INVESTIGATING TEACHER PEDAGOGICAL CONTENT KNOWLEDGE OF SCIENTIFIC INQUIRY

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ABSTRACT This paper analyses the scientific inquiry in the context of modelling physical systems and point out some related teaching/learning strategies. Two relevant points are also discussed: i)- the different representations of scientific inquiry held by a sample of secondary school physics teachers and their competencies in conducting investigations aimed at solving scientific problems; ii)- what kind of supports can be supplied to teachers in order to modify their misconceptions about scientific inquiry and develop adequate competences related to Pedagogical Content Knowledge of Scientific Inquiry. The topic will be analysed in the light of some preliminary results of a course for in-service physics teacher education held at University of Palermo in the framework of Establish, an FP7 EU Project.

1. Introduction

In designing innovative pedagogical materials usually supports for teachers' subject matter knowledge and pedagogical content knowledge for students' ideas (e.g., misconceptions), but rarely for pedagogical content knowledge of scientific inquiry, are provided. By inquiry we refer to learning experiences that engage students in various integrated activities of identifying questions, collecting and interpreting evidence, formulating explanations, and communicating their findings, that are consistent with science standards and recent reports (Duschl, Schweingruber,& Shouse, 2007; National Research Council, 1996; Singer, Hilton, & Schweingruber, 2005). Many researchers have shown that Inquiry-Based (IB) approaches to learning are able to increase student motivation, interest, understanding and development (Collins, 1997; Singer et al., 2005). However, despite the consensus found in educational research, teachers may have different ideas about the meaning of inquiry-based instruction and it has been shown that misconceptions abound (National Research Council. 2000). These mistaken notions about inquiry can, perhaps, deter efforts to reform science education.

In this paper, we analyse scientific inquiry in the context of modelling physical systems and point out some related teaching/learning strategies and how these are perceived by physics teachers. The topic will be analysed on the light of some preliminary results of a course for in-service physics teacher education held at University of Palermo in the framework of Establish (ESTABLISH, 2010), an FP7 Project aimed at extending the use of IBSE (Inquiry Based Science Education) in second level schools across Europe.

2. Theoretical Background

Despite the consensus found in educational research about the efficacy of IB approaches, it has been pointed out that misconceptions about IB instruction abound and serve to deter efforts to reform science education (National Research Council. 2000). The more relevant misconception involves the idea that " *IB instruction is the application of the scientific method"* Many teachers learned as students that the process of science can be reduced to a series of five or six simple steps. It has been shown that the notion that scientific inquiry can be reduced to a simple step-by-step procedure is misleading and fails to acknowledge the creativity inherent in the scientific process. Research has connected this view with what science's nature is perceived from samples of pupils and teachers (Akerson, et al., 2000; Lederman, 1992). Some studies showing that science teachers persist in holding views about nature of science qualified as empirical or naïvely empirical, identify two peculiar aspects in their thinking, involving: - the role accorded to observation, which is seen as giving experimental data an absolute value; - the role played by theory in conducting experiments and in making observations, along with the value of scientific knowledge as a means of explaining and predicting (Van Driel, et al., 1998; Glasson and Bentley, 2000; Abd-El-Khalick, 2005). Other studies report that teachers carry positivistic views of their discipline: i. e. they teach only the knowledge aspects of science and emphasize vocabulary rather than balance knowledge claims with knowledge generation and evaluation, and present science as "the method" of understanding the world (Gess-Newsome, 1999). Additional classroom consequences may include a decreased emphasis on inquiry-oriented and problem solving teaching methods that positively impact pupils' conceptions of science (Gess-Newsome, 1999; Lederman, 1992).

Teaching IB science entails ambitious learning goals for students and thus is complex and difficult for teachers to enact (Marx, et al., 1997; Roehrig & Luft, 2004). Moreover, most of teachers also have not experienced IB instruction as learners and thus need guidance in enacting this type of instruction (Windschitl, 2003). Researches specifically aimed at the implementation of the IB approaches to physics education have shown that teachers aren't able to make the transition from a purely transmitting didactics to an IB one only through the illustration of the new methods and strategies (Pinto, 2004). Training experiences based on new theoretical models have to be provided. Among these, models that underline the necessity of collaborative construction of understanding and reflection on the enactment of new practices in classrooms and on the consequent adaptation of materials and practices show a relevant efficacy. Such procedures require an accurate designing of the training activities where the roles of the different materials, the disciplinary conceptual knots, the problems related to the introduction of the innovative methods are evident. It has been pointed out that a conceptual change approach is not only relevant to teaching in the content areas, but it is also applicable to the professional development of teachers. For example, as constructivist approaches to teaching gain popularity, the role of the teacher changes. Teachers must learn different instructional strategies as well as also re-conceptualize or change their conception about the meaning of teaching.
Founding on research related to the Inquiry Based (IB) methodology and to models of the teachers training, our research takes as theoretical framework the following key points:

a) to analyze conceptions, reasoning schemes and teachers' knowledge in the light of the specific operative processes of an IB approach and to study how these can enhance or thwart the introduction of innovative strategies and contents;
b) to develop and to experiment a Training Action (TA) that proposes subjects and strategies focused on the specific operative processes of an IB approach.

3. Method

The TAs developed by our local project propose subjects and strategies focused on the specific operative processes of an IB approach, as well as on analysed ways to integrate them in a pedagogy aimed at pointing out relevant elements of a adequate Pedagogical Content Knowledge (Shulman, 1986) for SI. Some pilot teacher workshops (W) have been designed aimed at finding operative answers to defined research questions. Here, we report about some preliminary results of a 4 hours W where teachers were put in a real problematic situation that made them face with a real problem, whose solution required the activation of the typical operative processes (theoretical and experimental) of scientific investigation. Our research questions are the following ;

1) Which kinds of approaches to a complex problem are preferred by teachers ? Which cognitive resources are involved?
2) Which relevant procedures of scientific investigation are put in action and how are these intended by the teachers?

15 in- service secondary school teachers participated to the pilot workshop. They had different backgrounds of graduation, pre-service training and kind of teaching experience in different grade levels (junior or high school level). The W has been developed into two phases: a) analysis of a real problematic situation and development of a solution; b) reflection about the proposed solution and definition of the characteristics of the procedures put in action for the searching of the solution. During the first phase a real problematic situation involving the phenomenon of heat conduction through different materials was proposed to teachers (see Fig. 1).
In particular, teachers were requested, through a questionnaire, to look at seven different flat plates, different in material or mass, area and thickness and to predict what happens if seven identical ice cubes are placed upon them, i. e. to predict the time sequence of ice cubes melting. As a second question, they were requested to put into evidence the parameters they considered relevant in influencing the melting process, and to design a set of experiments devoted at checking the relevance of such parameters. Then, the experience was really performed and they were required to compare their predictions with the experimental results, writing down their comments.
The questionnaire sheets were photocopied and then returned to teachers for further processing. As a second phase teachers were divided into 3 groups (5 teachers in each group) to discuss their solutions with the guide of a researcher. The 3 researchers had previously developed common discussion guide-lines and questions in order to make explicit teachers conceptions about the meanings of investigation procedures as to make a hypothesis, to construct a descriptive model,

to find an explanation or to compare different kinds of explanations. All the discussions have been audio taped and the detailed analysis is in progress.

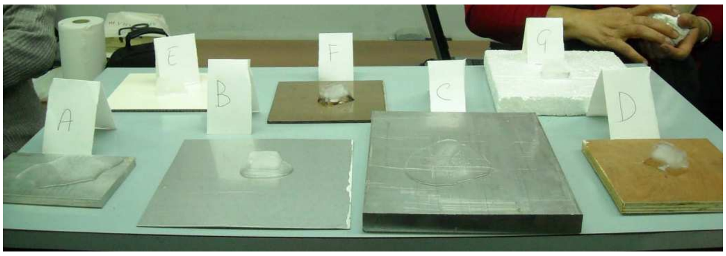

Figure 1. The experimental situation, first only theoretically proposed, then practically analyzed by the teacher group. Some ice cubes are placed on plates of different material, mass, area and thickness, identified by letters A, B, C, D, E, F, G, H.

4. Results

A detailed analysis of teacher incorrect predictions with the related explanations is in progress. We note here that all teachers correctly predicted that the ice cubes melt sooner when placed on aluminum plates, but only 3 teachers performed the correct prediction by appropriately ranking plates with different masses and thickness. By considering at a finer grain detail the predicted melting time sequence for the three aluminum plates (of different geometrical characteristics), as well as the teachers' explanations about the parameters that have to be taken into account for the correct description and explanation of the phenomenon, some considerations can be drawn about the procedures they followed in formulating their hypotheses.

The correct analysis of the proposed situation must take into account several parameters, i.e. the plates' geometrical characteristics (surface area and thickness), thermal capacity, thermal conductivity and the temperature difference between the two plate faces. All these parameters have to be considered together to correctly explain the phenomenon. An approach based on the typical theoretical knowledge about thermology, resulting from classical university education can easily guide the teacher to search for an explanation to the phenomenon based on thermal conduction, i.e. on the idea of heath flux between two surfaces at different temperatures. From the Fourier law, we know that this flux is proportional to the surface area and inversely proportional to the plate thickness, so thinner plates should make ice cubes melt quicker, as they allow a bigger heath flow. Indeed, for a clear understanding of the phenomenon other factors involved in the analysis of thermal interaction between two bodies (the ice cube and the plate that exchange thermal energy until equilibrium is reached) must be taken into account. This second kind of approach actually produces opposite predictions with respect to the previous ones, i.e. a greater melting speed of ice cubes placed on the thicker (and so heavier) plate. Our data show that 6 teachers appear to describe the phenomenon only on the basis of the Fourier law by considering as more relevant factor the plate thickness and 5 teachers that seem to consider thermal capacity as relevant for the explanation of the phenomenon, but not plate thickness or thermal conductivity coefficient. It is worthy to note that the 4 teachers performing the correct ranking (2 graduated in Biology, 1 in Physics and 1 in Natural Science) analysed the experimental situation by trying to point out the different characteristics of the various bodies and evaluating the relevance of each of them and not by searching, in their knowledge, for laws to apply to the experimental situation.

In comparing their predictions with experimental results, the majority of teachers that predicted the melting of the ice cubes on the basis of a partial acknowledgement of relevant variables expressed, in different ways, a sort of "surprise" with respect to the results. They did not try to search for an explanation of the differences by showing that their predictions were mainly driven by memory of subjects studied during past courses. Only a few made reference to the necessary comparison between what they remembered from textbooks and real-life experience. The great majority of teachers at last commented that the approach to the proposed situation posed them some difficulties, as it is one that is not part of their theoretical knowledge about thermology.

As previously mentioned, the group discussion during the second phase of the W was devoted to deepen the teacher conception of the different procedures involving in a scientific investigation stimulated by the real situation analysed. A preliminary analysis of the audio taped discussion shows the relevant factors described in the following.

During the discussion, all teachers mentioned (at least one time) the need to apply "the" Scientific Method (SM) in order to solve the different problems involved in the analysis of an experimental

situation. When requested to clarify what this means, most teachers recited from memory the steps of this process (with only minor variations): observe, develop a hypothesis, conduct an experiment, analyze data, state conclusions framed in some theory and generate new questions. In their idea, these unproblematic rules give them the guarantee to always find a solution to the problems posed. In order to understand this full confidence in the SM it must be taken into account that the first chapter of all the high school physics textbook has the title “ The Scientific Method”.
Another relevant factor is connected with teachers idea of scientific explanation; very few teachers are aware that explanations are representations of scientific phenomena that link observable features of that phenomenon with hypothesized events, properties, or structures that are not directly observable because of their inaccessibility (as for example the molecular movement) or conceptual nature (as for example forces, energy,….). They did not show a clear distinction between explanation and description, by often using observations or empirical laws as explicative or conjectural models. Finally the fully confidence in the mathematical laws as explicative framework was a common characteristic; our whole teacher sample was completely confident in the explicative value of the Fourier's law and no one was fully convinced that the Fourier's law is an empirical law based on observation.
These results obtained in the second phase of our W, integrated with the answers to the problem posed in the first phase account for the need of an epistemological clarification about what the term ‘scientific investigation’ means and how this can be related to the construction of scientific knowledge.

5. Discussion and conclusions

The analysis of data previously reported allow us to draw some conclusions with respect to our research questions.
The majority of teachers showed an approach mainly involving the activation of cognitive resources as memory of past learning experience in order to make sense of reality. It seems that the way the proposed situation is first considered, or “read-out”, plays a crucial role in achieving an accurate description and activating the correct strategies to select the relevant variables. In some cases, these strategies seems to activate “textbook-like” cognitive resources like memory and formulas, acting as conceptual obstacles to the IB approach. This, in some ways works like a sort of “short-circuit of knowledge”, avoiding a phenomenological approach to the problem and a complete formulation of hypotheses. This last conclusion seems to be enforced by the consideration that 3 out of the 4 teachers that correctly explained the ice melting process are not graduated in Physics and probably have superficially analyzed thermal conduction in their University courses. So, it seems that previous knowledge (particularly that coming from university) built in environments not linked with real life experience, is not really significant for the learner and acts as an obstacle for the inquiry competences that we want to develop in teachers. Practices as formulating hypotheses or design appropriate experiments are strongly influenced by the searching for appropriate physical laws.
The second phase of our W showed that our teacher sample had an uninformed view that the scientific method is a fixed step-by-step process; many teachers explicitly declared that “science is a systematic process and that only by following these steps in a orderly way, valid scientific knowledge can be constructed.” Teachers may have these uninformed views about scientific inquiry as a result of the traditional portrayal of recipe-like experiments in science textbooks, as textbooks often play a vital role in understanding the process of science (Abd-El-Khalick, et al., 2008). It may therefore be reasonable to argue that science textbooks should be revised in line with the contemporary conception that there is no single scientific method to be used in developing scientific knowledge (Abd-El-Khalick & Lederman, 2000; Abd-El-Khalick, et al., 2008; Lederman, 2004; McComas, et al., 1998).
Guide lines for future TAs suggested by the approaches followed by our teachers can be synthesizes as follows. During the training time, characteristics of IB practices must be explicitly addressed from a epistemological point of view, as well as problem based activities that are not too much focused on specific disciplinary knowledge. Preliminary results about teacher TAs involving environments based on problems and situations not belonging to the field where teachers are expert show a greater involvement of teachers that pay a greater attention to inquiry procedures rather than to the correct application of disciplinary knowledge. In this way the previously cited “short-circuit of knowledge” seems to be avoided and teachers can activate the reasoning

resources necessary for a profitable development of their Pedagogical Content Knoeledge about SI. Moreover teachers need to gain a more epistemically congruent representation of how contemporary science is done by developing activities across different domains of inquiry and many types of investigations.

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