Prospective primary teachers and physics Pedagogical Content Knowledge's

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Introduction

The knot of the construction of a culture in which science is an active and integrated part of the cultural baggage of the future citizen, that will call to do socially relevant choices, is a challenge that is played from the early years of schooling (Hubisz 2001; Lederman 2001; Euler 2004; Michelini 2005). From the first years of schools, in fact, mature, in the large majority of children, the separation between scientific knowledge, school learning, everyday knowledge at the origin of many of the difficulties of learning in the scientific field (McDermott, Redish 1999; Duit 2009) and the disaffection towards the scientific study and more in general over and above the actual value of science. It originates in the ways in which science is offered from kindergarten and primary. To affect this situation requires an effective teacher formation and preparation (Buchberger et al. 2000; Michelini 2001, 2003). Main problems in primary teacher training are: the lack in competence in Content Knowledge (CK) on scientific topics and on formalization; difficulties for the novice in putting into practice the Pedagogical Knowledge (PK) in relationship to CK; generalized difficulties in integrating PK and CK within a specific subject to build the related Pedagogical Content Knowledge (PCK) (Shullman 1987; Michelini 2004; Abell 2008, Berry et al 2008).

From the wide spectrum of research results it emerges that primary school teachers education requires a significant integration between the specific subject matter and pedagogical field (Patchen, Cox-Peterson 2008; Samarapungavan 2008; Schwarz 2009). In particular, knowledge of student's conceptual difficulties, competence on strategies effective to face it in classrooms, ownership on teaching methods are necessary (Corni et al 2004; Viennot 2003; Abd-El-Khalick et al 2004).

Relevant open questions remaining on how to test the PCK developed by teachers, how to promote competences related to phenomenological exploration, modeling and building formal thinking, how to construct competences in recognizing student learning paths and processes (Baxter, Ledermann 1999; Park, Oliver 2008).

The analysis of educational proposals and classroom works designed by prospective primary teachers give just some general information about their orientation to the teaching action, to their orientation to the student's learning path, in the use of laboratory, in the way they suggest to propose the contents to the pupils (Corni et al 2004; Samarapungavan et al 2008). Some researches has been oriented to establish detailed criteria for PCK evaluation (Loughran et al. 2008; Mavhunga, Rollnick 2011) or develop standard tools for formative and large-scale evaluation of teaching skills developed by trainees (Schuster et al 2008, 2009; Juttner 2011; Tepner, Witner 2011). These researches focused on the needs to analyze specific competences on CK from one side, and PCK form the other side. The need for collect integrated data on the two competencies it emerge as an open research problem (Schuster et al 2008, 2009¸ Juttner 2011).

To give a contribution in the evaluation of primary school teachers competencies, and in particular in the integrated analysis on CKs and PCKs related to the same knots, we designed some questionnaires based on PCK methodology, to study how prospective primary teachers during a formative module face CK and PCK with regard the main conceptual knots on: Kinematics and relative motion; Dynamics; Thermal processes, Energy, Equilibrium of fluids.

Here we present the design and the general structure of these questionnaires. A selection of items is also discussed to exemplify the typology of implementation of the items itself, how are presented the different situations analyzed, how sort of answers we obtained in the first experimentation. Final conclusion and remark close this paper.

Design and structure of the questionnaires

In literature about PCK evaluation and assessment some typologies of questions are more used to evaluate specific PCK competences, as: attitude to a direct instruction versus an inquiry based approach; what type of activity a teacher use to propose a specific content; how a teacher should deal with specific classroom situation for instance created by pupils questions or sentences (Shuster et al 2009; Tepner, Witner 201). The way to present the question is also an important aspect of the design of PCK questions, usually proposing specific situations, a story setting, a classroom case-based or a problems-based situation. Some authors recently, suggesting the needs to explore CK as well PCK competencies, proposing a separate use of CK questionnaires as well as PCK questionnaires (Tepner, Witner 2011; Jüttner 2011). In this way it is not possible to individuate if a PCK problem is rooted in a lack of competence on the related CK, or if a learning problem about CK appear only considering PCK question, but not a CK question.

Our purpose was to design an integrated tool which can be used to explore at the same time CK as well as PCK related to the same specific knots, obtaining punctual information about the correlation between CK and PCK.

A research based path was followed, to design the CK-PCK questionnaires for primary teachers. We individuate subject related knots from literature about the different topics of interest, and in particular the literature about tutorials for basic physics teachers (Arons 1996; Vicentini 1996; Viennot 2002, 2003; McDermott 1996; Whitmann et al. 2004). In Parallel, we collected a set of CK questions and typical student's answers from literature about educational path and students learning (McDermott, Redish 1999; Duit 2009).

The process of selection of items, therefore, started collecting a wide range of questions and a first selection of knots and questions. Then we check the questions selected and the objectives of the Physics Education for primary courses. This give use indications on how integrate or modify some questions to cover effectively the field of interest.

A preliminary version of each item was sub-posed to a cross control by tree different researchers. From this control it emerged the final version of each item. Finally we selected a set of items to include in the final version of the questionnaire. Usually the final version follows 2-3 draft versions.

A further revision of the PCK questionnaires was performed after a first experimentation. The questions that gave rise to ambiguous interpretations, not allowing us to explore the specific knot that was focused by the question have changed, replacing or modifying substantially the ones that gave not-significant results.

The questionnaire for each topic concern 5-15 content knots, summarized in the table 1, and it propose 10-15 items subdivided in 2-8 questions. Here we give just some examples, referring to other works for the discussion of individual questionnaires and analysis of results and achievements in relation to different disciplines (Michelini et al. 2011a,b).

Kinematic
The CK knots explored about Kinematic are the following: Need of the system of reference to describe the motion (Malgrande, Saltiel 1986; Viennot 1994); Analyze the velocity using displacement for fixed time intervals (Karplus 1997); Graph of motion (Beichner 1994; Sokoloff, Thornton 1999; McDermott 1999, Sperandeo et al 2002)
Relative Motion & Dynamic
The CK knots concerning relative motion regards: Composition of velocity, relative motion and description of trajectory and velocity in different reference systems (McDermott, Shaffer 2002). Parabolic projectile motion (Hestenes et al. 1992; Beichner 1994); Principle of independence of motion; Description of the motion in different reference systems; Coriolis acceleration in a rotating reference system (Malgrande, Saltiel 1986; Viennot 1994 Sokoloff et al 2004; Wittman et al 2004)
The CK knots related to force are: the effects of a force acting on a body put on a frictionless plane (a disk on the ice); The dynamical analysis of the inclined plane motion; The inertia principle and the inertial forces; The dynamic of a bouncing ball (Hestenes et al. 1992; McDermott 1996;

Wittman et al 2004; Sokoloff et al. 2004)
Fluids
The CK knots explored concerning statics of fluids, regards: the role of density in the distribution of different liquids in a tube; the physical processes at the base of siphon functioning; the buoyancy and the hydrostatic force; the buoyancy and the role of relative density; the atmospheric pressure; the communicating vessels; the emission of a liquid from a container; the nature of the hydrostatic pressure and the Pascal principle; the compressibility of air (Viennot 2002; Heron et al. 2003, 2010).
Thermal phenomena
The knots explored in the case of thermal phenomena: The thermal dilatation coefficient ; The distribution of liquids in a tube; The volumic dilatation; Thermal equilibrium of mixed mass of water initially at different temperatures; Thermal equilibrium of interacting mass of water initially at different temperatures; Phase transitions, Role of the mass in the heating (Tiberghien 1986; Sciarretta et al. 1990).
Energy
The knots explored in the case of energy are: Transformation of Kinetic energy in Internal energy; Conservation of energy , Energetic analysis of process (bouncing ball); Combined Energy transformations (wind mill); Transformation of Kinetic energy-Gravitational Potential energy ; Transformation of Kinetic energy-Elastic potential energy (Driver, Warrington 1986, McDermott 1996; Millar 2005; Heron et al 2008)

Table 1. Conceptual knots and contexts explored in the CK-PCK questionnaire for the different topics.

The structure of the single item and of the questionnaires

In the majority of cases (from 50% to 70%), each item is divided in two parts: The first (CK part) explores how a specific subject knot is analyzed by the prospective teachers; a second part (PCK part) explores how typical students answers on a specific question are discussed by them. From 30% to 50% of the items of each questionnaire regard only CK and usually concern that conceptual knots that we know from literature to be particularly problematic for novices.

Each item concerns a specific content knot and the related different learning problems of students. It present:

A) the problematic situation, usually illustrated with a figure as a map, a graph or a diagram (as in the questions on kinematic reported and more extensively discussed in other work of the present book – Michelini et al. 2011a), a cartoon suggesting the situation (fig. 1), a picture representing a real situation or a photo of a real situation (fig. 2), a schematic representation of the situation (fig.3), some figures reproducing typical students pictures (fig. 4).
B) then just in the PCK items the typical students answers, as emerged in literature (McDermott, Redish 1999; Duit 2009),
C) one or two questions that poses to the prospective teachers the subject related knot,
D) finally, for the PCK items, usually two questions: the first concerning the analysis of the students answers and related learning knots, the second requesting how they can propose in classroom each of knots identified in the answers of the previous questions. In the next paragraph we exemplify some typical items of our questionnaire.

The students answers are often reported from literature, but in some cases, some simulated answers of students was constructed when the real answers including at the same time more than one learning knot, or are too long and do not show clearly the knot faced by the items.

The entire questionnaire provides a picture of the competencies acquired by teachers in the first training on the conceptual knots for the different subjects and the more important aspects remaining open. The PCK questions, which also included a reflection on the main learning problems of children and how to deal with in class, provide also an output on the didactic competencies, in particular about:

- the recognition of the students learning knots

- the identifications on what kind of aspect can be face with pupils to address each specific knots
- the methodology and the strategy they suggest to adopt, in particular if they adopt a direct didactic centered on teacher explanation, or they involve pupils in an open discovery learning environment, propose to pupils some simple experiments and observation, involve actively them in the exploration
- the activity they just suggest, or delineate in an operative way, or plan as effective proposal of intervention in the classroom to face each knot with pupils, focalize on the knot to be faced or the proposal is too generic.

The PCK questionnaires also provide useful feedback of the impact of university training modules that we designed, and indications on how to change them to improve the training proposal where it was less effective.

Examples of items.

In the present paragraph we exemplify the different typology of items proposed in the PCK questionnaires in particular for what concern the modality of the presentation of the situations and of the specific questions posed, giving also some general results about each items, when proposed to two groups of 234 university students (prospective primary teachers) in the academic years 2008/09 and 2009/10. Here, we propose items concerning the different subjects explored, giving a scenarios also about contents explored, referring for other paper for more deep discussion (Michelini 2011a, b).

***Example 1. Relative motion and reference frame*.**

The item illustrates the situation with a cartoon in which Donald Duck is chasing, with a club in hand, Fethry Duck. It also specifies that "Duck Fethry runs with a speed of 7 m / s. Donald Duck is moving at a speed of 5 m / s.

In the CK part of the item, you are asked to indicate reasons for each answer: 1) how quickly Donald Duck sees Duck Fethry, 2) how quickly Duck Fethry sees who pursues, 3) How are these two speeds up with each other, 4) if to answer you must specify one or more reference frame and 5) such as.

Figure 1. The situation related to relative motion is presented with a cartoon.

The PCK part require to discuss the following answers given by three students to question 3: “S1: The two speeds are equal, to ask how quickly Duck Fethry flees from Donald Duck is like asking how Donald Duck quickly Duck Fethry lags behind with respect to Donald Duck. S2: The two velocity has the same magnitude but opposite sign, because the two velocity vectors are oriented in opposite directions. S3: I cannot speak only about the speeds. I need also to talk about how I defined the reference frame of Duck Fethry and Donald Duck one. For example, if Duck Fethry is running back, escaping from Donald Duck, the two speeds will have the same sign.

The CK questions bring into play the recognition and explanation, which three reference frames are required: the first is that the road, to refer the seeds indicated Donald Duck and Duck Fethry, the second is Donald Duck Don solidarity and the third is in solidarity with Fethry Duck. To answer in the sign of the speed also requires the elaboration of a positive direction with respect to which the two characters move in each of the references indicated.

The assumption of implicit reference frames has been the way in which almost all prospective of the sample (90%) answered to the three questions in this item. They have also focused on only one (48%) or two (27%) reference frames for what concerns the question four. Finally the 60% of answering prospective teachers they have mainly (402%) focused on the correctness of student answers, looking at the content aspects involved, rather than discuss the knots underlying the students answers, as the remaining 18% done.

Example 2. Coriolis acceleration.

The third example concerns the relative motion questionnaire and precisely the Coriolis acceleration in a rotating system. It concerns the CK part as well the PCK part, proposing the question with a photo of a real situation (a photo from the video: “The Coriolis force”, at http://www.youtube.com/watch?v=_36MiCUS1ro)

Alberto, Giacomo, Rossella e Stefano are on a carousel. The carousel rotates clockwise. Stefano launch a ball toward the center of the carousel. The CK part is the open ended question: "Who reaches the ball? Explain”.

The PCK part presents the answers to the question of the students:

Rossana: "The ball moves in rectilinear motion, then the ball goes straight to Alberto"

Giacomo: "As the ball moves, the carousel rotates and then the ball will come to Rossana"

Alberto: "It depends on the speed with which Stefano throws the ball. In any case, is not straight at me, but to his right. "

This item brings into play the identification of the reference frame in motion, of the role that plays the Coriolis acceleration in the phenomenon observed and hence the direction in which the ball is deflected.

It offers an important context, because a large majority of the everyday dynamical processes observed in relative motion phenomena concern rotating systems and are due to the Coriolis acceleration, rather than the centrifugal acceleration, as it was mistakenly led to believe.

Fig. 2. The carousel turns in a anti-clockwise direction while Stefano launch the ball the direction of Alberto. To who will arrive the ball? (Picture from the video “The Coriolis force”, at http://www.youtube.com/watch?v=_36MiCUS1ro)

In the answers to the CK part, the 64% of the sample indicated that the ball follow a curved trajectory because of the Coriolis acceleration, divided equally among those who say that the ball comes to Giacomo, and who to Stefano. In this large group 22% give more explanation, making reference to the speed drive of the rotating carousel or constructed the trajectory in the rotating frame with a step by step construction. Other 12 % answered that the ball will arrive to Alberto, because Rossana launches the ball in this direction, while 5% sentences that the problem is undetermined because the answers is depending from the speed of the carousel as well as the velocity of the ball. As regards the PCK part, the 67% of the answering students analyzed each student prevision or in terms of content correctness or simply in term of their own accord with the opinion of students. A percentage less than 5% individuate almost a knot in the sentences.

***Example 3. Water and oil in the U-tube and the role of density*.**

The item suggests a situation where: "Water and oil are arranged in a U-tube as shown", usually given in textbooks as an example or exercise on the physics of fluids (see e.g. Halliday et al. 1981). The situation is illustrated with a picture of the section of the U-tube and two quantities of water and oil, represented with appropriate color and eight in the two branches. The item proposes two parts. In the first one, two CK type question are posed: "1) Why is the branch containing oil higher than the one containing water? 2) Determine the density of the oil [Use the following data: water $\rho = 1.0\ 10^3$ kg m^{-3}, Z1= 11.2 cm =, Z2 = 12.1 cm].

In the second part, a problem solving situation suggested by a female student is presented, including CK and PCK sections: “A female student use a very long U tube so she can put a big amount of oil (about 8 liter). Her objective is to move the water column just in the left arm of the U tube.
Her schoolmates say: Paolo: it is sufficient add a quantity of oil equal to the volume of the elbow of the U; Sara: you don’t will be successful in any case; Luca: it is sufficient to put a quantity of oil equal to two times the weight of the water”.
The requests are: “3) What kind of answer give you to the problem? 4) How you comment the answer of Paolo, Sara e Luca?
In a first formulation, the item was proposed illustrating the U-tube and requiring only a draw as the two quantities of the liquids would be willing. The difficulty to face a so open question, evidenced in a first implementation, suggested to formulate this final version.

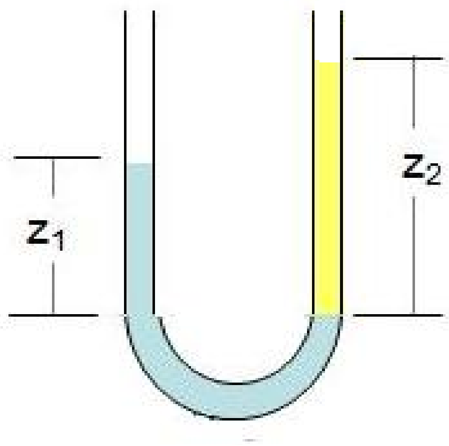

Figure 3 The figure shows how a certain amounts of water and oil arrange themselves in a U-tube.

The two parts of the item are closely related on a subject related point of view and in particular the questions 1) and 3) need to recognize the different density of the liquid from the situation shown in the figure and that actually takes place when water and oil are putted in a U-tube The question 2) if one side is proposed as a simple exercise, the other seeks specifically to enable this recognition. From the cognitive point of view the experiment proposed by the child brings into play the idea that to determine the disposition of liquids is their weight, rather than their relative density, as underlying the suggestions of Paulo and Luca. The observation of Sara, who correctly predicts the negative outcome of the experiment, leaving open the exploitation of the explanation, it stimulates the comments to provide it, although not explicitly requesting it.
Only 12% dealt with the simple exercise proposed again underlining the great difficulty coping with even simple exercises that require the use of mathematical formalism. 28% identified the role of density in the two situations discussed and useful, but only 10% knew how to use this concept to answer the questions. 60% answered the questions proposed focusing on the concept of weight. The comments to suggestions of children, expressed mainly on the disciplinary aspects of teaching are rather more than those related to disciplinary skills highlighted in the previous answers and not go beyond general indications to suggest unspecified experiments

Example 4. The buoyancy of solids in fluids, pressure in a fluid and the Pascal principle.
The item, redesigned by similar open ended question proposed to investigate the students' ideas on the waterline (Heron et al. 2003), proposes the following situation: "Five compact objects, the same shape and volume but of increasing mass ($m1 < m2 < m3 < m4 < m5$), are left in a tank containing water. The object of mass m5 sinks, while the object of mass m2 floating on the water (the upper surface of the object is located at the free surface of water). Two students in a class have the following drawings to illustrate how you arrange the objects in the water ". The item requires to "Comment on each of the two illustrations, pointing which learning knots and how they could intervene in the classroom to overcome them”. The item is of type PCK, since the two pictures are typical drawings made by students in response to the question, but in an indirect way it explores CK also.
The answer to this question requires the recognition that an object thrown into the water or sink, if its average density is greater than water, or floats if its density is less than that of water.
It is expected therefore that the objects 3-4-5 sink, or sink up to 4 and 5 and the object 3 can float in any position, in equilibrium with the water, as the authors have suggested the same question (Loverude et al. 2003). It can also be handled if it is not explicitly recognized the role of the density

of water, taking into account the fact that when a body is thrown into water or sinks or floats and then taking into account the fact that all the cubes "heavier" of the cube 3 must necessarily sink.
68% of the sample chose the picture B), providing an explanation, in little more than half the cases, based on the concept of density in (20%), the concept of weight (15%). 19% choses the drawing B) by adding that the cubes arrange themselves at different depths in order of increasing weight.

Fig.4 The pictures illustrate that typical patterns of students, about the results of immersion of objects of equal shape and volume but different mass.

Example 5. The constancy of temperature at a phase transition.
About thermal phenomena, here we present a classroom context, where three children, Marco, Stefano, Rossana, face the everyday life situation: "When the water boils in a pot, what happens to its temperature?"
Marco says: "Continues to rise, because the water continues to be heated"; Stefano explains: Continue to rise, but very little (about 1-2 ° C); Rossana says: It remains constant".
Related to these assertions, the requests are: to discuss each answer, to indicate the related knots and how it is possible to modify and/or support the learning. To address this question it is necessary to take into account the constancy of the temperature at the phase transition. The assertion of the children bring into the field typical beliefs, that the temperature rise during the phase transition, or that come up, but in a different way with respect to the heating phase.
The question was answered by the 70% of the sample that has framed the situation as a case in which the temperature does not change. The predictions of the three students were mainly analyzed in terms of discipline, highlighting the correctness or not, according to the CK question.

Conclusions
The need to train the prospective primary school teachers, both as regards content and disciplinary competences (CK), as well as those related to pedagogical content knowledge (PCK), requires specific training activities. The evaluation of competences developed in training requires tools specifically designed to assess both CK on each specific knot, for the PCK and their relationship. Therefore, PCK-questionnaires were designed, based on different physical content (kinematics and relative motions, dynamics, statics of fluids, energy and thermal phenomena). These questionnaires were implemented in the context of a University module for the formation and preparation of prospective primary school teachers on the physics education.
The questionnaires were constructed with a number of items, each of them focuses on a conceptual knot of the main disciplinary subject concerning the University courses. The design of the questionnaires started from a re-analysis of the typical questions developed from the literature, investigating the learning processes of students, about the different topics. These questions have been reformulated in general by providing some type CK, which is to explore the conceptual knot from the point of view of discipline, and a second PCK part which require the analysis and discussion of the typical student responses.
The formulation of each question followed a long process of discussion among researchers to get to the final shared formulations and in some cases to a redesign after a first implementation, especially in the cases where the questions had given rise to ambiguous interpretations, or where the results

had few significant. Particular attention has been dedicated in the design of each question, to how present the situation proposed with appropriate maps, graphs, charts on which to build graphics, or sketch the responses. The integration each item of a part on CK and a related part on PCK give the opportunity to collect information about how CKs and PCK affect each other. The results of the implementation of the questionnaires showed the effectiveness of the instruments made, both in providing information on the outcome of training, and also a feedback to the prospective teachers on the issues unresolved, or on their main training needs. The proposed questions have been shown to be effective in identifying specific learning knots conceptual of future teachers, in particular giving useful indications on how to change the formation. They have also made it possible to show that lack in the PCK, are not only related to problem about specific CK, but also to a lack of focus in the educational activities of defined learning objectives.

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