendix to this chapter), the TTs answered to a written initial test, aimed to explore their conceptions about classic concepts like heat, temperature, energy, descriptive capabilities about phenomena and ideas about mechanisms behind observed or described situations.
- in the first operative phase, the TTs analysed the answer sheets of some questionnaires and/or recorded interviews, previously administered to high school pupils in order to draw their common conceptions and reasoning. At the end of this phase, they were supposed to synthesise, in a report, the pupils' ideas about the analysed physics field;
- in the second phase, the TTs were stimulated to suggest observations about common phenomena that, in their opinions, constituted the ground of pupils' conceptions that have been pointed out;
- in the third phase, experiments and data analysis were performed by the TTs in a small group setting, by making use of information technology tools, such as Microcomputer Based Laboratory systems;

- the fourth phase involved different aspects of modelling and the gradual enlargement of the experimental field for the following introduction of more powerful conceptual models;
- in the fifth phase, the TTs prepared a report defining in details teaching-learning sequences for high school classroom activities. They were supposed to pick out some experiments and computer activities, among those performed during the workshop, and to organise them in Learning Units by preparing pupils' guides for classroom work. The structure of questioning was to be defined through TTs' metareflection activities on their own knowledge processes in order to point out the details of different steps.
- In the post-test (reported in the appendix to this chapter), the TTs answered to another written test, aimed to explore in some way the TTs' understanding of some relevant ideas discussed during the workshop.

The in-class phases involved the TTs for approximately 20 hours; individual homework was also requested.

5.2 Educational reconstruction of the heat transfer processes

5.2.1 General introduction of the TLP

The category of phenomena used to describe thermal interaction can be divided into three subcategories: interaction where the bodies only change their temperatures, interaction between liquids and gasses with mixing of substances and interaction where bodies change their state (liquefying, boiling,...). Physics theory describes these phenomena through transfer of energy (heat) between the two interacting systems.

Educational research shows that pupils' explanations of thermal phenomena are usually different from scientific models. In fact, the scientific view of thermal processes is subtle and difficult: their description in terms of microscopic structure of matter, or more simply in terms of the particulate nature of matter, shows many learning problems.

In the educational approach developed for this TLP, empirical qualitative and/or quantitative experiences are strictly integrated with the searching of explanations through modelling procedures. The main point is in maintaining coherence between the

models to be taught and the corresponding experimental field which provides the experiential basis for meaning making.

The construction of physics models representing adequate and plausible representations of phenomena and on helping pupils to integrate their different unrelated understandings is now focused upon. The main point is that model properties have to be at the same level of analysis as pupils' observations of the natural world. For this reason we call upon the introduction of 'intermediate models' that, in our opinion would help pupils to the transition from their spontaneous models to the more abstract kinetic model. The "intermediate models", which we introduced in this case, is very similar to the 18th century caloric model in which heat is intended as a substance and/or 'something' that flows from hot to cold bodies. This is a model of the category called by Gilbert et al. (1998) "consensus models", that is, models that are important for the development of a given field of inquiry and are significant for provision of appropriate explanations readily accessible to pupils. The need to define in detail the model, their relationships with observations and experimental outcomes and how/where new *ad-hoc* hypotheses are necessary, has been the main objective in introducing such intermediate models. The kinetic model is introduced later, consequently to the gradual enlargement of the experimental field, as a more powerful conceptual model in order to find a common explanation of all the observed phenomena. The modelling procedures are described in the relevant section of paragraph 5.2.3 .

Temporary and pragmatic qualitative models have already been adopted in many teaching learning situations (Tiberghien, 1994, Linn and Songer, 1991); in fact, the qualitative heat-flow model is found to be the easiest model for high school pupils (Linn and Songer, 1991), the best understood and well respondent to the need of qualitative explanations of phenomena (White, 1988). This model is at a level of abstraction relevant to pupils (Clement and al.,1989), less abstract than the kinetic models typically used in pre-college courses, and provides concrete ways of thinking about a large range of thermal phenomena and of predicting their outcomes.

In our approach this is only an intermediate phase in order to gradually induce students to understand more comprehensive and predictive physical models. Although many obstacles to learning in the field of particulate structure of matter have been put into evidence (Novick and Nussbaum 1978, Andersson 1990), we think the

understanding of microscopic models of matter is an important objective for high school physics teaching. The reason is twofold: the epistemological features of physics models (including their character of hypothetical models sometimes based on theoretical more than on empirical foundations) and the need to realise, co-operatively with the other disciplines (as for example chemistry), possible unitary descriptions of systems and phenomena.

5.2.2 A more accurate description of the TLP's phases

In the first phase, questionnaires and interviews, reported in literature (Engel-Clough and Driver 1985, Rozier and Viennot 1991), have been used. TTs analysed answer sheets of questionnaires previously administered to a group of high school pupils. The main ideas drawn from this analysis are basically the ones reported in Chapter 4 about previous results in research in this field, and can be resumed as follows:

1. the experimental fact that all objects in prolonged contact reach the same final temperature is not obvious to pupils;
2. the ability to be heated is considered a 'natural' property of particular substances;
3. the substances are divided by pupils in two categories, 'hot' and 'cold', but their "coldness" depends on the peculiar situations in which they are used.

By synthesising, the typical pupils' interpretation of thermal phenomena seems to take origin from two ideas very common among students: the conception of heat as a form of substance and/or energy stored in the bodies and its partial or total coincidence with the concept of temperature. As a consequence, for a large number of high school pupils bodies at higher temperature contain a bigger quantity of "heat-energy" or "heat-substance".

During the second phase of the workshop, TTs discussed suitable observations to be performed and/or to be recalled by common experience in order to stimulate useful discussions concerning the spontaneous models pointed out by the questionnaire analysis. They were supposed to prepare a detailed list of observations (see table 5.1) also including the relevant characteristics of phenomena to be pointed out. TTs were, then, able to identify variables influencing cooling and/or heating of substances and the equilibrium temperatures of thermal interacting objects.

Table 5.1

List of observations about common phenomena and relevant features to be pointed out, resulting from the second phase of the workshop.

Observations:	Features to be pointed out:
1) different objects that have been maintained in the same environment for long time;	1) differences/equalities in their temperatures
2) two cups (metal and Styrofoam) each containing equal quantity of hot coffee and both cooling in the same environment;	2) similarities/differences in the evolution of their temperatures and in their cooling rates ;
3) two equal cans of hot water cooling in environments at different temperatures;	3) " "
4) different quantities of hot coffee in two equal cups cooling in the same environment;	4) " "
5) the different cooling /heating efficiency of radiators of different shapes;	5) " "
6) objects at different temperatures placed in thermal contact;	6) " "
7) explosion of hermetically sealed containers heated to very high temperature;	7) pressure is involved;
8) water mixed with melting ice;	8) quantity of melted ice and temperature;
9a) heating a liquid by using a mixer;	9) temperature is increased by
9b) a drill just turned off is very hot;	friction;

In the third phase, TTs worked in small groups of two or three to perform quantitative and semi-quantitative experiments (see table 5.2). All the experiments used cheap and easy available materials and commercial sensors (with computer interfaces) in order to reduce the time available for each experiment (for example, by reducing the quantities of substances to be heated or to be cooled) and to perform more experiments in a class period. Moreover, the real time graphical display allowed them to modify variables “on

the fly". Experiments were never accompanied by "cook-book" procedural directions, but were rather open-ended investigations: TTs were supposed to build the experimental protocol and to perform the experiments in order to find relationships among the identified variables.

Table 5.2
Experiments and relative variables to be investigated performed by TTs.

Experiments:	Investigated variables:
1) measurement of temperatures of various objects set on the lab table from long time;	1) equilibrium temperature is not influenced by body characteristics
2) two different containers with hot water cooling in the same big environment (thermostat);	2) the material of the containers;
3) two equal containers with hot water cooling in two different thermostats;	3) the temperature of the thermostats;
4) different quantities of hot water put in two equal containers and cooling in the same thermostat;	4) the quantity of water;
5) two containers (same material but different shapes) containing equal quantities of hot water and cooling in the same thermostat;	5) the extension of the external surface of containers;
6a) two quantities of water at different temperatures in thermal contact (without mixing);	6a/b) the equilibrium temperature and the cooling/heating rates;
6b) an hot metal body put in cold water inside an insulated container;	
7) gasses heated or cooled at constant volume;	7) pressure related to temperature
8) determining latent heat of fusion/vaporisation;	8) transferred heat and system temperature;
9) solids and liquids heated (adiabatically) by friction/electric work.	9) relationship between work and increase of system temperature.

The fourth phase, concerning modelling, included two activities: the mathematical fitting of experimental data and the dynamical modelling through numerical integration of the Newton cooling law or use of other modelling environments. Spreadsheets were used to perform the activities, and relationships were found between fitting of experimental data and hypotheses supporting the dynamical models. Then, TTs were induced to reflect on the relationships between their real-world observations and the results of their experiments in order to foster a common interpretation. They were requested to find analogies and differences between the process of cooling a given quantity of hot water contained in a beaker and different procedures of emptying a graduated cylinder filled with water (by taking away from the cylinder constant quantities of liquid each time, or 10% of the volume of liquid each time, or by making a hole at the bottom leaving the water to freely go out, or going along a capillary tube, and so on). Records of the temperature decreasing of the hot water were compared with records of the water level in the cylinders and hypotheses were performed about the kind of "substance" flowing out from the cooling bodies: has it a mass? Is it compressible? ... The descriptions of the various experiments were, then, re-analysed and explanations as well as previsions were performed in the light of the proposed model features.

A first gradual widening of the experimental field, for the introduction of more powerful conceptual models, has been performed by introducing observations and experiments concerning cooling and heating of gasses (see n° 7 in tables 5.1 and 5.2). These have been postponed to the introduction of the "intermediate" model, in order to focalise that the widening of the experimental field very soon involves the need to define more in detail the properties of the model by introducing some "ad-hoc" hypothesis. Some TTs thought that by attributing to the "heat-substance" the property of elasticity, the gas pressure variation could have been explained, while the majority considered that gas pressure variations with temperature could be better related to a "heat-energy" model involving a gain or a lost of energy by the gas molecules.

Very few TTs really supported the "heat-substance" model; in all their physics courses at high school and university levels they have read and heard about atoms and particles. Their learning difficulties concerned with the finding of a meaningful correlation between static/dynamics properties of particles and bulk properties of matter. It has been shown (Andersson 1990) that many high school students have developed an

atomistic idea, even if in many cases, they attribute macroscopic properties, like melting, expanding to microscopic particles. TTs' particle models (certainly more complex than high school students' models) were, in many cases, combined with a continuous model producing different "ad-hoc" explanations of the various experimental facts. (Persisting misconceptions or an example of "on the spot" activation of "à la diSessa" resources? See section 2.4.1 for more details). In our approach, the focusing in the search for correlations between experimental outcomes and model features was just aimed to put in evidence the rational rather empirical origin of physics models and their character of images to describe, explain and predict facts.

The further enlargements of the experimental field concerning heat transfer without temperature change (boiling, liquefying, ...) had the objective to further clarify the difference between the heat and the temperature concepts. Moreover, TTs verified that, in order to explain the new experimental outcomes, "heat-substance model" needed the introduction of many "ad-hoc" hypotheses in order to justify its capacity of modifying the structure of matter.

The modelling procedure was, then, completed by the introduction of the equivalence between heat transfer and work production. Following the last two points (see n° 8 and n°9 in tables 5.1 and 5.2), the kinetic model was introduced in order to find a unitary interpretation of the studied phenomena. Microscopic models of matter were visualised using computer simulations whose results were compared with experimental results.

The fifth phase was realised by taking into account some relevant principles of metacognitive instruction (Simons 1995). Among these, we privileged those aspects helping TTs to become aware of learning strategies and self-regulation skills applied in the various phases of their work and how these strategies and skills were related to learning goals. The starting point was a class discussion where the workshop's previous phases were analysed. Then, TTs, working in groups of two or three, were requested to prepare Learning Units whose objective was the modelling of common phenomena and/or problems in the analysed field. The requirements were to prepare a conceptual map connecting the involved concepts, detailed questions for pupils, activities to be performed and evaluation materials. The need to evidence their role as teachers, in each moment of the programmed classrooms activities, was outlined.

In this phase, tutors and researchers directly managed the TTs' working groups; their function was that of 'professional coaches' bringing into action interpersonal practice to be learned and recreating patterns of interaction that each TT can face in his/her practice. Following Schön's hall-of-mirror approach (1988), TTs and coaches continually interchanged prospective: coaches never had to figure out how to solve a peculiar problem. Instead, they introduced new problematic elements in order to put into evidence the real complexity of situations. The coach main role was in simulating pupils meeting learning difficulties and in analysing these to stimulate TTs in surfacing their own difficulties and in reflecting on their own learning, putting into action some possible ways of searching for appropriate solutions. In few words, the hall-of mirror experience gave TTs the opportunity to share with each other and with their coach how they dealt with difficulties, questions and problematic situations of their future teaching/learning environments. During the experimentation of the pedagogical tools in real high school classrooms, the tutors and researchers experience has been the main point for the implementation of the fifth phase: to observe the knotty problems of the physical content and the crux of the used pedagogical tools have given useful indications in outlining possible teaching/learning settings for the analysed context.

5.2.3 A description of the TLP

The proposed TLP was developed by using several educative tools:

- printed material (available also from the internet site of our research group: <http://www.difter.unipa.it/~griaf/termomod/il%20progetto.htm>) finalized to stimulate TTs towards a process of critical reflection on their knowledge in thermodynamics and mechanics for a pedagogical reconstruction on the basis of the proposed approach;
- pedagogic tools based on the Information and Communication Technologies as support to the learning processes (real time experiments, modelling and visualization environments);
- materials for the analysis (to adult level) of the physical content's structure;
- materials for the evaluation of the common knowledge representations relative to the analysed contents and of the common errors related to conceptual nodes

arising from differences and analogies between common and scientific knowledge;

Physical content

For “thermal processes” we mean the processes of change in a thermodynamic system due the thermal interaction with other systems or between the system and the surroundings.

We start from the observation that some characteristics of objects, persons and of the whole world in which we live can change, as times go on, while maintaining some other unchanged. The change is evidenced in contrast with the not-change. That is, while some things modify some their properties, others do not change, or they are repeated cyclically (at least in short times): objects placed on a room’s table, in thermal equilibrium with the surroundings, do not change (for short times) their temperature; the Sun rises and sets continuously, respecting a very precise rhythm; a small pot placed on the stove is heated up,

The various observations allow us to first schematise the different phenomenological situations through a classification in two typologies: change or equilibrium situations. The change situation can be described by various terms of the daily language: transformation, process, evolution, The various terms put in evidence particular aspects of the change; we will use here the term **process** in order to indicate that in the analysed system there is at least an observable property varying in time and that the phenomenon can be described through an events succession.

The proposed approach can be developed by following the conceptual map showed in figure 5.1:

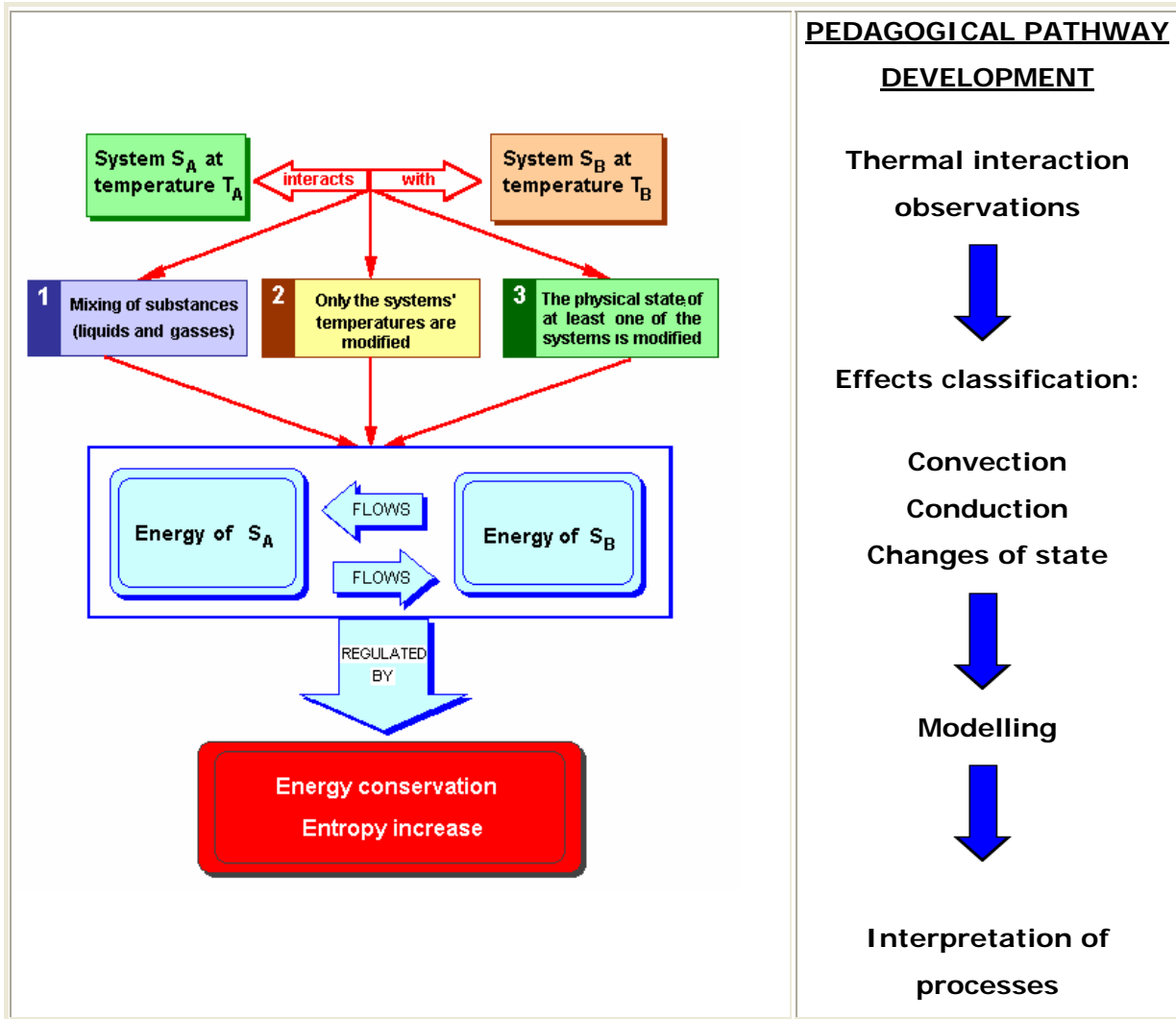


Figure 5.1. the conceptual map for the proposed TLP

Several learning sequences can be developed following the map but one common point is the accurate description of some kind of observed phenomena and the development of descriptive and interpretative models of them. The learning sequences always aim to the construction of microscopic models that can give explanations for the described processes and allow to give a prediction of the behaviour of analogous systems in similar situations. The general aspects of the modelling process are described in section 1.2.1; here we want just to recall that for model we mean a representation of a physical system built by making explicit approximations and exemplifications and applying the fundamental principles of a theory that allows us to explain the observed phenomena and to predict behaviours in analogous situations.

Experimental activities

An important part of our TLP is composed by laboratory activities, thought to help TTs to develop laboratory practical abilities that will surely will be precious for their apprenticeship activities and, more generally, for their subsequent activity as real teachers. (We recall here that the majority of our TTs is graduated in Mathematics and they have never attended an experimental laboratory course).

Experiments proposed in the learning pathway can be grouped in two different categories:

- A. qualitative and quantitative experiments, developed from the instructor desk, aiming to stimulate TTs to the observation, linked to a “thinking” activity developed by a constant request to formulate hypotheses, trends prediction and explications showing pupil’s mental representations and knowledge schemes;
- B. experiments conducted by TTs working in small groups, aiming to the acquisition of both experimental competences (abilities in planning and actually developing an experiment, related to the variables to analyse and/or control) and decisional abilities, with respect to the quality and quantity of data needed to draw some conclusions.

For every type of experiment the aspect of criticism of the proposed project and the choices done (the reasons of the choice of the tools, of the objects, of the samples,...) have been taken care of and carefully discussed. This is an extremely remarkable aspect of the teacher’s PCK, as he/she will very often be found to have to modify proposed experiments and to plan new ones.

A. A-type experiments are:

- EA1: Observation of objects on a table;
- EA2: Warming of water at room temperature;
- EA3: Mixing of liquids initially at different temperatures;

B. B-type experiments are:

- EB1: Cooling of different liquids;
- EB2: Cooling of a liquid in different material containers;
- EB3: Cooling of two different solids;
- EB4: The measure of the heat of fusion of ice.

Two worksheets (EB2 and EB4) used by TTs during the development of the teaching/learning sequences aimed to improve their experimental competencies are reported in the appendix of this chapter. They make deep use of MBL/RTL systems for data acquisition and analysis and use a “Prediction-Experiment-Confront” pedagogic cycle (Lombardi et al., 2002) to make the user reflect about measurements done and try to develop some PCK to put in use during real classroom activities.

Modelling activities

With the term *modelling* we mean that cognitive process aimed to apply the basic elements of a theory *to build a model* of an object or a real process. Our pedagogical approach contains many modelling activities comporting the use of computers and different modelling environments. We can separate the proposed activities in two categories, containing TLSs aimed to the understanding of the significance of:

- A. *descriptive models*, developed on the basis of experimental observations and laboratory results. They are mainly descriptions of observed processes through the use of verbal and/or mathematical languages (data fitting);
- B. *interpretative models*, developed on the basis of hypotheses on system’s properties not directly observable but playing a role in the observed experimental results. This second kind of model normally contains hypotheses on the microscopic nature of the observed systems.

A. Support worksheets for the descriptive modelling activities are :

MA1: Experimental data analysis: cooling curves

MA2: Let’s build a model

MA3: a STELLA¹ model for systems at variable rate and the cooling process

MA4: The Newton’s model of cooling

MA5: Thermal equilibrium of two bodies at different initial temperatures_

B. Support worksheets for the interpretative modelling activities are :

¹ STELLA is a simulation environment developed to build descriptive model of phenomena through the use of an iconic language; its main advantage is to eliminate the need to manipulate symbols and to make complex mathematics understandable and easily manageable. For some more details see paragraph 5.2.4 and visit the STELLA web site: <http://www.hps-inc.com/>

MB1: Microscopic models for solids and gasses

MB2: A model for thermal interaction: a solid cooling in a lower temperature environment

MB3: A model for thermal interaction: two solids at different initial temperatures go to thermal equilibrium

Five worksheets (MA1, MA2, MA3, MB2 and MB3) used by TTs during the development of the modelling part of the TLP are reported in the appendix of this chapter. The first one is aimed to the development of data analysis abilities through the use of simple mathematical tools or a computer spreadsheet. The second helps TTs to understand the phases requested to build a model by analysing a simple phenomenon, give a first verbal description and then trying to transform this qualitative description in a quantitative one. The last three worksheets make use of innovative Information and Communication Technology tools (STELLA and NetLogo²) to make easier to implement models describing a phenomenon (MA3) and to give a microscopic interpretation to the heat transfer process (MB2 and MB3). Some relevant points TTs deepen in the modelling phases of the TLP are: - the analysis of experimental data on the basis of the development of some kind of model explaining them; - the need to choose “good” variables to describe an observed phenomenon in the best possible way; - the significance of commonly used physics concepts, like the cooling speed; - the search for the dependence of physical variables used to describe a phenomenon from specific body’s characteristics; - the “translation” of relevant concepts in quantitative (i.e. in mathematical) form; - the search for microscopic mechanisms able to explain macroscopic properties of matter; - the implementation of a “classic” model (the Einstein model of solid) to build a simulation giving results in accord with some evident macroscopic properties of thermal interaction of solids.

In the following two paragraphs we report two examples about:

² NetLogo is an Object Based Parallel Modelling Language projected for simulating natural and social phenomena. It is an extension of the Logo language and it is particularly well suited for modelling complex systems developing over time, as NetLogo users can easily give instructions to hundreds or thousands of independent “agents” all operating in parallel. This makes possible to explore the connection between the micro-level behaviour of individuals and the macro-level patterns emerging from the interaction of many individuals. For more information, see <http://ccl.northwestern.edu/netlogo/>

- the description of the use of STELLA to build a model describing the concept of “rate of variation” of a variable through the use of the iconic language of this simulation environment and an example of simple model for the description of a cooling process, supported by worksheet MA3;
- the description of the rationale behind the TLSs about a proposed model for the thermal equilibrium process in solids, supported by worksheets MB2 and MB3, making use of NetLogo.

5.2.4 A descriptive model for the “rate of variation” of a variable with STELLA

The description of a typical thermal phenomenon like the cooling of a substance in an environment at a lower temperature can be performed at different complexity levels, starting from a first qualitative (verbal) description. Experimental evidence as well as real life experiences very soon make evident that a variable relevant for the (qualitative as well as quantitative) description of the phenomenon is the *rate of variation* of the temperature difference between the cooling substance and the environment. Actually, the cooling process can be categorized (Fazio et al., 2001, 2004) in a wider class of phenomena that can be described with a variable, y , whose rate of variation, dy/dt , is proportional to the variable itself. The mathematical model describing the process is

$$\frac{dy}{dt} = -Ky$$

Important as it is for the development of descriptive models of thermal phenomena, the concept of “rate of variation” of a variable with respect to another variable (time in cooling or heating processes, space in processes of heat conduction, etc.) poses some problems when it comes to the understanding of its formal counterpart, the derivative symbol, d/dx , seen as an operator that, applied on a generic function $y(x)$, gives its rate of change with respect to x . In this sense d/dx could be seen as the “rate of change” operator. One could think that, substituting the x variable with something “real”, as the time can be, could help the understanding. Actually, the application of the operator d/dt to the variable position is very often well understood by the majority of students, probably because the concept of speed as an indicator of how much quickly a body is moving belongs to the customary experience. Unfortunately, the same cannot be said for other physical quantities (Newburgh, 2002); if, then, we apply d/dt to the temperature of

a cooling body, very seldom students are able to grasp the meaning of the symbol, that is the rate of variation of temperature.

This example can help to explain why the formalism of differential equations, although considered the starting point in the “mathematisation” of physical situations, results in practice to be badly understood. In this context modelling activities could help students to develop competencies in translating different descriptions of real world into each other. In fact, modelling may be considered as a translation procedure from verbal description of real world to other forms of representation, such as the mathematical or iconic ones.

The use of “simulation environments”, whose components allow to easily visualize physical objects and processes, makes possible the construction of operative thinking forms.

STELLA is a programming/simulation environment that helps the user to represent the dynamic changing of a variable by using an “object based” approach. It makes use of objects like “stocks”, that can be filled or drained through incoming or out coming “flows”, i.e. objects whose main role is to represent the rate of variation of stocks. Other objects allow the user to build models of dynamic phenomena. The main STELLA graphics interface makes available the basic elements assigned to the model building. They are:

- Stocks** □ containing amount of a variable changing in time,
- Flows** ⇄ representing the action to fill or drain stocks,
- Converters** ○ additional objects used to complete logic sentences building a model,
- Connectors** ↗ used to link objects together and define their relationships.

In natural language a mental model is generally associated to a verbal description; STELLA allows the users to translate the verbal model of the system under scrutiny into a symbolic scheme, by representing carefully all the elements of the idea describing its evolution. The program automatically generates a code, associated to the iconic representation done by the user and describing it. This code is, then, ran by STELLA and the time evolution of the variables representing the system is obtained through graphs, tables etc. Modelling becomes a “translation” from verbal descriptions to iconic

representations; mathematical equations are, consequently “built” translating the specific iconic language of STELLA.

In order to introduce the concept of “rate” (the amount of change of some quantity during a time interval divided by the length of the time interval) we usually begin by studying what happens to the volume of water in a container in the situation represented in fig. 5.2.

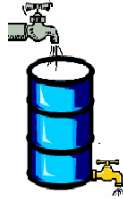


Figure 5.2. A container continuously filled by a tap and emptied by another one

In figure 5.3a we can see the simple STELLA iconic model for this process, where it is easy to recognise the stock used to represent the volume of water and the two flows representing the taps of figure 5.2, i.e. the action to fill or drain stocks at defined constant rates R_{in} and R_{out} .

The system can be verbally described by a statement like: *the volume of water is dependent by both the outflow and the inflow of water.* Of course, in order to quantify the relationships we have to say some more : *the rate of change of volume is given by the algebraic sum of the two rates R_{in} and R_{out} .*

The iconic model of the process and the results for different values of the ratio *Inflow-rate/Outflow-rate* are represented in fig. 5.3.

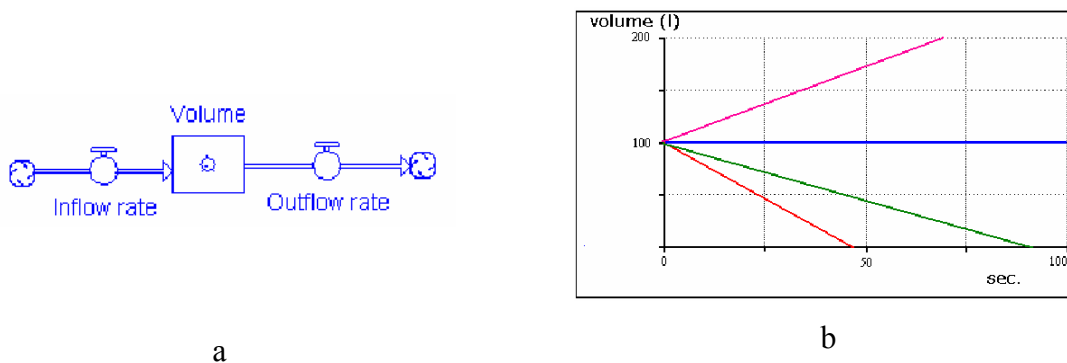


Figure 5.3. a. The Stella model for the process represented in Figure 5.2.

b. The results of simulation for different values of the ratio Inflow rate/Outflow rate

The translation of the iconic model to the mathematical formal model is straight:

$$\frac{dV}{dt} = R_{in} - R_{out}$$

And then a quantitative descriptive model of the Figure 5.2 phenomenon is easily build and verified.

The next point is to introduce the concept of variable rate and to use it in the description of cooling processes. We consider a container with a given mass of, say, water at temperature T_W set in an environment at a lower, constant temperature T_E . The process of water cooling is easily observed, as well as the experimental fact that the cooling rate is not constant. The appropriate variable to describe the phenomenon is the temperature difference between water and the environment, $T(t) = T_W(t) - T_E$. It decrease as a consequence of the heat flow from the system to the environment. If we call K the cooling coefficient, depending from the physical parameters of the system (liquid and container)³, we can hypothesize a dependence of the cooling rate dT/dt from the instantaneous value of T .

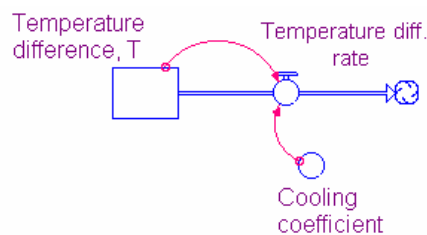


Figure 5.4. The iconic model of the cooling process with STELLA

Figure 5.4 shows the simple STELLA model for the cooling, built by using a stock, a flow, a converter and two connectors. T is represented by the stock and the flow represents the rate of change of T with time. The proportionality of the cooling rate, dT/dt , to the instantaneous value of T , with a proportionality constant, K , is implemented in the STELLA model by simply indicating, by means of the connectors, the fact that the flow (the cooling rate) is influenced by the stock (the variable, T) and by the converter (the cooling coefficient, K). The mathematical model behind the iconic STELLA construction is, obviously

$$\frac{dT}{dt} = -KT$$

³ From the Newton's cooling law, the cooling coefficient, K , is equal to hS/C , were h is the "external conductivity coefficient", S is the thermal contact surface between water and the environment and C is the thermal capacity of the sample of water

The results of the simulation for the time dependence of the temperature difference between the cooling substance and the environment are reported in figure 5.5a; they appear remarkably similar to the results obtained in an actual cooling experiment (figure 5.5b).

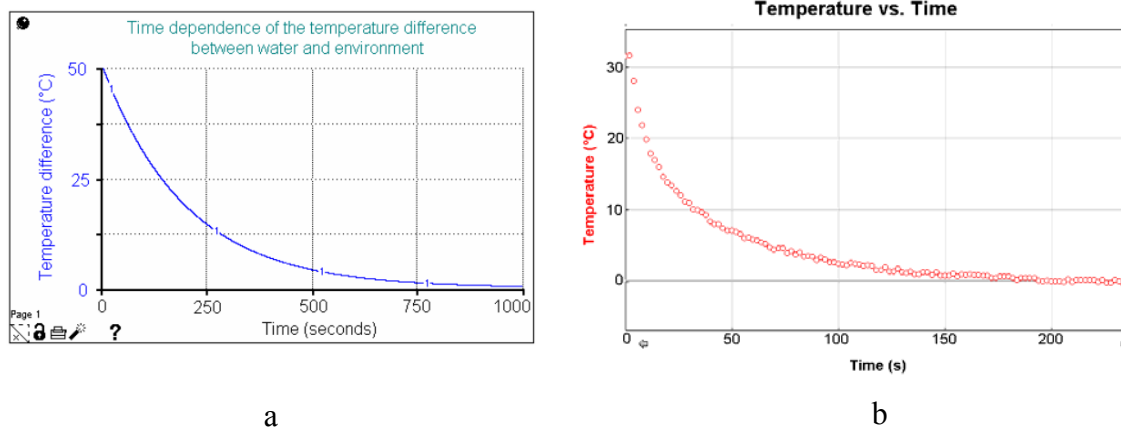


Figure 5.5. a. the time dependence of the temperature difference, T , between a cooling substance and the environment as obtained by implementing the STELLA model described in Figure 5.4.

b. the time dependence of T as obtained in a real cooling experiment, where 100 cc of water, initially at 32° C, reached the environmental temperature of 0°C.

5.2.5 Building an interpretative model of the heat transfer process

An interpretation of the matter behaviour, observed at the macroscopic level, can be given by a change of analysis and observation level. We can, for example, try to build a simple microscopic model hypothesizing the existence of well defined elements constituting matter (molecules) and of equally well defined interactions between them and between them and the environment. Then, we have to check if, and in what extent, this model can explain the macroscopically emerging matter's properties.

Models built with this aim should help us to explain answers to question like:

- In what a "hot" body is different from a "cold" one?
- What happens when a body reaches thermal equilibrium with another body?
- How is the inner energy (i.e. the energy of atoms and molecules) distribution of a body when the body's temperature is constant?
- Why is the final act of the thermal interaction between systems always a situation where temperature is uniform?

Models for the solid and the gaseous states are easier to describe and simulate than models for the liquid state. In this pedagogic path we will, then, analyse models to interpret the macroscopic behaviour of solids and their interaction with gasses by using some innovative simulation environments that will help us to visualise the fundamental characteristics of the models and to build them at different formalization levels.

Crystalline solids exhibit a regular structure, where atoms are positioned in a lattice and repeat almost exactly a fundamental structure (the “primitive cell”) in all the space. The existence of a crystalline lattice implies a high symmetry grade, giving some interesting macroscopic properties to the solid. The easiest way to think about the solid’s structure is to imagine a set of atoms disposed in a lattice and interacting so that they can oscillate with respect to their respective equilibrium positions. A simple way to represent these interactions is to do it with springs connecting all the atoms in the lattice.

A solid can be studied at different levels of understanding. We will describe here two worksheets used in TLS about

- the thermal interaction of a solid with the environment
- the thermal interaction of two solids initially at different temperatures

These worksheets are based on the implementation of the Einstein model of solids with the NetLogo simulation environment. We remember here that a consequence of the regular lattice structure of solids is the existence of characteristic lattice oscillations for each solid type. Einstein was the first to propose that these oscillators can be treated as identical; but, in a regular lattice disposition each atom should influence other atoms’ oscillation, giving as a result oscillations different from each other. Einstein then hypothesised a system where each oscillator/atom was acting as if it was confined in a “cell”, a small space region where it could move and exchange energy with other atoms, while the level of interactions were not so high to make the characteristics properties of the oscillators different from each other.

Einstein’s model is not the best way to imagine the solid’s structure (an improvement is obtained, for example, with the Debye model) but it is surely a simple model that allows us to describe the heat flux in a solid and the establishing of thermal equilibrium. This has as a consequence that some results of our simulations are only valid for the model itself and not for the reality it wants to describe. On the other hand, several results of the

simulation give information in accord with the macroscopic characteristics of a solid and are obtained with such an ease to make this simulations very useable at different levels of education.

Just as an example, let's see a simple model simulating the atoms of a solid as little spheres and their interaction forces as springs allowing atoms to oscillate with respect to their equilibrium positions. The temperature of a solid is linked to the oscillation energy in the sense that in two identical solids at different temperatures, the atoms of the solid at a higher temperature possess an higher medium energy. The simulation is built on a bi-dimensional lattice of spheres, linked by springs and free to oscillate on a plane surface. An initial velocity is given to spheres, identical in module for each sphere but randomly directed in the plane. Because the springs are initially in the equilibrium positions, spheres have initially the same (kinetic) energy. The total energy has been divided in ten intervals, represented, in the simulation interface, by ten different colours; initially, then, the spheres have all the same colour. Starting the simulation, the "atoms" are free to interact and one can observe a variation of their individual energy, described by a window reporting the number of molecules with a well defined energy (i.e. colour) that updates while times goes on.

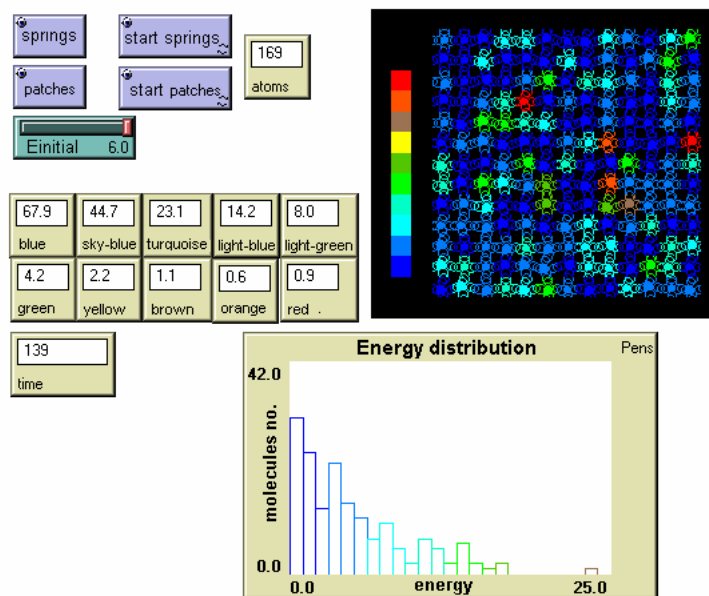


Figure 5.6. The NetLogo screenshot of the simulation of the energy distribution in a thermally insulated solid

The same basic model is used to simulate the phenomena on which our TLSs are based (the thermal interaction of a solid with the environment and the thermal interaction of two solids initially at different temperature). Figures 5.7 through 5.10 show the screenshots of these simulations interface, respectively (Figs. 5.7 and 5.9) when no interaction is active and (Figs. 5.8 and 5.10) when thermal interaction is established and the equilibrium is almost reached.

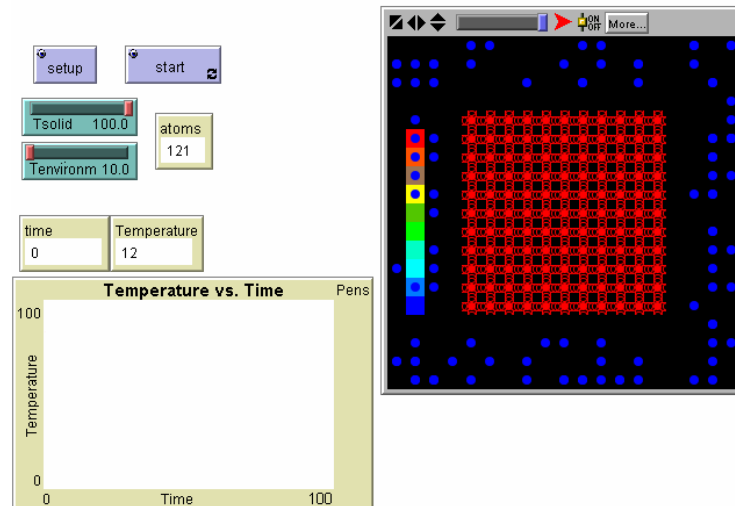


Figure 5.7. The NetLogo screenshot of the simulation of a solid interacting with the environment. Phase 1: the initial situation, where the hot solid is placed in the environment

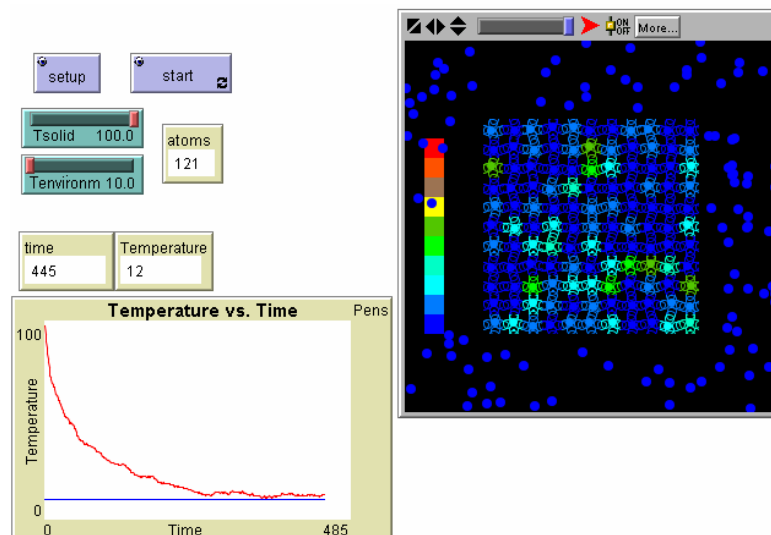


Figure 5.8. The NetLogo screenshot of the simulation of a solid interacting with the environment. Phase 2: the final situation, when the solid is at the same temperature of the environment. Note the Temperature-Time graph, indicating the reaching of thermal equilibrium

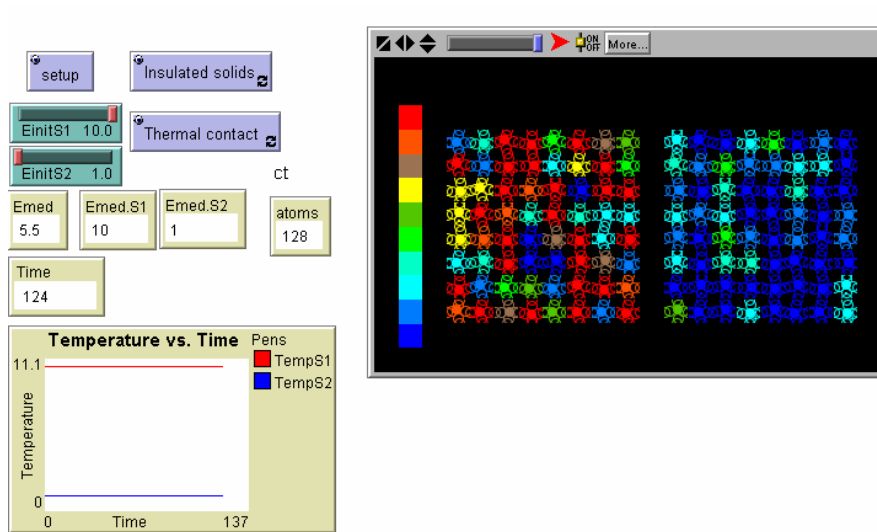


Figure 5.9. The NetLogo screenshot of the simulation of two solids thermally interacting. Phase 1: the solids have different temperature

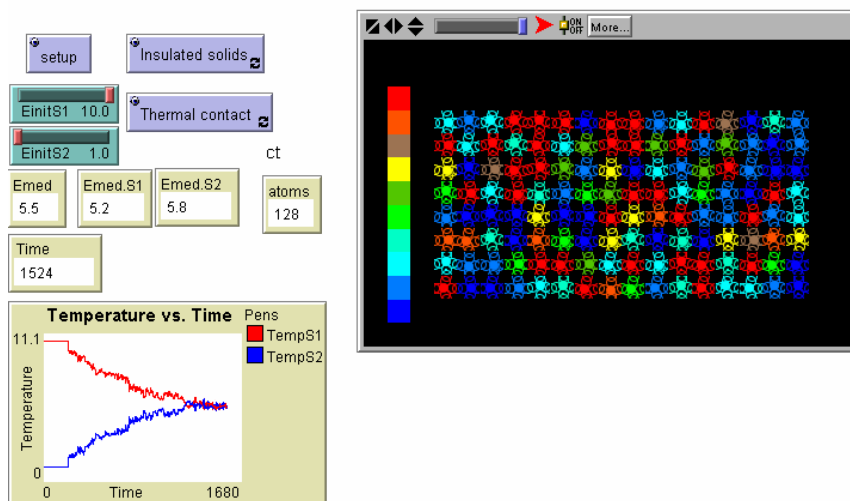


Figure 5.10. The NetLogo screenshot of the simulation of two solids thermally interacting. Phase 2: the final situation, when the solids are at the same temperature. Note the Temperature-Time graph, indicating the reaching of thermal equilibrium

APPENDIX TO CHAPTER 5.

Some pedagogical material used in the TLP

INITIAL QUESTIONNAIRE

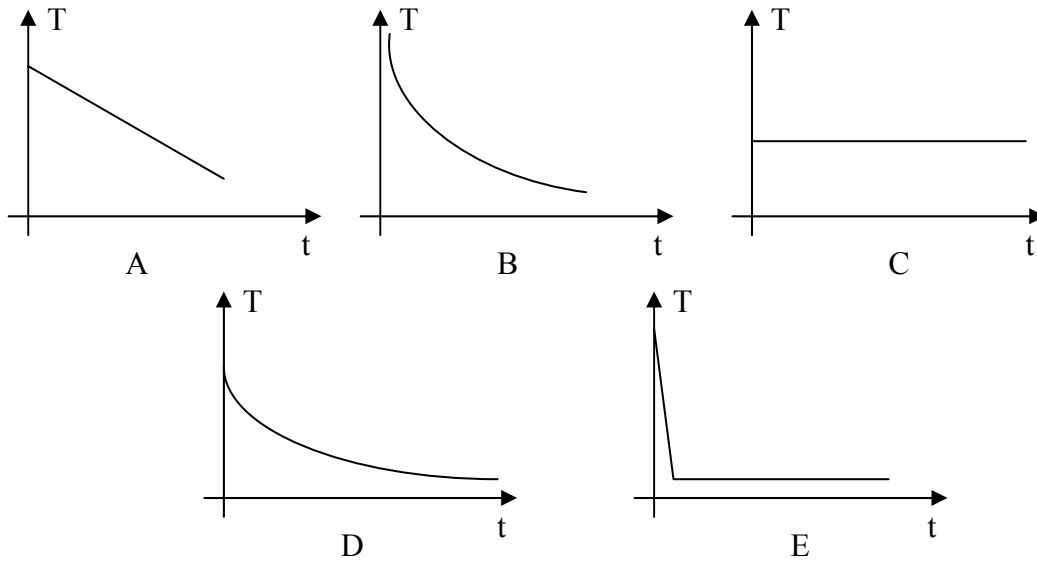
Name _____ Course _____

Degree _____ High school attended _____

- 1) Some different bodies, [(A) plastic, (B) metal, (C) wood, ...] are placed in a room at an environmental temperature $T_0 = 20\text{ }^\circ\text{C}$, for about 12 hours. Then the temperature of each body is measured; Can you tell how (A), (B), (C) temperatures are with respect to the environmental temperature, T_0 ? Try to briefly explain your answer.

- 2) Consider two equal quantities of hot coffee, placed in cups of equal volumes but different in shape and material. The cups are in the same room, at an environmental temperature lower than the coffee one. What cups characteristics do you think could affect the coffee cooling rate? Try to briefly explain your answer.

- 3) With regard to question 3), choose from the proposed graphs the one you think could best represent the time dependence of the coffee temperature during the cooling process.

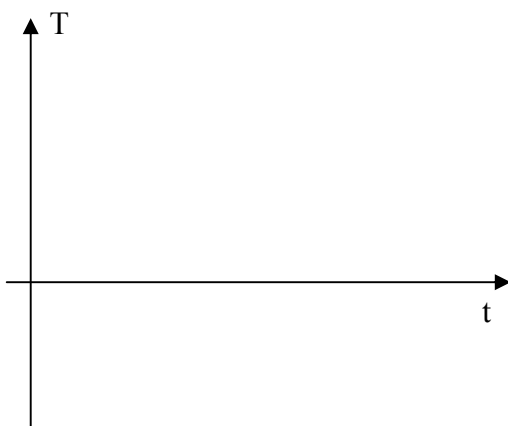


4) Two identical bottles containing the same amount of water have been taken out of the refrigerator at the same time; one has been placed on the table in the 20°C air conditioned kitchen and the other on the picnic table outside (under the porch) where the temperature is 40°C. If you want to drink water at about 10 °C, which bottle do you think will reach sooner this temperature? Try to briefly explain your answer.

5) 100 g of water, at $T = 100\text{ }^{\circ}\text{C}$, are mixed with 50 g of the same liquid at an initial temperature of $50\text{ }^{\circ}\text{C}$. What will be the final temperature of the resulting 150 g of water? Try to briefly explain your answer.

- 6) Imagine to place equal quantities of oil and water in two similar beakers and heated, starting from the same temperature, with two identical heaters. Which liquid do you think will reach $100\text{ }^{\circ}\text{C}$ first ? Try to briefly explain your answer.

- 7) Consider an ice block with a thermometer firmly inserted in it, so that the ice inner temperature can be measured continuously. The ice block has been placed for all the night into a freezer, at $T = -18\text{ }^{\circ}\text{C}$ and, at $t = 0$ seconds, it is taken out of the freezer and placed in a room at an environmental temperature $T = 20\text{ }^{\circ}\text{C}$. Represent the Temperature vs. Time graph during all the phases of the ice's warming process. Then, briefly explain what happens to the ice during the warming and try to make explicit the relations between heat and temperature that can be found in this process.



- 8) Two containers, identical in dimensions but one metallic and the other wooden, contain equal quantities of air at the same temperature, higher than the environmental one. How would you explain the experimental evidence that the two containers transfer the inner thermal energy to the surroundings at different rates?

EB2: COOLING OF A LIQUID IN DIFFERENT MATERIAL CONTAINERS

Lab equipment

Two small containers, identical in shape and volume, made of different materials (for example, plastic and metal);

Two stoppers of cork or rubber with a hole, for the containers;

A 1 lt. Pyrex glass beaker;

A 2 lt plastic thermos ;

An electric stove;

A Real Time Lab (RTL) System with temperature sensor;

A thermometer;

Water, ice in small pieces.

Fill up to half capacity the beaker with water and put it on the stove. Take the two containers and fill them with identical water quantities. Use the stoppers to close the containers. Fill up with water the plastic thermos to a third of its capacity and put the ice pieces in the water, mixing well. Use the thermometer to control the ice-water mixture temperature and note when it reaches a value near 0 °C.

In the meantime, put the temperature sensor in the hole of one of the stoppers and place the correspondent container in the beaker. Wait until the inner water temperature, shown by the RTL's Data Logger live readouts, is near 40 °C, then quickly extract the container from the beaker and insert it in the thermos, beginning at the same time the temperature data acquisition with the RTL system.

Watch to the Temperature-Time diagram, gradually building up on the Data Logger computer screen, while continuing to gently stir the container, to help the thermal exchange.

When the temperature of the container's water has reached 0 °C, stop the data acquisition and save the experimental graph. Be sure to have the graph still displayed on the Data Logger screen when you will take the temperature data for the other container's water.

Extract the first container from the thermos, take out the temperature sensors from the stopper and place it in the second container stopper. Be sure that there is still a sufficient amount of ice in water. If necessary, add other ice pieces. Place the second container in the water in the beaker on the stove and wait again for that the temperature of the system reaching 40 °C. Repeat the same actions made for the first container and obtain a second Temperature-Time graph.

We are now about to start the analysis of our data; let's search for a mathematical expression for the Temperature-Time data in the two different experimental sets. This can be done by exporting the data in a spreadsheet, where they can be easily analysed but it is possible to use also the Data Logger built-in data analysis functions.

In what the two Temperature-Time graphs appear to be different?

In which of the two data sets the water in the container appears having cooled off before?

How is it possible to define, in a qualitative way, the concept of "cooling speed"? Try to make some example that can be helpful to better explain.

How can the concept of "cooling speed" be represented in a mathematical model?

Apply this model to the data taken in the two experimental sets. Comment the results.

Try, now, to calculate the Temperature/Time ratios between 0 and 2 seconds, 2 and 4 seconds, 4 and 6 seconds in the two data sets. Do you think that this ratio could be a good candidate in order to describe, through formulas, the concept of "cooling speed" discussed before?

Do you think the cooling speed in each time interval is constant or variable in the two data set?

If you think the cooling speed is not constant, in which case is it higher?

Which physical variables can be taken into account to explain the difference in cooling speeds in the two cases?

Can you propose a physical model able to explain the difference in cooling speeds in the two cases?

Try to graph the two sets' cooling speed data as a function of the temperature. Discuss the results

EB4 : THE MEASURE OF THE HEAT OF FUSION OF ICE

Lab equipment

A 2 lt plastic thermos with a polystyrene stopper;

A 1 lt. Pyrex glass beaker;

A balance;

Ring stand and utility clamp

A Real Time Lab System (data logger plus interface) with temperature sensor;

Water, ice in blocks (made, for example, with 150 cc plastic glasses)

A plastic clamp to easily take ice blocks

A long plastic stirrer

Take the ice blocks out of the freezer (it is normally at -18°C) and leave them at the environmental temperature, so that their temperature gets to 0°C .

Measure the thermos mass, $M_T = \underline{\hspace{2cm}}$

Secure the temperature sensor with the utility clamp and mount it on the ring stand, so that the final part of the sensor, the one actually sensing temperature, is vertically suspended into the thermos, at a couple of centimetres from the bottom of the container. Make two small holes in the polystyrene stopper, one for the sensor, the other for the stirrer.

Take a mass M_W ($= \underline{\hspace{2cm}}\text{ g}$) of water, at the environmental temperature, and pour it into the thermos. Place the sensor and the stirrer in the holes of the polystyrene stopper, close the thermos and begin acquiring data. The temperature-time graph should show a constant line, indicating the environmental temperature, $T_E = \underline{\hspace{2cm}}^{\circ}\text{C}$

Insert into the thermos some ice blocks, ensuring to perfectly dry out with paper towels all the fusion water that could be covering them. Stir the water-ice mixture with the plastic stirrer, while watching its temperature going down in the computer data logger screen. If temperature decrease stops at a value too distant from 0°C , add some more ice.

When the mixture has reached a temperature of about 4°C , quickly remove **all ice pieces** from the thermos with the plastic clamp and take note of the water temperature, that should remain constant for some time (after a couple of minutes the temperature will rise

again due to the thermos thermal dispersion). Write down the minimum temperature, T_m , reached by the water and stop the data acquisition.

$$T_m = \text{_____} \text{ } ^\circ \text{C}$$

Determine, now, the total mass of water contained into the thermos, $M_{TW} = \text{_____}$ g and, then, the amount of water due to the fusion of ice, during the temperature decrease from T_E to T_m , i.e. the mass of ice melted during the process. $M_I = \text{_____}$ g.

1) On the basis of your observations during the experiment, has the ice temperature changed? Explain your answer.

2) Write a formula useful to calculate the heat quantity absorbed by the ice mass M_I during the melting process.

3) Is the fundamental relationship of thermal physics, $Q = M c \Delta T$, applicable to mass M_I during the melting process? Explain your answer.

4) Is it correct to say that the heat lost from the mass M_W of water is all absorbed by the mass M_I of ice during the melting process? Explain your answer.

5) Write down how to calculate the heat amount needed to make the mass M_I of ice changing state (melting)

6) Using your experimental data, give your best estimate for the heat of fusion of ice, λ_F , i.e. *the heat amount needed to make the ice mass unit changing state (in this case, from solid to liquid)* .

7) confront your found value with the accepted value, $\lambda_F = 79,7$ cal/g.

8) What is the percentage deviation of your experimentally found value of λ_F with respect to the accepted value? Try to think about the experimental operations to find error sources possibly influencing your measurement

Think now carefully about the reasoning at the basis of the model used to obtain your best estimate for the fusion heat of ice

9) Describe briefly what happened to M_I while all the process developed and, finally, the temperature increased from 0° C to T_m .

In particular, is it correct to say that all the heat lost from the water quantity, M_W , was absorbed by the ice quantity, M_I , during the melting process? Explain your answer

10) What is now the percentage deviation of your newly found experimental value of λ_F with respect to the accepted value? Is the improving of this new estimate notable?

11) Find the ratio between the heat quantity actually absorbed by the M_1 ice mass during the melting process and the heat quantity absorbed from it during the following increase of temperature from $0\text{ }^\circ\text{C}$ to T_m .

12) Write now your final considerations about this experiment. What do you think about the pedagogical usefulness of this experiment? Try to find and write some competencies that could be developed by pupils during this experiment.

MA1: EXPERIMENTAL DATA ANALYSIS: COOLING CURVES

Today, we will analyse some Temperature-Time data obtained in an experiment where some water, initially at temperature T_0 , is placed in thermal contact with an environment at a lower temperature.

Data have been already exported from the Data Logger program and are available as a spreadsheet file for you to work with. First, try to build with the spreadsheet a graph reporting the water temperature, T_w , as a function of time.

Copy the graph obtained on the computer screen to the space below.

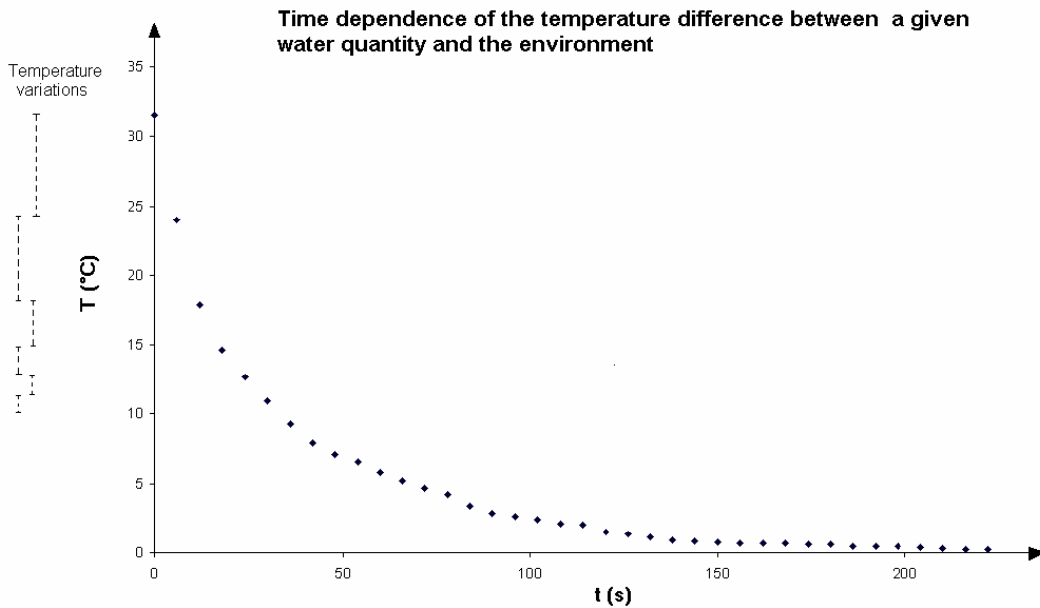


Our data refer to a cooling experiment where the environmental temperature was $0\text{ }^\circ\text{C}$, so our graph actually represent the time dependence of the temperature difference, ΔT , between the cooling substance and the environment. When trying to describe a cooling process, the most adequate variable is ΔT and not the temperature of the cooling substance. We will denote it with the “T” symbol for sake of simplicity.

So, every time the experimental data refer to cooling in an environment at a (constant) temperature different from $0\text{ }^\circ\text{C}$, it is convenient to build a new graph reporting in ordinate the difference between the cooling substance and the environmental one. This is exactly as vertically translating the cooling body temperature vs. time graph by an amount equal to the environmental temperature.

If we want to fit a mathematical function to data it is possible to see that a good candidate for the fit is a decreasing “base e” exponential function but a very interesting point is to try to understand what sort of model it is necessary to develop to justify such a mathematical function.

For this reason, analyse the T vs. t graph previously build and take note of variations of T with respect to equal time intervals, as reported in the following figure.



Consider, now, the data table and give your answers to the following questions, operating, if necessary, directly with the spreadsheet to make mathematical calculations

Can variations of T (for equal time intervals) be considered constant?

Can you find a mathematical form for the time dependence of the “rate of variation” of T, $\Delta T/\Delta t$?

Try now to build a table containing the average temperatures, T_A , between those corresponding to the maximum and the minimum temperature in each time interval. Build a graph of $\Delta T/\Delta t$ as a function of T_A . What kind of mathematical function could best fit data?

Write your comments about these last operations and find now the mathematical function that best fits to your data of rate of cooling as a function of the average temperatures.

Discuss your results with your colleagues.

The time dependence of the temperature difference, T , between a cooling body and the environment is the mathematical solution of a differential equation like

$$\frac{dT}{dt} = -kT$$

This equation can be obtained considering the fundamental calorimetric relation $Q = mc\Delta T$ and a phenomenological formula taking into account the rate of transfer of heat, $(\Delta Q/\Delta t)$, from the body, at temperature $T(t)$, in thermal contact with the environment at constant temperature, T_e . This formula was firstly found by Newton and is, as a consequence, known as “Newton’s cooling law”.

$$\frac{\Delta Q}{\Delta t} = -hS(T(t) - T_e)$$

Here t is time, S is the contact surface between the body and the environment and h is a coefficient (usually called “external conductivity coefficient”); h depends from the nature of the body and of the environment and from the thermal contact surface. The minus sign shows that if $T(t) > T_a$, the thermal energy of the body must decrease, while it has to increase if $T(t) < T_a$.

MA2: LET'S BUILD A MODEL

The modelling of a container filling process by the means of a tap.

Figure 1b represent the process of filling up a cylindrical container through the use of a tap. The tap is first opened (Fig. 1a) until a constant water flux is obtained and then the empty container is placed below the tap.

Figure 1a



Figure 1b



Try to simply verbally describe what will be, in your opinion, the time evolution of the filling process

If we would like to predict what could happen in similar situations (with similar containers or taps), a mathematical model of the process could be useful. Such a model can be obtained by searching relations between the characteristic quantities of the process to investigate.

What are, in your opinion, the relevant variables that can help us to formulate a mathematical model for the process?

What relations do you think there should be between these variables ?

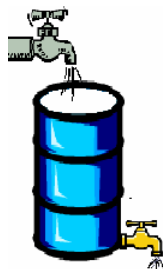
Can you describe such relations with mathematical expressions?

A variable relevant for the description of the filling container process could be the “filling rate”, i.e. the speed at which the container is filling up. Can you give a mathematical expression for this variable?

What is, in the case showed in Figure 1, the water rate of input (R_{in}) represented from ?

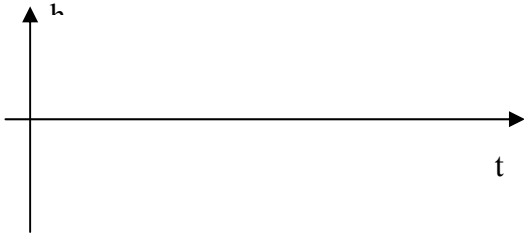
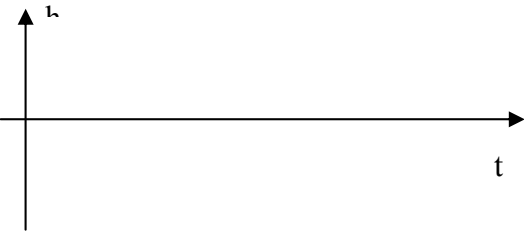

Consider, now, the situation represented in Figure 3, where the tap in the lower part of the container is supposed to produce a constant water flow; label as R_{out} the rate of loss of water from the lower tap and try to write a mathematical expression giving the total rate of change of the water level in the container.

Figure 3



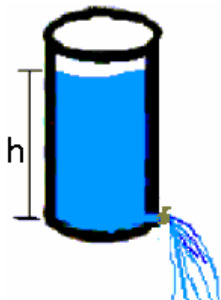
$$R_h = \Delta h / \Delta t = \dots\dots\dots$$

What do you think will be the time evolution of the water level in the container for different values of R_{in} and R_{out} ? Try to graphically represent three examples, for three different values of the ratio R_{in} / R_{out} .

$R_{in} / R_{out} = \dots\dots\dots$	
$R_{in} / R_{out} = \dots\dots\dots$	
$R_{in} / R_{out} = \dots\dots\dots$	

Consider now Figure 4, where a container filled with water, with a special tap in the lower part of it, is represented. Imagine to have adjusted the tap so that the outflow rate of water is proportional to the instantaneous height of water in the container, h , with a proportionality constant $k = 2 \text{ cm}^3/(\text{sec} * \text{m})$. Write the mathematical expression of the rate of variation of the water height, R_h , in the container

Figure 4



$$R_h = \Delta h / \Delta t = \dots\dots\dots$$

MA3. A STELLA MODEL FOR SYSTEMS AT VARIABLE RATE AND THE COOLING PROCESS

Consider the process we have studied in the last part of the previous modelling activity “MA2: LET’S BUILD A MODEL”. It represents a situation where

$$\begin{aligned} & \text{the outflow rate of water is proportional to the instantaneous height} \\ & \text{of water in the container, } h, \text{ with a proportionality constant, } K. \end{aligned} \quad (1)$$

Report in the graph below your prevision for the time dependence of the water height in the container.



Now, try to represent in the space below a STELLA model for this situation, making use of the programming objects (stocks, flows, connectors, etc.) of this simulation environment. Think carefully about the verbal definition (1) of the process and try to clearly understand the role of each piece of the iconic representation of the model you are building.

When you have finished and are sure of your STELLA schema, copy it to the STELLA interface and, when finished, run the simulation.

Report in the graph below the simulation results for the time dependence of the water height in the container



Were your previsions correct?

If not, review the iconic schema you built; is it a correct object representation of the verbal description (1) ? Try to correct it and run again the simulation.

If you don't manage to obtain results in accord with your previsions try to open a discussion with your colleagues and the instructor.

If yes, try to slightly modify the model to obtain different rates of variation of the water height. What parameters can actually influence it? How do you implement this in the STELLA code?


Consider now the cooling process of a substance in an environment at a lower temperature. Give a verbal description of the process, on the basis of the experimental results you obtained in previous lab activities and of real life phenomena. In particular, individuate the variable(s) you think are important for the description on the cooling process and their relationships.

Do you think this process can be considered similar to the process treated before, where a water container is emptied by a small hole in its lower part? Try to explain your answer.

Report in the graph below your prevision for the time dependence of the temperature difference between the cooling substance and the environment container.



Repeat now the steps followed in the first part of the activity: represent in the space below a STELLA model for this situation, report the model in the simulation environment and graph the simulation results.

<p>The STELLA model</p>	 <p>The simulation results</p>
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Write your comments about this modelling activity.

What do you think are the most relevant points you have learnt? What are the points you think could be important to develop in an actual pedagogical activity with high school students?

MB2: A MODEL FOR THERMAL INTERACTION: A SOLID COOLING IN A LOWER TEMPERATURE ENVIRONMENT

This worksheet will help you to use the NetLogo environment to study the temperature changes of a solid in thermal contact with an environment at a lower temperature. The solid is simulated by using the Einstein model for solids. In particular:

- the solid is represented by a 2-dymensional lattice of N atoms behaving as $2N$ identical and independent harmonic oscillators (an oscillator for each freedom degree);
- The energy associated to each oscillator is quantized and each energy quantum depends from the oscillation frequency. In our model a quantum is equal to 1 and the zero-point energy is equal to 0. We neglect other possible energy terms;
- The energy exchanges between two oscillators are realised only when they are near: in this case, one of the oscillators gives to the other a number of quanta chosen randomly from 0 to its energy content.

Set-up the simulation, setting the solid initial temperature to 100°C and the environment temperature to 10°C . Run it and observe the figure with the solid representation by oscillators. Give a first, qualitative description of what happens while time goes on.

In particular, do you think atoms exchange energy with other atoms? Is the energy distribution uniform in the solid? What about zones of solid with higher energies? Use the colour schema building up as the time goes on to answer to these questions.

Stop the simulation , set-up it again with the same values used before and run it. Observe the temperature-time graph describing the cooling process. Give a description of it, trying to find similarities and differences with cooling results obtained in real experimental trials you made before and/or simulations you ran with other programming environments, like STELLA.

Again, stop the simulation, set-up it with a different initial temperature of the solids (for example, 50° C) and run it. Do you observe *qualitative* differences with respect to the previously ran simulation? What about *quantitative* differences (time needed to obtain a given temperature decrease, slope of the T vs. t curve for small values of time, etc.). Try a new value for the temperature difference between the solid and the environment. If you want, sketch graphs of simulation results

How do you explain the fact that the solid temperature appears to fluctuate even when the solid has reached the thermal equilibrium with the environment ?

What aspects of a real solid behaviour do you think this simulation well represents? In what is not a good model for a real solid?

MB3: A MODEL FOR THERMAL INTERACTION: TWO SOLIDS AT DIFFERENT INITIAL TEMPERATURES GO TO THERMAL EQUILIBRIUM

This worksheet will help you to use the NetLogo environment to study the thermal interaction of two solids initially isolated at different temperatures, shown in the simulation as different medium energies. As in MB2 activity, the solid is simulated by using a 2-dimensional Einstein model for solids and the simulation hypotheses are the same.

Set-up the simulation, setting the left solid initial medium energy to 10 (arbitrary units) and the right solid medium energy to 1. Run the simulation, activate the thermal contact and observe the figure with the solids representation by oscillators during the process. Give a first, qualitative description of what happens while time goes on.

In particular, do you think atoms exchange energy with other atoms? Is the energy distribution uniform in the solids? Use the colour schema building up as the time goes on to answer to these questions.

Stop the simulation , set-up it again with the same values used before and run it. Observe the temperature-time graph describing the thermal interaction process. Give a description of it, trying to find similarities and differences with cooling results obtained in real experimental trials you made before and/or simulations you ran with other programming environments, like STELLA.

Again, stop the simulation, set-up it with a different initial energies of the solids (for example, 10 for the left solid and 5 for the right one) and run it. Do you observe *qualitative* differences with respect to the previously ran simulation? What about *quantitative* differences (time needed to reach the thermal equilibrium, etc.). Try a new value for the temperature difference between the solid and the environment. If you want, sketch graphs of simulation results

Repeat the simulations by changing other parameters, like the atom numbers or the contact surface of the solids. Do you obtain quantitative differences with respect to results obtained before? In particular, what about time needed to reach thermal equilibrium?

How do you explain the fact that the solids' temperatures appears to fluctuate even when the solids have reached the thermal equilibrium ?

What aspects of a real solid behaviour do you think this simulation well represents? In what is not a good model for a real solid?

FINAL QUESTIONNAIRE

Name _____ Course _____

Degree _____ High school attended _____

- 1) A common idea about heat is that it is a form of energy “stored” in a body, similarly to potential energy. Do you think this idea is in contrast with the interpretation of heat as energy transferred between two bodies as an effect of their temperature difference ? Explain your answer.

- 2) A mass $M_A = 100$ g of water is placed in a room at 10 °C and another, $M_B = 50$ g, is placed in a room at 70 °C, so that they reach the thermal equilibrium with the environments.

The two water masses are, then, carried to two different environments, at temperature different from the initial ones. In particular, M_A is placed in an environment at 20 °C and M_B is at 90 °C. If we wait for a sufficient amount of time, so that the two water masses can reach thermal equilibrium with the surroundings, what can you say about energies they exchange with the environment? Explain carefully.

- 3) Imagine to be a Physics teacher at an High School and to have to discuss with your pupils about the fact that objects different in nature give different feelings if touched,

even if they have been placed in the same environments since a long time. Try to build a pedagogic approach, not more than ten rows long, containing:

- a) a first part , of descriptive type,
- b) a second part, of explicative type, dealing with the subject.

4) Two identical bodies, A and B, of mass 100 g, are placed in an environment at constant temperature, $T_A = 20\text{ }^\circ\text{C}$. Body's A and B initial temperatures were, respectively, $40\text{ }^\circ\text{C}$ and $30\text{ }^\circ\text{C}$.

4a. Which body will exhibit an higher initial cooling rate?

4b. Will the two bodies both reach the same final temperature?

4c. Which body will reach sooner its final temperature?

Explain carefully your answer.

- 5) Two identical cups, A and B, contain each 100 g of water. Water in cup A is initially at 45 °C, water in cup B is at 35 °C. Both the two cups are placed at the same time in the same environment, at a temperature $T_A = 25$ °C but two electric heaters are used to maintain unchanged the initial water temperatures. Which of the following sentences better describe the time-rate of energy that has to be transferred to each cup's content to maintain its initial temperature unchanged?

Cup A requires heat with a rate

- A) about three times higher than that required by cup B
- B) about two times higher than that required by cup B
- C) just a bit higher than that required by cup B
- D) equal to that required by cup B

Cup B requires heat with a rate

- E) about five times higher than that required by cup A
- F) about two times higher than that required by cup A
- G) just a bit higher than that required by cup A

Explain your answer

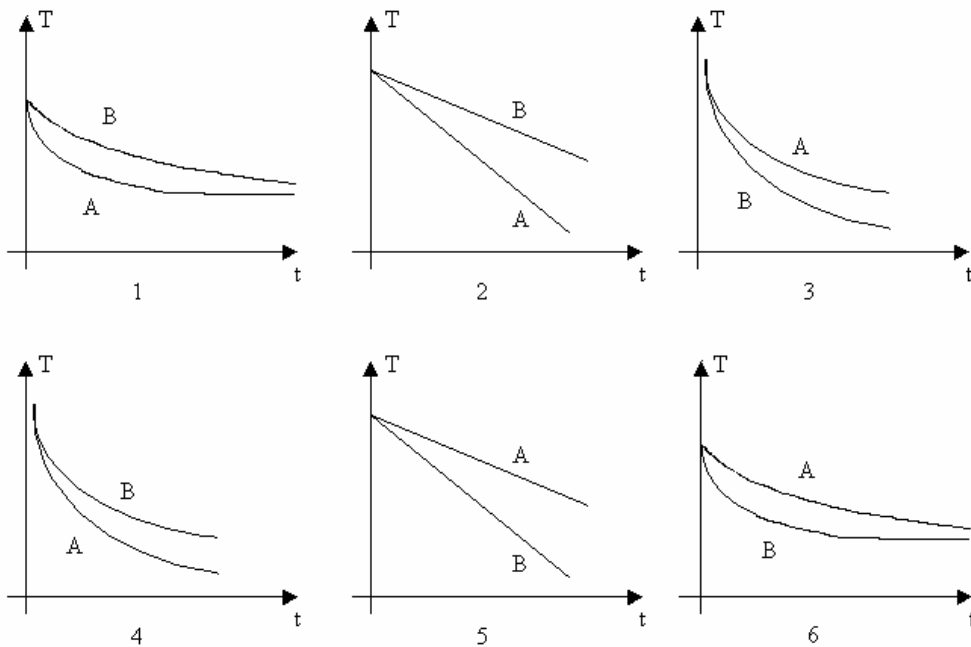
- 6) Imagine to take cup A of question 5) in another room, where the environmental temperature is 5 °C. How should the time-rate of heat exchange be to continue to maintain the initial 45 °C temperature with respect to the case (described in question

7)) when the environmental temperature is 25 °C? Explain, trying to give a quantitative expression useful to support your answer.

7) A small water quantity is placed in a metallic container. The container is, then, hermetically closed and inserted into an oven at 80 °C. After some time, the container is taken out of the oven and let cooling in air to the environmental temperature (20 °C).

The container is again inserted into the oven and, after some time, taken out and let cooling in a big container full of water at 20 °C .

If we call A the first process and B the second, which of the following graphs better describes the time dependences of the temperature of water inside the metal container?



8) Two containers, identical in dimensions but one metallic and the other wooden, contain equal quantities of air at the same temperature, higher than the environmental

one. How would you explain the experimental evidence that the two containers transfer the inner thermal energy to the surroundings at different rates?

6. Teaching-Learning Pathway experimental data analysis and research findings

Our research mainly conforms to qualitative research methods but some quantitative methods are also recalled in posing our research hypotheses and during data analysis. Our research is based to the 'Case Study' approach in educational research (Stake, 1995, 2000), it is naturalistic and interpretative and it seeks to examine meaning in a given context. Our 'case' is the sociological and organizational unit of our teaching/learning settings, with the intent of assembling its comprehensive description in terms of a discrete number of research objectives. In this sense, it is a multiple or collective case study: data obtained from TTs' individual work and group interactions were analysed in order to produce a description of the setting complexity and of the knowledge development of the class as a whole.

Data were mainly analysed using a phenomenographic approach (Marton, 1988; Marton and Both, 1997) in order to reveal the different ways in which some classroom learning episodes were experienced by our TTs. The aim of phenomenography is to map different ways in which a phenomenon can appear and to find out an interpretation by grouping these ways into categories (Marton and Both, 1997). In fact, Marton and Both (1997) have identified a limited number of different ways of experiencing a given phenomenon that are qualitatively different and capture the differences of understanding from different points of view.

Our objective was in identifying how TTs experienced, understood, conceptualised and made sense of the teaching/learning environment proposed by our workshop. Data have been collected from a variety of sources, during two academic years, 2000/2001 and 2002/2003:

- the analysis of TTs' discussions while conducting the various workshop activities;
- the admission test (AT) to the graduate program for pre-service teacher preparation, assessing the knowledge of the basic topics of Physics;
- two open answer tests (pre-test and post-test), administered to TTs at the beginning and at the end of the activities, to investigate the changes in the

nature of TTs' models and explanations involved in the studied physical processes;

- the analysis of TTs' worksheets and other empirical material prepared by TTs during the workshop;
- the logbooks of the two tutors and the researchers.

Some open interviews to TTs were also conducted by the researchers during the workshops and at the end of it, to gain information about TTs' ideas about the developed activities and the self-perception of their own improvements in analysing natural phenomena, build models and develop a useable pedagogical content knowledge.

Data were usually triangulated in order to minimise the impact of the researchers' interventions, to present a comprehensive analysis of TTs' participation in the work from several perspectives and, in general, to enhance the internal validity or credibility. The aim of the approach was to present a detailed contextual analysis of a limited number of events or conditions, with the goal of seeking to understand how the prospective teachers' behaviours might change or be influenced in response to the environment designed by the authors.

6.1 Data analysis and results discussion

Our approach in redesigning, implementing and evaluating the structure of the workshops was based on some preliminary hypotheses concerning our TTs physics knowledge and on the efficacy of some interaction strategies in the teaching-learning processes. As a consequence, the data analysis was based on the research of supportive and non supportive evidence for our preliminary hypotheses.

The data to be analysed consisted in empirical material constituted by open answer tests, TTs' worksheets, direct observations of TTs' discussions, the Learning Units prepared by the TTs at the end of the workshop and open interviews conducted to all workshop's participants.

The test analysis gave information about the different types of model building procedures, used by TTs, to explain thermal processes at the beginning and at the end of the workshop activities. The data scanning of the direct observations and TTs'

worksheets supplied information and new insights about the TTs' learning processes, their needs and the necessary supports, allowing the formation of new hypotheses about the workshop organisation. Moreover, the analysis of the Learning Units, prepared by TTs', gave information about the acquired competencies in transforming their physics knowledge in an aware PCK.

6.1.1 Assessment of TTs' typology of explanations

Modelling is strictly connected with the procedures to find explanations of phenomena. An explanation has been defined as "an answer sought or provided to a specific question" (Gilbert, Boulter, and Rutherford, 1998). Scientific questions involve the modelling of the natural world and different kinds of models supply different kinds of explanations. Gilbert, Boulter and Rutherford (1998) pointed out a pattern of relationships stemming from the interactions between the nature of questions and the explanations elicited: questions like "how does the phenomenon behave?" or "why does the phenomenon behave as it does?" or "how might it behave under other conditions?" are perceived differently by pupils on the basis of their different models. As a consequence, in order to analyse scientific modelling competencies of our TTs we have chosen to involve them in finding explanations of some phenomena.

6.1.2 Results for the Educational Reconstruction of the heat transfer process TLP

The pre- and post- tests were identical for both the two TTs groups (Set 1, academic year 2000/2001; Set 2, academic year 2002/2003), As described in Chapter 5, tests presented some theoretic and/or experimental situations (described by using text and/or pictures) and TTs were requested to explain the involved thermal processes.

The TTs' written descriptions were qualitatively analysed and classified in categories, at the same manner for Sets 1 and 2. The construction of the analytic categories was based on a close reading of the TTs' explanations within a framework provided by domain-specific expertise. The specific categories into which the responses were coded are *everyday/practical explanation*, *descriptive explanation* and *interpretative explanation*. The category of *everyday/practical explanation* reflects the creation of situational meanings derived from informal every-day contexts. The *descriptive explanation* category describes and characterises the analysed process by summarising

the perceived patterns, but does not explain the causal relationships of the physics involved parameters. The *interpretative explanation* proposes a qualitative model based on a cause/effect relationship or provides explanatory hypotheses introducing models, able to be visualised at a theoretical level. Table 6.1 summarizes the three categories and gives some examples concerning item four of the pre-test (see Chapter 5 Appendix).

Table 6.1

Categories describing the nature of the students' explanations in the pre- and post-tests

Nature of explanations	Definition	Examples from the data
Practical/Everyday	Explains thermal processes with practical, everyday examples	<i>The bottle outside warms faster..... as it happens to me if, in a cold day, I enter in a well heated room; ... I warm faster than if I enter in a cold room.</i>
Descriptive	Describes thermal processes giving a result and the explanation does not clarify causal relationships	<i>The bottle in the environment at higher temperature warms faster since the warming rate is higher in the hot roomthe water reaches a higher temperature.</i>
Interpretative/ Explicatory	Includes informal reasoning whilst conceptualising a cause/effect relationship or provides a theoretical model.	<i>The bottle put at higher temperature warms faster because water molecules transfer their thermal energy more easily to cold air molecules.</i>

The category of interpretative/explicatory explanations also contains answers not completely adequate for a scientifically correct explanation of the phenomenon (as the one reported on Table 6.1). However, these kinds of answers were also classified in this category if they evidenced a search for cause/effect relationship and/or qualitative mechanisms of functioning.

Pre-test and post-test analysis

The TTs' answers of pre- and post- tests have been analysed by two independent researchers. Each answer was coded in only one of the analytic categories (reported in Table 6.1). The agreement between the coders was 93%. Disagreements have been negotiated to construct a consensus.

The data show that the TTs' explanations supplied in the pre-test were mainly practical (42%, Set 1; 36%, Set 2) and descriptive (39%, Set 1; 42%, Set 2) in nature, suggesting that most students approached the topic on the basis of their everyday understanding of the phenomenon or confining their explanations to descriptions summarising some perceived patterns. Only 19% of all answers in Set 1 and 23% in Set 2 have been classified as interpretative explanations.

In order to analyse the relationships between the level of TTs' physics knowledge and the nature of the supplied explanations, our TT sample has been divided in two sub-samples on the basis of the Admission Test (AT) achievement scores. High (H) and low (L) achievement groups, grouping TTs whose scores S were respectively: $S \geq M_{AT}$, $S < M_{AT}$ (with M_{AT} the mean score of the AT, administered to the whole group of TTs admitted in to the Graduate School for Mathematics and Physics Teacher preparation; 80 in academic years 2000/2001 and 70 in academic years 2002/2003). The L and H groups were composed in total by 15 and 13 TTs, respectively, for Set 1 and 13 and 12 TTs for Set 2.

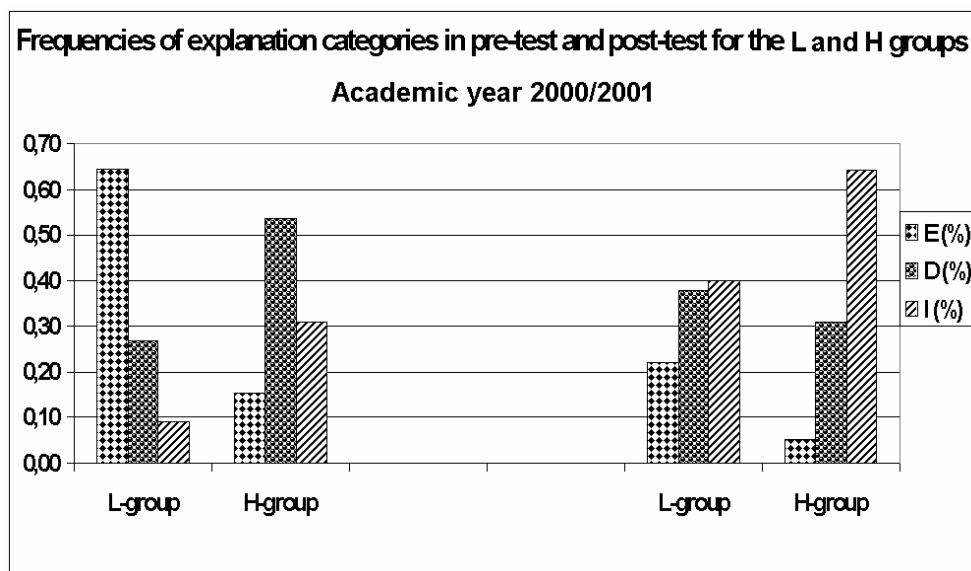


Figure 6.1. frequencies of different types of explanations given by the L and H groups in the pre (left) and post (right) tests for the Set 1 TTs

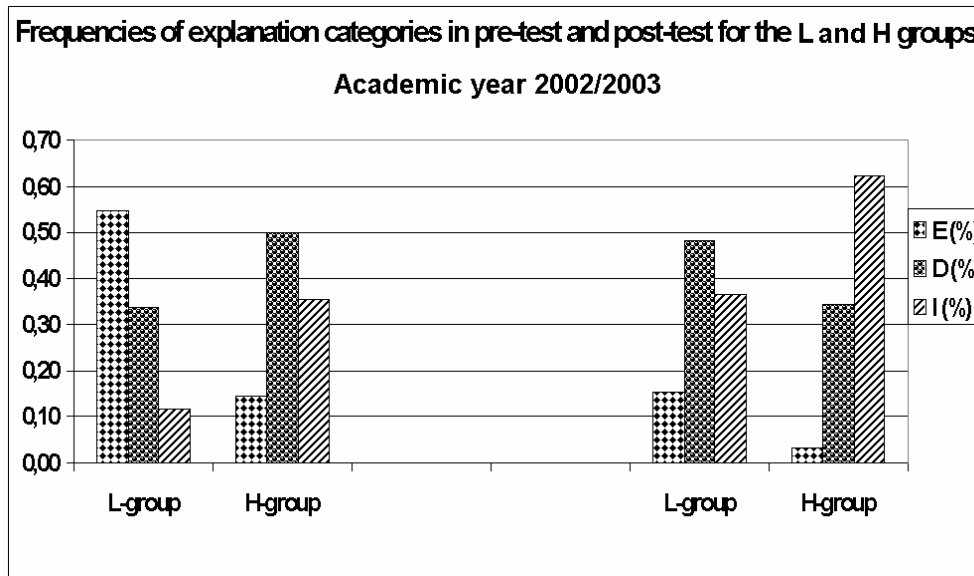


Figure 6.2. frequencies of different types of explanations given by the L and H groups in the pre (left) and post (right) tests for the Set 2 TTs

Figures 6.1 and 6.2 report the frequencies of different types of explanations given by the L and H groups in the pre- and post- tests. By separately analysing the pre-test data of the two groups, a significant difference (Set 1: $\chi^2 = 55.95$, $p < 0.001$; Set 2: $\chi^2 = 38.34$, $p < 0.001$) in the L and H group TTs' distribution among the three categories of explanations was identified. The great part of answers (Set 1: 64%; Set 2: 55%) given by the L-group analysed the processes using explanations of the everyday category, many (Set 1: 27%; Set 2: 34%) using the descriptive category and very few (Set 1: 9%; Set 2: 12%) the interpretative category. For the H-group, the majority (Set 1: 54%; Set 2: 50%) of answers has been classified as descriptive explanations, only 31% (Set 1) or 35% (Set 2) as interpretative explanations (the most of them using qualitative microscopic models in order to predict and interpret phenomena) and very few (15% for both Sets 1 and 2) as everyday explanations. However, it should be noted that the physical content of the interpretative explanations, supplied by the majority of TTs, was not fully adequate for a scientific interpretation of the experimental situations proposed in the pre-test.

The post-test data show that 51% (Set 1) or 49% (Set 2) of answers of the TTs' total sample gave explanations interpretative in nature, including explanations proposing cause/effect relationships as well as more formal scientific explanations. The total number of E-type explanations in the post-test is diminished (Set 1: 14%; Set 2: 10%),

although the total number of the D-type explanations is still high (Set 1: 34%; Set 2: 41%). By comparing the post-test results of the two groups, the difference in the TTs' distribution among the three categories of explanations results at slightly lower levels of significance (Set 1: $\chi^2= 19,42$, $p< 0.001$; Set 2: $\chi^2= 17,03$, $p< 0.001$).

Figures 6.1 and 6.2 also show the results concerning the nature of the TTs' explanations in the post-test for both groups. By comparing the pre- and post- test results, differences between the categories of explanation are evidenced for both groups (Set 1: L-group, $\chi^2= 49.44$, $p< 0.001$, H-group, $\chi^2= 24.68$, $p< 0.001$; Set 2: L-group, $\chi^2= 39.19$, $p< 0.001$, H-group, $\chi^2= 17.09$, $p< 0.001$).

These results suggest that the learning approach developed in the workshop gave to TTs of both groups opportunities to elaborate their own models in order to describe and explain thermal processes; nevertheless L-group TTs seem to have improved more. Tables 6.2 and 6.3 show the ratios between the frequencies in the post-test and the corresponding frequencies in the pre-test, for both groups and for the three categories of explanations.

Table 6.2

Set 1: ratios between the post-test frequency and the pre-test frequency in the two groups for the different categories of explanations.

Groups	Ratio(E-category)	Ratio(D-category)	Ratio(I-category)
L-group	0.35	1.41	4.36
H-group	0.31	0.57	2.09

Ratio (category) = frequency of answers of a given category of in the post-test / frequency of answers of the same category in the pre-test

Table 6.3

Set 2: ratios between the post-test frequency and the pre-test frequency in the two groups for the different categories of explanations.

Groups	Ratio(E-category)	Ratio(D-category)	Ratio(I-category)
L-group	0.28	1.43	3,17
H-group	0.21	0.69	1,76

Ratio (category) = frequency of answers of a given category of in the post-test / frequency of answers of the same category in the pre-test

The analysis of the ratios in both Sets 1 and 2 shows a decrease of the E-category of answers for both groups, an increase of the D-category and a very high increase in the I-category of explanations for the L-group. For the H-group the I-category shows also an increase while the D-category shows a decrease.

The data indicate that TTs of the L-group showed an initial significant lower level of categories of explanations than TTs of the H-group, although they appear to have gained more by the new learning method.

In order to look for insights into individual learning outcomes, the TTs' answers in the pre- and post- tests have been more carefully analysed. TTs have been classified in three different classes on the basis of their aggregate answers to each test. Assigning a numeric value of 1 to all E-category answers, a value of 2 to all D-category answers and a value of 3 to all I-category answers, I-class includes all the TTs that obtained a total score comprised between 8 and 13, II-class include all the TTs that obtained a total score comprised between 14 and 19 and III-class include all the TTs that obtained a total score comprised between 20 and 24. On the basis of their answers to the pre-test, in Set 1 (28 participant TTs, academic year 2000/2001) 26 TTs have been classified into one of the three classes, described above, only 2 TTs having given answers not coherent with one of the assessment categories (i.e. total score less than 8, due to too many answers not given). Among these, 24 TTs have been successively classified in one of the three classes, described above, on the basis of their answers to the post-test. Consequently we could analyse, in Set 1 a sub-sample of 24 TTs. At the same manner, in Set 2 (25 participant TTs, academic year 2002/2003) 23 TTs have been classified into one of the three classes, E, D or I. All of them have been successively classified in one of the three classes on the basis of their answers to the post-test. Consequently we could analyse, in Set 2 a sub-sample of 23 TTs.

Tables 6.4 and 6.5 report the contingency tables for Sets 1 and 2, showing the number of TTs classified in the three different classes on the basis of the pre- and post- test results. The categories along the two sides represent the classifications in the pre-test and in the post-test, respectively. The tables show the changes which took place in the TTs' classification on the basis of the kind of explanations supplied to two items in the pre- and in the post- tests. In both data sets, a shift can be observed from I-class to II-class and III-class (for example, in Set 1, among the 10 TTs classified, on the basis of the pre-

test, in the I-class, 3 remained in the same class, 2 shifted to the II-class and 5 to the III-class; in Set 2, among the 9 TTs classified in the pre-test in the I-class, 3 remained in the same class, 1 shifted to the II-class and 5 to the III-class). A shift is also observed in Set 1 for 4 of the 9 TTs classified in the II-class on the basis of the pre-test and in Set 2 for 5 of the 9 TTs classified in the II-class on the basis of the pre-test.

Table 6.4

Set 1: contingency table showing the number of TTs classified in the I-class, II-class and III-class in the pre-test and in the post-test.

	I-class(post-test)	II-class(post-test)	III-class(post-test)	Total
I-class(pre-test)	3	2	5	10
II-class(pre-test)	0	5	4	9
III-class(pre-test)	0	0	5	5
Total	3	7	14	24

$$\chi^2 = 10.01, p < 0.04.$$

Table 6.5

Set 2: contingency table showing the number of TTs classified in the I-class, II-class and III-class in the pre-test and in the post-test.

	I-class(post-test)	II-class(post-test)	III-class(post-test)	Total
I-class(pre-test)	3	1	5	9
II-class(pre-test)	0	4	5	9
III-class(pre-test)	0	0	5	5
Total	3	5	15	23

$$\chi^2 = 9.54, p < 0.05.$$

The analysis of the TTs' worksheets and the reports of class discussions gave us information about the teaching strategies that could account for the TTs' learning gain.

Other qualitative data

The analysis of data concerning TTs' worksheets, reports of class discussions and observations of laboratory work was performed by the two tutors and the researchers. It

was aimed at clarifying the process of development of PCK of our TTs by pointing out their growing awareness of what they knew and of what they needed to know and how their awareness grew. The results also give an indication of the changes in the TTs' subject matter knowledge supported by the performed learning activities in all the phases of the workshop.

All the qualitative data show that modifications in TTs' abilities and knowledge were individually coming to light, while the workshop progressed. We here refer to prevalent features of TTs' behaviours and to some factors that have been identified as mainly responsible of fruitful changes.

The analysis of data concerning the initial part of the workshop supplies us some keys of interpretation of the surprising pre-test results: in fact, although thermodynamics was a familiar topic for all the TTs, they had not been involved in elaborating and investigating the topic in a context focusing the direct analysis of experimental facts (or phenomena) without any direct reference to formulas and/or laws to apply. The majority of our TTs showed two levels of analysis: a concrete level, where a given process is explained on the basis of analogue processes showing the same characteristics, and a formal level where formulas and laws are applied to solve problems.

As an example, we report two transcripts of discussions registered by the researchers, at the beginning of the workshop, relating the analysis of thermal conduction phenomena. The first transcript refers to the discussion between two TTs (named A and B) and the tutor (T); the second one to the discussion between three TTs (C, D and E) and the tutor (T).

Transcript 1

Activity: Analysis of an experimental situation: two equal hot bodies (initial temperature $T = 60^{\circ}\text{C}$) cooling in two environments at different temperatures (40°C and 20°C).

T: Do you think that this experiment is related to the situation you have analysed in the item 4 of the pre-test?

A: Yes, ... item 4 describes a process of heating, here we have to analyse a process of cooling, but in both cases the processes occur in two environments at different temperatures.

T: You answered to item 4 that the two bottles, after some time, will reach the environment temperatures, but you have not supplied any kind of explanation.

A: It is clear..... The two bottles must reach an equilibrium condition.

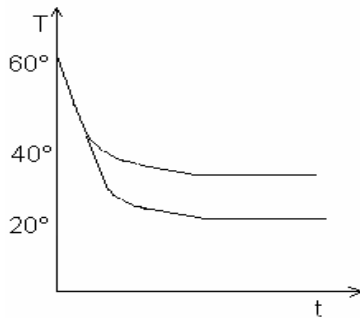
B: Yes.....All the bodies are at the temperature of their surrounding.

T: You have seen (in the first phase of the workshop) that many pupils think that this is not the case. How do you think that you can convince them?

B: We will arrange an experiment to measure the temperatures.

T: Can you predict the kind of plot of temperature vs. time you will obtain for the two bodies?

A and B, after some tries, agreed that the plot reported on the left is the best prediction.



Sketch drawn by TTs

A: The two bodies start to cool....., when the first reaches the temperature of 40° it stops to cool and the second continues until its temperature reaches 20°. The cooling curves are exponential curves.

B: Yes the first body will make over less heat to the surrounding,..... in fact, $Q = C\Delta T$, where C = the thermal capacity and ΔT the variation of temperature. C is the same in the two cases, but ΔT is less in the first case,..... I am sure, it will go faster to the equilibrium.

Tutor's comment: **A and B** seem not to have understood the role of the environment temperature in the rate of heat transfer process. I suggested to perform the experiment and, then, to reflect on the obtained data.

Transcript 2

Activity: Cooling of two object X (a sphere of glass) and Y (a sphere of aluminium) of the same dimensions and of almost the same mass. The two spheres were taken out from the same oven (at $T=60^{\circ}\text{C}$) and placed on the laboratory table (T of the environment is equal to 18°C). TTs were requested to predict the evolution of the temperature of the two sphere, to perform an experiment in order to test their prediction and then to supply an explanation of results.

D: I think that the two spheres will reach the temperature of the surrounding.

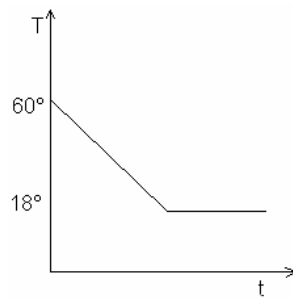
C: But they are not equal, their material is different,..... they will behave in a different way.....

T: In what their behaviour will be different?

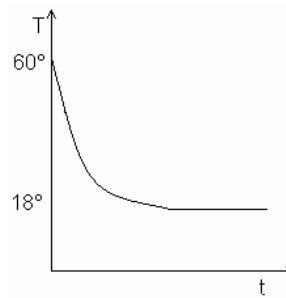
D: They cannot behave in a different way since they must cool to the temperature of their surrounding. This is the zero principle of thermodynamic.

E: Yes both will reach the temperature of 18°C .

T: Can you predict the kind of plot of temperature vs. time you can obtain if you put a thermometer inside each body?



Sketch drawn by **D**



Sketch drawn by **C**

T: Despite of the fact that the approach to the equilibrium is linear or on the base of a different curve, do they reach the equilibrium in the same time?

D: This depends on their thermal capacity.

E: No... this depends on their thermal conductivity, but perhaps also by their heat capacity.....

C: I think that we have to do the experiment..... It is impossible to predict the time of cooling.....

T: O. K. Can you predict if they will cool in the same time or in different times, or at the same rate or at different rates?

C: Usually metals are better thermal conductor than glasses, then..... perhaps the aluminium sphere will become cool in less time.

E: Yes it is a better conductor

T: Why?

C: Its heat will flow more easily toward the surrounding.

Tutor's comment: **D** and **E** seem not to have understood the physical meaning of the concepts of heat capacity and thermal conductivity. I suggested to perform the experiment and to reflect on the obtained data. **C** was a TT of the H-group and he seemed to apply the correct physics concepts in order to analyse the experimental situation, but he was not able to make some hypothesis about a mechanism (even at qualitative level) useful to explain the situation..

The TTs' understanding of the analysed physics topic was usually weak; their university courses supplied some sets of formulas that they were able to superficially manipulate in order to solve some quantitative problems, without deeper understanding of the fundamental concepts involved.

Although our physics educational reconstruction was aimed at high school level, we verified that the approach produced in TTs a better understanding of the physics content: at the beginning of the workshop, they were not able to relate ideas and concepts learned in their physics courses to real-world contexts while, as the workshop went on, they appeared more and more able to apply their knowledge in programming and performing experiments and in pointing out relationships among variables and explanations.

The TTs' progress in scientific thinking was revealed by specific details (drawn from reports of class discussions and observations of laboratory work) concerning some elements that facilitated their learning. Some of such elements are here reported, together with some examples of discussions of TTs during their lab-work.

- a) The request to verbalize ideas forced TTs to confront aspects they were unsure of and to recognize similarities and differences between their ideas and those of colleagues.

Two TTs (named **M** and **N**) are requested by the tutor to put a small glass containing water into the freezer. A temperature sensor was also put inside the glass in order to register the plot of temperature vs. time. The two TTs were asked to predict the shape of such plot.

M: The freezer is at -18°C , so the water temperature will decrease from $T=20^{\circ}\text{C}$ (the initial temperature of the water) to -18°C and then it will maintain this value. (She plots (on the plane $T-t$) an oblique segment representing the decrease from 20°C to -18°C and an horizontal segment at -18°C representing the equilibrium state).

N: The water temperature cannot go to -18°C .

M: Why not?

N: It becomes ice.

M: O.K. We will have ice at -18°C .

N: It is not so easy..... I remember that something happens, when water is transformed into ice.

M: Yes, this happens at zero degrees.

N: Yes,..... but I also remember that during the transformation the water temperature does not change then, it must stop at 0°C .

M:I am not sure,..... the equilibrium is at -18°C and the change of state is at 0°C it is better if we ask the tutor.....

T: Make the experiment and then we will discuss the problem.

- b) The request to make predictions, formulate and test personal hypotheses forced TTs to make explicit their representations of phenomena.

T: From the experimental plot you can see that we have two processes: the cooling and the change of state.

M: Yes, at zero degrees the temperature remains constant for some minutes and then begins to decrease again.

T: This is the fact. Can you make some hypothesis about the exchange of heat with the surrounding?

N: During the change of state the water stops to transfer heat to the surrounding since the temperature is constant.

T: Then, you think that we can obtain a change of state of matter without supplying or to taking away heat from the body.

M: No this is impossible,..... we have to supply heat to transform liquids in vapours and I think that we have to take away heat in order to transform water in ice that is solid.

N: Oh yes..... Heat continues to flow from the water to the cold surrounding, but the temperature does not decrease for the heat of fusion that is the opposite of the heat of solidification.

M: I don't understand..... What supplies this heat?

N: The molecules of water..... They must assume a rigid structure. To do this they have to make over,.... to transfer energy..... I do not know what kind of energy.

The tutor continues to analyse different qualitative microscopic models that can help TTs in visualising what happens at the melting point.

The reported discussions show that, very soon, TTs showed to possess knowledge of facts and laws involved in the analysed phenomena, although this knowledge was mainly entrusted to memory. To have learned the facts seemed insufficient to reach a coherent understanding of the involved concepts. This was evidenced by observing TTs during their lab-work concerning simple heat transfers as well as changes of state.

In conclusion, testing thinking through practical investigation induced TTs to review, refine and reformulate thinking in the light of experimental evidence. Although our approach was aimed at modelling, laboratory experiments played an essential role: TTs needed much 'hands-on' involvement to get a feel for the phenomena they had to model.

In fact, the topics supported by experimental work have been better understood and stimulated more TTs' interest.

The analysis of TTs' worksheets shows that they initially intended the experiments as verifications of the studied theory and, for this reason, assigned much more relevance to quantitative experiments designed to 'verify laws'. They were not used to look to experiments as a controlled reproduction of phenomena in order to search for correlations among variables. At the beginning of the workshop, they persistently asked to know what results they were supposed to obtain; only at the end of the workshop they started to appreciate a possible different pedagogical value of the experiment.

We find an example of this kind of approach in the TTs' worksheets concerning the study of thermal properties of gasses. This topic is widely studied in Italian high schools as well as in university introductory physics courses. This involves that the laws of gasses are usually well known by the majority of graduates in mathematics, physics or general science. The worksheet gave to TTs three assignments: a) to suggest observations evidencing the behaviour of a given quantity of air when its temperature is modified; b) to identify the involved physical variables; c) to perform an experiment useful to identify the relationships between the relevant physical variables.

We found out that more than half of TTs presented an introductory part where they described the laws about thermal properties of gasses from an historical point of view (according to the classic Charles's and Gay-Lussac's formulations). Successively, they provided experimental situations that qualitatively evidenced the relationships between the involved physical variables and, then, they performed experiments useful to verify the formal descriptions of the gas laws.

A different approach had been later followed by TTs when they were requested to analyse situations where gasses, at constant temperature, were modified in their volume or pressure. The majority followed the approach proposed in the worksheet: -by identifying situations of everyday life (the functioning of a bicycle pump, a syringe with its bottom closed,.....) useful to evidence some relationships between the relevant variables; -by making qualitative hypotheses about these relationships; -by programming and performing experiments in order to make these relationships quantitative.

In introducing the modelling procedures, emphasis has been given to the concept of physics model as a representation of the observed reality and to its connection with the

involved experiential field. This approach presented two kinds of initial difficulties met by TTs:

- I. TTs were not fully aware of the difference between descriptive and explicative models (Gilbert, Boulter, and Rutherford, 1998);
- II. they (mainly at the beginning of the workshop) were easily induced to give interpretative explanations based on their knowledge rather than on the appreciation of the entities composing the studied systems and their observed/measured properties.

Concerning the first point, many discussions (in small groups or involving the whole TTs group) had been devoted to point out that model-based reasoning are strongly based upon different kinds of hypotheses (Giere, 1990): empirical law hypotheses, that are summaries of perceived patterns in observations and explanatory model hypotheses, introducing models able to be represented at a theoretical level and often containing currently unobservable entities. The study of gas properties gave TTs a good support in understanding this distinction. In fact, being merely able to make predictions from the empirical gas law ($PV = nRT$) is not equivalent to understand explanations, for gas behaviour, in terms of a sense making model of billiard ball-like molecules in motion. As described by TTs:

- the model provides a description of a hidden process that explains how the gas work;
- the model answers “why” questions, since it hypothesises about where observable changes in temperature and pressure come from;
- the model explains mechanism of functioning;
- the model makes visible things invisible.

While the workshop went on, TTs gradually became able to produce explanations based on interpretative and predictive procedures rather than confine themselves to descriptive explanations (how the phenomena behave) or explanations given by quoting a theory from which a law or a concept may be deduced.

Concerning the second point, related to the difficulties faced by TTs in connecting models to the involved experiential field, we focused on two factors that, in our opinion, are relevant for the understanding of the modelling process: i) to clarify that models are selective abstractions of reality, constructed in order to make sense out of what we are

experiencing; ii) the careful and gradual enlargement of the experimental field, pointing out the need to correlate model properties and experimental outcomes.

The understanding of the need of a selective abstraction is well described by a TT:

If I am trying to understand the reason why my daughter isn't doing well in arithmetic, I safely ignore the colour of her eyes, when I select the aspects of reality to be included in the mental model I am constructing. But, if I want to choose a blouse for her, eye colour has to be included in the mental model I am going to build of my daughter..... A model must include the aspects of reality that help us to understand.

The need to connect model properties to experimental outcomes is particularly relevant for the topic chosen; in fact, the research evidence for pupils' difficulties in grasping the scientific view of temperature, heat, and internal energy is considerable. It is well known (Engel-Clough and Driver, 1985; Rozier and Viennot, 1991) that most pupils consider heat simply as something hot that warms other things. This 'something' corresponds to a hot body or to a kind of substance given off by a heat source. Moreover, many ideas, simplification of the full scientific picture and rather closer to the 18th century 'caloric' model of heat, are useful in understanding many everyday phenomena.

In our approach, empirical qualitative and/or quantitative experiences were strictly integrated with the search of explanations through modelling procedures. The main point was in maintaining coherence between the models and the corresponding experimental field which provided the experiential basis for meaning making. For this reason we called upon the introduction of 'intermediate models' that, in our opinion, would help pupils to the transition from their spontaneous models to the more abstract kinetic model. The 'intermediate model', which we introduced in this case, is very similar to the 18th century caloric model. The kinetic model was introduced later, consequently to the gradual enlargement of the experimental field (change of state and equivalence between heat transfer and work production), as a more powerful conceptual model in order to find a common explanation of all the observed phenomena. Intermediate and pragmatic qualitative models have already been successfully adopted in other teaching learning situations (Linn and Songer, 1991).

TTs were guided in the pedagogy of modelling procedures through metareflection activities in order to stimulate them to make explicit their personal content knowledge as well as to describe the strategies to be activated in order to present to pupils the

procedures connected with the modelling process. The following is a transcript taken from a TT worksheet.

Activity: Analysis of a simulation aimed at visualising small systems of molecules undergoing a phase change (through variations of the ratio between the mean potential energy and the mean kinetic energy per molecule).

The simulation shows that if we heat a liquid substance we obtain an increase of the kinetic energy of molecules interacting with the heat source. This also involves the increase of the mean velocity of molecules and this fact can produce a breaking of the forces that maintain bonded the liquid molecules. Some molecules become free (as in the gas phase). The energy supplied is used by the liquid molecules to break the bond and to transform themselves in gas molecules. This involves that until all molecules are not in the gas phase the temperature does not change. Energy is not used to increase the temperature, but to break the bonds among molecules. The contrary happens in the transition from gas to liquid.

Then, we can improve our previous model of heat (energy transferred by hot bodies that produces an increase of temperature) by introducing a model at microscopic level: at the interface between hot and cold bodies a transfer of kinetic energy occurs between the interacting atoms or molecules, involving the variation of temperatures, related to the mean kinetic energy per atom or molecule.

By analysing the difference in metacognition processes activated by low and high performing TTs, we have pointed out that the former, also at the end of the workshop, found many difficulties in the modelling process: they persisted in searching for model features in their physics knowledge rather than in the empirical evidences and/or properties of the analysed systems (for example, even if the performed experiments were adequately explained by the qualitative model of heat flow, they searched for a 'more complete explanation' recalling information irrelevant from an experimental point of view).

Metareflection processes have been mainly involved in the fifth phase of the workshop, where TTs were requested to prepare a Learning Unit inspired by the approach experimented during the workshop. They were asked to choose an everyday phenomenon, an experimental problem or a particular pupil learning difficulty (among those evidenced in the first phase of the workshop) and, working in groups of two or three, to develop a project for classroom activities involving nearly two class periods.

TTs spent three/four hours in lab-activities, discussing their ideas with the tutors, and then completed their work at home. The majority of TTs chose to work in couples (Set 1: 11 couples; Set 2: 8 couples) and focused their Learning Unit on the analysis of an

experimental situation. 6 of Set 1 TTs and 9 of Set 2 TTs chose to work in groups of three and addressed their learning units to pupils' learning knots faced in the first phase of the workshop: a group of Set 1 and all three of Set 2 focalised their work on the teaching/learning problems connected with the concepts of heat and temperature; the remaining group of Set 1 addressed its work to the concept of pressure of gasses (from a macroscopic and microscopic point of view). It is interesting to note that for both Sets, some of the TTs that chose the heat/temperature concepts did not seem to have clearly understood, in the first phases of the workshop, the two physical concepts.

The discussion registered during the initial phase of the preparation of the Learning Units allowed us to explore not only the TTs reasoning about the physics content, but also how that thinking was influenced through the teaching and learning experiences they encountered. Consequently, TTs began to be able to identify valuable implications for their own teaching.

The majority of TTs seemed, from the beginning, to have a clear orientation in identifying in detail goals of their Unit: these were usually defined as goals for knowing and doing (what pupils should know and be able to do). Very few TTs defined the main goal of their Unit as, for example, 'the knowledge of the heat concept', rather they used such expressions 'to know that heat can be transferred through materials...'. The need to make explicit the main idea of their Learning Unit as well as what they thought that pupils could learn about this idea, activated some effective procedures of metareflection triggered by appropriate questions posed by the tutors, such as:

- Which knowledge about pupil common knowledge influences your teaching of the main idea of your Learning Unit?
- Which other factors influence your choice of the sequence and pedagogical strategies?

Tutor and researcher analysis of the prepared Learning Units has pointed out a basic agreement about some key features of the TTs' learning processes as well as how the awareness of the nature of learning itself produced useful changes in their PCK. The two key elements that, in our opinion have triggered this change are: 1)-the knowledge of specific conceptions and learning difficulties of pupils and 2)-the knowledge of instructional strategies incorporating different representations of subject matter. These

two points can be considered, according to Shulman (1987), as two relevant categories in describing PCK. Moreover, some TTs' sentences show that these key elements can be translated in operative characteristics of the PCK, as reported in the following points.

- To take into account that explanations are built personally by the learner. This involves that the subject matter knowledge required for teaching has to encompass much more than scientific facts if teachers are to develop understanding.
 1. pupils experiment that wood seems, to the touch, warmer than metal. I can perform an experiment that shows that this is just a tactile sensation. However, I have also to explain what is the mechanism that brings to this conclusion on the basis of the touch sense. It is necessary to introduce thermal conductivity that will give insights to understand the sense of hot or warm and how this is related to the rate of cooling or heating.
 2. the fact is that in order to increase of 20°C the temperature of 100 gr. of water I need more heat than to increase of 20°C the temperature of 100 gr. of oil. However, I have to answer to the question 'why' in order to convince my pupils. I need a repertoire of models giving explanations at different levels of accuracy and formalisation.
- To help learners to build connections between tacit knowledge/beliefs and scientific explanations must be accomplished in relevant and meaningful ways.
 3. the proposed experiment is aimed at connecting the pupil idea that 'the temperature of a body is the amount of heat in the body' with the scientific meaning that temperature is an intensive quantity.
 4. in teaching the changes of state of matter, I have to take into account that usually, pupils do not know the stability of temperature during a change of state, but also that such a stability over time is often considered as affected by the rate of heating. The activities proposed in this Unit are aimed at giving experimental supports for such behaviour of matter and at finding qualitative explanations of what is happening to the liquid, at the molecular level, in order to make sense for temperature invariance.
- To search for qualitative explanations (also for what had been previously taught to them in a quantitative way) has a relevant role in developing understanding and empowering the potentiality of using instructional strategies incorporating different representations of subject matter.
 5. In order to design a teaching sequence for the analysis of the thermo-elastic properties of gases, we take into account some specific features of atomic models and some pupils 'misconceptions' and ways of reasoning. We choose the characteristic properties of the analysed model in close

connection to phenomena. Such model will make possible the explanation and the prediction of phenomena at a qualitative level. Then, the model will be improved to take into account some quantitative characteristics of the analysed phenomena.

6. Our Learning Unit concerns the distinction between the concepts of heat and temperature in the analysis of thermal properties of gasses. Our objective is to make students put into play microscopic models instead of complying with phenomenological explanations. Pupils initially will carry out an experiment (the dilatation of heated gasses), afterwards we introduce a first qualitative model of heat flow and, then, they are guided by appropriate questions to provide explanations of the observed experiment in terms of the model. Successively, an experiment of variation of gas pressure temperature will be analysed and the model will be improved to account for the new properties of gasses. A kinetic model of heat transfer will be, then, introduced.

It can also be considered a result the following comment of a TT:

“To have experienced the same learning environments we are supposed to realise in our future classrooms had, on one hand, put in evidence the learning knots of the topic, and on the other, extended our subject matter knowledge”.

6.2 Conclusions

The findings previously reported allow us to draw some conclusions about our research hypotheses aimed at implementing useful and formative strategies for science teacher preparation.

Concerning our first research question, we can conclude that the initial subject-matter understanding of our TTs was not adequate to develop the disciplinary competencies required by teaching approaches which focused on modelling of the natural world. Although many of them showed a good knowledge of thermodynamics, they were not equipped with a deep knowledge of some significant factors which are considered relevant in influencing modelling learning, such as: to encourage accurate observations of phenomena, to carefully plan experiments and to search for predictive explanations.

This involved focusing our study on the difference between knowing and understanding and on the role of explanations in understanding. In fact, explanations must provide learners with a convincing and coherent rationale for their observations and ideas about how the world works. The relevant value of qualitative reasoning in the

understanding of physical systems has been pointed out (Dillon, 1994). Such qualitative reasoning is relevant in understanding scientific ideas as well as in translating them into effective pedagogy, i.e. the resourceful knowledge of pedagogical implications for teaching a given topic. As a consequence, the search for explanations deeply grounded on qualitative reasoning has become the central point of our approach.

Concerning our second research question, our data show that the implemented teaching/learning environment had been effective in guiding TTs toward the construction of an appropriate PCK. In fact, to allow TTs to experience the same learning environments they were supposed to implement in their future classrooms showed a two-fold advantage: they could directly verify their pedagogical validity and, at the same time, made use of them to master the physics subject at the level of conceptual understanding that they will need to develop in their future students.

Some basic principles of metacognitive instruction have shown their validity in making TTs aware of their future role of teachers, and among these:

- to emphasise learning activities and processes, rather than learning outcomes;
- to spend sufficient time in reflecting on learning strategies and self-regulation skills.

The application of some aspects of Schön's (1988) reflective practitioner, in some phases of the workshop, helped TTs to think about teaching and planning in ways that they had not before. They gained, through reflection, a framework in order to build meta-learning awareness in terms of both the content and process of learning. In our opinion, this framework helped them to generate significant changes in their teaching/learning approach.

Concerning our third research question, we can infer that to gain familiarity with the pedagogical tools, useful for the required modelling procedures, was relevant for the conceptualisation of the physics model role. The possibility to change parameters, variables, fitting functions in an easy way, gave TTs a deeper understanding of model features. As previous researches have shown (Schecker, 1993; Raghaven and Glaser, 1995), the activities performed using both laboratory work and access to computer modelling facilities stimulated TTs to play an active role in the modelling process and in appreciating its role in developing ideas and explanations. Moreover, the Learning Units realised by our TTs gave us evidence that the acquired abilities in the modelling procedures can be effectively translated in the ability to transfer knowledge to pupils.

According to our results, the familiarity with the pedagogical tools is related to good conceptualisation of the physics model role and to good ability in planning activities to transfer knowledge to pupils.

As it has been pointed out (Duit, Roth, Komorek, and Wilbers, 1998) personal construction of knowledge is related to the context. Moreover, metareflection strategies, in order to be effective, should be practised in a given context (Magnusson, Krajcik, and Borko, 1999). How these abilities can be transferred in situations that are subjected to different contextual, situational and personal influences needs further research. This involves that an answer to our fourth research question can be given in terms of evidence of acquired knowledge and abilities. We can infer that many of our student teachers gained good levels of PCK, but how it will be translated in effective competencies, to guide a given classroom in a given teaching/learning approach, requires further research.

In order to draw some conclusions concerning the adequacy of our approach for the construction of an appropriate PCK, we would like to outline that most research on teachers' PCK has pointed out relevant general elements concerning the nature and the development of PCK, rather than to investigate science teachers' PCK development with respect to specific topics. PCK was initially perceived as encompassing knowledge of representations of subject matter and understanding of specific learning difficulties as well as student conceptions with respect to specific topics (Shulman, 1986b). However, it must be taken into account that very soon prospective teachers (and some times experienced teachers) show the same learning difficulties and representations of their future pupils. This fact points out the need to supply TTs with tools aimed at a deeper understanding of specific topics.

Other researchers have pointed out the need to design teacher education programs aimed at studying the subject matter of specific topics from a teaching perspective: i.e. by studying the structure and evolution of pupils' ideas about particular topics as well as by emphasising possible different representations of the same topics (Shymansky, Woodworth, Norman, Dunkhase, Matthews, and Liu, 1993). Our research identified the importance of a thorough and coherent knowledge of subject matter and offers general guidelines in designing teacher education programs aimed at the development of PCK. In our view, the value of PCK lies essentially in its relation with specific topics. Therefore, PCK is to be discerned from general pedagogical knowledge on the one hand,

and from subject-matter knowledge on the other. As the results from our case study show, we have gained insight into the ways physics teachers can transform their knowledge of thermal properties of matter not only to stimulate pupil understanding of this topic but also to gain a better understanding of the topic. Our study shows ways to provide prospective teachers with a knowledge base which enables them to teach specific topics in a more effective and flexible way.

The identified teaching strategies are not useful in a universal sense, but this does not involve to conclude that they refer exclusively to this topic. Some research studies in different scientific fields show similar results (Niess and Scholz, 1999; van Driel, De Jong, and Verloop, 2002). We argue that our study may significantly add to the value of the concept of PCK within the domain of research on science teaching and that other teachers may benefit from this type of topic-related PCK as it can be used as input in pre-service or in-service teacher education.

7. Summary

Introduction

Many international surveys and research results show that, in these last years, the more technologically developed countries are facing a worrisome haemorrhage of interest of the young population towards the scientific culture. This situation is reflected also from the fact that enrolments in University scientific faculties are now at their lower levels. Diagnosis for such situation must take in consideration several factors, amongst which one have to certainly 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 to guide 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 restructuring of Science, and in particular Physics, Education appears to be more compulsory than simply needed and, in doing this, it is impossible to ignore the fundamental role played by teacher during the educative process. On the other hand, 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 possess and improve to help their future pupils to actually develop a *culture* able to usefully understand the scientific progress. 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 physics courses is not adequate to teach physics according to many proposed innovations involving deep changes in contents and pedagogical methods.

New models of pre-service Physics teacher formation have, then, to be thought and experimented to transform and deepen prospective teachers' understanding of subject matter and to redirect their habitual ways of thinking about *subject matter for teaching*. Prospective teachers must understand the importance of modifying the "classic" 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 is a not so easy objective, as it really involves a substantial 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 experience pre-service teachers the same teaching/learning environments we think they will have to provide to their pupils during actual classroom activities. 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 have 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 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).

In the research this dissertation is based on, we share the hypothesis that a focus on metareflection is key to getting students to learn with greater understanding. The structure and content of pre-service teacher preparation courses have to be organised to prepare teachers to carry out the teaching tasks required from the proposed teaching/learning approach focused on modelling procedures. Our research hypotheses concern 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.

The basic principles of our teaching method are the following:

- to make experience to prospective teachers attending our courses, the same learning environments they are supposed to realise 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.

With this in mind, the following interrelated goals were set for the model of pre-service teacher formation we want to discuss here:

- To project “Teaching/Learning Pathways” (TLPs) constituting the framework of “Pedagogical Physics Laboratory” courses of the Italian Graduate School for Pre-service Teachers Preparation (S.S.I.S.). These courses are thought to be *learning environments* where prospective teachers (TTs) develop new teaching approaches and strategies by performing a synthesis between scientific and pedagogic competences and enabling conditions for collaborative inquire in model building procedures. Each TLP is 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).

- To investigate 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 “Subject Matter Knowledge”, “Pedagogical Knowledge” and “Pedagogical Content Knowledge” (see Chapter 1 for a deeper discussion of these terms) and their role in teaching and learning.

About Teaching/Learning Pathways and Sequences

Several research-inspired pedagogic activities and approaches for improving students’ understanding of scientific knowledge have been developed as a result of ‘70s and early ‘80s research studies eliciting students’ conceptions regarding natural phenomena and concepts and to theoretical developments on teaching and learning as a constructive activity. An interesting line of inquiry involves the design and implementation of topic-oriented sequences for teaching physics, inserted in a more general context regarding a specific content to be developed; this trend can be inserted in the context of a science education research tradition by which teaching and learning are investigated at a micro (e.g. specific session) or medium level (e.g. single topic sequence) rather than at the macro level of a full year’s or multi-year curriculum

A distinctive feature of these pedagogic activities and products is their dual character: both research and development, targeting a close linking of the teaching and learning of a particular topic are involved. Actually, teaching sequences of that kind draw on the tradition of action research, being both research tools and innovations aiming at the handling of specific topic-related learning problems. Lijnse (1994, 1995) brought to the attention of the European research community questions and issues regarding the character of research into teaching sequences. It is argued that this sort of activity is a kind of “developmental research” involving the linking of design, development and application of a teaching sequence on a specific topic, usually lasting a few weeks, in a cycling evolutionary process enlightened by rich research data. Kattman et al. (1995) have developed a framework for elaborating and improving the design of teaching learning sequences in terms of “Educational Reconstruction”. It is worth noting that in

mathematics education, Artigue (1988) has already suggested a fruitful theoretical framework for developing teaching sequences drawing the attention to *a priori* epistemological analysis of the topic to be taught, an issue which is also fruitful for science education.

Though various terms have been used in the past, the term “Teaching/Learning Pathway” and the recently introduced “Teaching/Learning Sequence”, following recent international symposia, are now commonly used to connote the close linkage between proposed teaching and expected student learning as a distinguishing feature of a research-inspired topic-oriented sequence (Psillos and Méheut, 2001). A TLP and, more specifically, its component TLSs are both interventional research activities and products, like traditional curriculum unit packages, including well-searched teaching-learning activities empirically adapted to student reasoning. At times, teaching guidelines covering expected student reactions are also included. Considerations that in one way or another seem to influence the development of TLSs have included research into students’ conceptions, features of the specific scientific domain, epistemological assumptions, learning perspectives, current pedagogical approaches and features of the educational context.

A notable characteristic of a TLS is its inclusion in a gradual research-based evolutionary process aiming at linking the scientific and the student perspective and trying to fill the gap between scientific models and pupil’s alternative representations of natural phenomena. For this reason, a fundamental point in the design of a TLS is taking into account different aspects such as content analysis, epistemology, student’s conceptions and motivations, learning and pedagogical theories and other educational constraints.

Research methods adopted

Our research study was conducted by adopting qualitative as well as quantitative methods. We chose the classic ‘Case Study’ approach (Stake, 1995, 2000). Our ‘case’ is the sociological and organizational unit of our teaching/learning settings, with the intent of assembling its comprehensive description in terms of a discrete number of research objectives. In this sense, it is a multiple or collective case study: data obtained from TTs’ individual work and group interactions were analysed in order to produce a description of

the setting complexity and of the knowledge development of the class as a whole. Data were mainly analysed using a phenomenographic approach (Marton, 1988; Marton and Both, 1997), in order to reveal the different ways in which some classroom learning episodes were experienced by our TTs.

Chapter 3 reports some literature review about the research methods adopted in our study, based on well known papers widely available also on the world wide web. First, the main aspects of qualitative and quantitative research methods are discussed and their main characteristics, differences and similarities are analysed. Then, the Case Study method is described and the meaning of the phenomenographic approach to qualitative research is discussed by evidencing points of strength and also some criticisms .

Physical content dealt by the Research and description of the Teaching/Learning Pathway

We have chosen to experiment an educational reconstruction of physical content related to thermal processes. Lots of research results show that this subject matter seems to be harder to understand than others, at both student and teacher levels, maybe due to the fact that spontaneous models about thermal phenomena can be heavily persistent even after scholastic formation. A discussion about typical problems evidenced by pupils and teachers is reported in Chapter 4; here we want just to note how scientific view of thermal processes is subtle and difficult: their description in terms of microscopic structure of matter, or more simply in terms of the particulate nature of matter, shows many learning problems.

The educational approach developed in the TLP, described in Chapter 5, is related to the S.S.I.S. “Thermal Phenomena Laboratory” course, held by the author of this dissertation during two academic years, 2000/2001 and 2002/2003. Experimental data about TTs’ response to the TLP development have been gained during both the yearly courses and have been labelled respectively as Data Set 1 and Data Set 2.

In the approach, empirical qualitative and/or quantitative experiences are strictly integrated with the searching of explanations through modelling procedures. The main point is in maintaining coherence between the models to be taught and the corresponding experimental field which provides the experiential basis for meaning making. Model properties have to be at the same level of analysis as pupils' observations of the natural world. For this reason we call upon the introduction of 'intermediate models' that, in our

opinion would help pupils to the transition from their spontaneous models to the more abstract kinetic model. The 'intermediate models', which we introduced in this case, is very similar to the 18th century caloric model in which heat is intended as a substance and/or 'something' that flows from hot to cold bodies. This is a model of the category called by Gilbert et al. (1998) 'consensus models', that is, models that are important for the development of a given field of inquiry and are significant for provision of appropriate explanations readily accessible to pupils. The need to define in detail the model, their relationships with observations and experimental outcomes and how/where new 'ad-hoc' hypotheses are necessary, has been the main objective in introducing such intermediate models. The kinetic model is introduced later, consequently to the gradual enlargement of the experimental field, as a more powerful conceptual model in order to find a common explanation of all the observed phenomena. The modelling procedures are describe in the relevant section of paragraph 5.2.3.

Chapter 5 Appendix reports some pedagogical materials used during the TLP development. They include initial and final questionnaires, as well as laboratory and modelling activities worksheets. These last worksheets were used by TTs in a peer to peer learning environment, with the declared objective to make experience TTs the same learning environments they are supposed to realise in their future classrooms.

Data analysis and research results

According to the phenomenographic approach (Marton, 1988; Marton and Both, 1997) chosen for this study, our objective was in identifying how TTs experience, understand, conceptualise and make sense of the teaching/learning environment proposed by our workshop.

The main research questions involved in this study were the following:

- Are the nature and level of the TTs' initial physics knowledge adequate to develop the disciplinary competencies required in performing teaching approaches focused on modelling of the natural world?
- Was the proposed learning environment able to stimulate modifications in the disciplinary as well as pedagogical competencies required?
- How the characteristics of the proposed learning environment have modified TTs' approach to modelling procedures?

- What kind of evidence have TTs shown about their ability to transfer knowledge and abilities to their pupils?

Our approach in redesigning, implementing and evaluating the structure of the workshops was based on some preliminary hypotheses concerning our TTs physics knowledge and on the efficacy of some interaction strategies in the teaching-learning processes. As a consequence the data analysis was based on the research of supportive and non supportive evidence for our preliminary hypotheses.

The data to be analysed consisted in empirical material constituted by open answer tests, TTs' worksheets, direct observations of TTs' discussions, the Learning Units prepared by the TTs at the end of the workshop and open interviews conducted to all workshop's participants. The test analysis gave information about the different types of model building procedures, used by TTs, to explain thermal processes at the beginning and at the end of the workshop activities. The data scanning of the direct observations and TTs' worksheets gave information and new insights about the TTs' learning processes, their needs and the necessary supports, allowing the formation of new hypotheses about the workshop organisation. Moreover, the analysis of the Learning Units, prepared by TTs', allowed us to deduct information about the acquired competencies in transforming their physics knowledge in an aware PCK.

The TTs' written descriptions were qualitatively analysed and classified in categories, at the same manner for Data Sets 1 and 2. The construction of the analytic categories was based on a close reading of the TTs' explanations within a framework provided by domain-specific expertise. The specific categories into which the responses were coded are *everyday/practical explanation*, *descriptive explanation* and *interpretative explanation*. The category of *everyday/practical explanation* reflected the creation of situational meanings derived from informal every-day contexts. Answers categorised as *descriptive explanation* described and characterised the analysed process by summarising the perceived patterns, but did not explain the causal relationships of the physics involved parameters. The *interpretative explanation* proposed a qualitative model based on a cause/effect relationship or provided explanatory hypotheses introducing models, able to be visualised at a theoretical level.

A comprehensive analysis of data is reported in Chapter 6. We want just note here that significant differences emerged from pre-test and post-test analysis. While in pre-test

answers were mainly practical (42%, Set 1; 36%, Set 2) and descriptive (39%, Set 1; 42%, Set 2) in nature, suggesting that most students approached the topic on the basis of their everyday understanding of the phenomenon or confining their explanations to descriptions summarising some perceived patterns, a great shift to interpretative-type explanations has been observed in post-test analysis. 51% (Set 1) or 49% (Set 2) of post-test answers have been classified as interpretative in nature, including explanations proposing cause/effect relationships as well as more formal scientific explanations.

The analysis of data concerning TTs' worksheets, reports of class discussions and observations of laboratory work was aimed at clarifying the process of development of PCK of our TTs by pointing out their growing awareness of what they knew and of what they needed to know and how their awareness grew. The results also gave an indication of the changes in the TTs' subject matter knowledge supported by the performed learning activities in all the phases of the workshop.

All the qualitative data showed that modifications in TTs' abilities and knowledge were individually coming to light, while the workshop progressed. We here refer to prevalent features of TTs' behaviours and to some factors that have been identified as mainly responsible of fruitful changes.

The analysis of data concerning the initial part of the workshop supplied us some keys of interpretation of the somehow surprising pre-test results: in fact, although thermodynamics was a familiar topic for all the TTs, they had not been involved in elaborating and investigating the topic in a context focusing the direct analysis of experimental facts (or phenomena) without any direct reference to formulas and/or laws to apply. The majority of our TTs showed two levels of analysis: a concrete level, where a given process is explained on the basis of analogue processes showing the same characteristics, and a formal level where formulas and laws are applied to solve problems.

Transcripts of discussions registered by the researchers at the beginning of the workshop, relating the analysis of thermal conduction phenomena, are reported as an example in the second part of section 6.1.2. Summarising, the TTs' understanding of the analysed physics topic was usually weak; their university courses supplied some sets of formulas that they were able to superficially manipulate in order to solve some

quantitative problems, without deeper understanding of the fundamental concepts involved.

Although our physics educational reconstruction was aimed at high school level, we verified that the approach produced in TTs a better understanding of the physics content: at the beginning of the workshop, they were not able to relate ideas and concepts learned in their physics courses to real-world contexts while, as the workshop went on, they appeared more and more able to apply their knowledge in programming and performing experiments and in pointing out relationships among variables and explanations.

The TTs' progress in scientific thinking was revealed by specific details (drawn from reports of class discussions and observations of laboratory work) concerning some elements that facilitated their learning. Some of such elements are here reported.

1. The request to verbalize ideas forced TTs to confront aspects they were unsure of and to recognize similarities and differences between their ideas and those of colleagues.
2. The request to make predictions, formulate and test personal hypotheses forced TTs to make explicit their representations of phenomena.

The discussions reported in Section 6.1.2 evidenced the very fact that TTs actually showed to possess knowledge of facts and laws involved in the analysed phenomena, although this knowledge was mainly entrusted to memory. To have learned the facts seemed insufficient to reach a coherent understanding of the involved concepts. This was evidenced by observing TTs during their lab-work concerning simple heat transfers as well as changes of state.

In conclusion, testing thinking through practical investigation induced TTs to review, refine and reformulate thinking in the light of experimental evidence. Although our approach was aimed at modelling, laboratory experiments with real-time equipment played an essential role: TTs needed much 'hands-on' involvement to get a feel for the phenomena they had to model. In fact, the topics supported by experimental work have been better understood and stimulated more TTs' interest.

The analysis of TTs' worksheets showed that they initially intended the experiments as verifications of the studied theory and, for this reason, assigned much more relevance to quantitative experiments designed to 'verify laws'. They were not used to look to experiments as a controlled reproduction of phenomena in order to search for correlations among variables. At the beginning of the workshop, they persistently asked

to know what results they were supposed to obtain; only at the end of the workshop they started to appreciate a possible different pedagogical value of the experiment.

The findings previously reported allow us to draw some conclusions about our research hypotheses aimed at implementing useful and formative strategies for science teacher preparation.

Concerning our first research question, we can conclude that the initial subject-matter understanding of our TTs was not adequate to develop the disciplinary competencies required by teaching approaches which focused on modelling of the natural world. Although many of them showed a good knowledge of thermodynamics, they were not equipped with a deep knowledge of some significant factors which are considered relevant in influencing modelling learning, such as: to encourage accurate observations of phenomena, to carefully plan experiments and to search for predictive explanations.

Taking in consideration our second research question, our data show that the implemented teaching/learning environment had been effective in guiding TTs toward the construction of an appropriate PCK. In fact, to allow TTs to experience the same learning environments they were supposed to implement in their future classrooms showed a two-fold advantage: they could directly verify their pedagogical validity and, at the same time, made use of them to master the physics subject at the level of conceptual understanding that they will need to develop in their future students.

Concerning our third research question, we can infer that to gain familiarity with the pedagogical tools, useful for the required modelling procedures, was relevant for the conceptualisation of the physics model role. The possibility to change parameters, variables, fitting functions in an easy way, gave TTs a deeper understanding of model features. As previous researches have shown (Schecker, 1993; Raghaven and Glaser, 1995), the activities performed using both laboratory work and access to computer modelling facilities stimulated TTs to play an active role in the modelling process and in appreciating its role in developing ideas and explanations. Moreover, the Learning Units realised by our TTs gave us evidence that the acquired abilities in the modelling procedures can be effectively translated in the ability to transfer knowledge to pupils. According to our results, the familiarity with the pedagogical tools is related to good conceptualisation of the physics model role and to good ability in planning activities to transfer knowledge to pupils.

As it has been pointed out (Duit, Roth, Komorek, and Wilbers, 1998) personal construction of knowledge is related to the context. Moreover, metareflection strategies, in order to be effective, should be practised in a given context (Magnusson, Krajcik, and Borko, 1999). How these abilities can be transferred in situations that are subjected to different contextual, situational and personal influences needs further research. This involves that an answer to our fourth research question can be given in terms of evidence of acquired knowledge and abilities. We can infer that many of our student teachers gained good levels of PCK, but how it will be translated in effective competencies, to guide a given classroom in a given teaching/learning approach, requires further research.

In order to draw some conclusions concerning the adequacy of our approach for the construction of an appropriate PCK, we would like to outline that most research on teachers' PCK has pointed out relevant general elements concerning the nature and the development of PCK, rather than to investigate science teachers' PCK development with respect to specific topics. PCK was initially perceived as encompassing knowledge of representations of subject matter and understanding of specific learning difficulties as well as student conceptions with respect to specific topics (Shulman, 1986b). However, it must be taken into account that very soon prospective teachers (and some times experienced teachers) show the same learning difficulties and representations of their future pupils. This fact points out the need to supply TTs with tools aimed at a deeper understanding of specific topics.

Other researchers have pointed out the need to design teacher education programs aimed at studying the subject matter of specific topics from a teaching perspective: i.e. by studying the structure and evolution of pupils' ideas about particular topics as well as by emphasising possible different representations of the same topics (Shymansky, Woodworth, Norman, Dunkhase, Matthews, and Liu, 1993). Our research identified the importance of a thorough and coherent knowledge of subject matter and offers general guidelines in designing teacher education programs aimed at the development of PCK. In our view, the value of PCK lies essentially in its relation with specific topics. Therefore, PCK is to be discerned from general pedagogical knowledge on the one hand, and from subject-matter knowledge on the other. As the results from our case study show, we have gained insight into the ways physics teachers can transform their knowledge of thermal properties of matter not only to stimulate pupil understanding of

this topic but also to gain a better understanding of the topic. Our study shows ways to provide prospective teachers with a knowledge base which enables them to teach specific topics in a more effective and flexible way.

The identified teaching strategies are not useful in a universal sense, but this does not involve to conclude that they refer exclusively to this topic. Some research studies in different scientific fields show similar results (Niess and Scholz, 1999; van Driel, De Jong, and Verloop, 2002). We argue that our study may significantly add to the value of the concept of PCK within the domain of research on science teaching and that other teachers may benefit from this type of topic-related PCK as it can be used as input in pre-service or in-service teacher education.

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