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EDITORS
Derek Raine, Cheryl Hurkett & Laurence Rogers
EVALUATING PEDAGOGICAL CONTENT KNOWLEDGE
OF ENERGY OF PROSPECTIVE PRIMARY TEACHERS


[1] Physics Department of the University of Washington
[2] Physics Department of the University of Udine

ABSTRACT

A Formative Intervention Module on Energy (FIME) was implemented for two different groups of 250 prospective primary teachers over two years. FIME included a preliminary subject centered part (CK) and an innovative proposal on energy for primary school, based on simple qualitative exploration and inquiry strategy by means of tutorials. From the first application of the FIME emerged a progression in CK, but no evident gain was obtained in pedagogical competencies of the prospective teachers. In the second year a part of the FIME was restructured to include a Pedagogical Content Knowledge (PCK) laboratory involving prospective teachers in a personal reflection and a group discussion of the main conceptual knots and learning problems documented in the literature on energy. A post questionnaire combining CK and PCK was carried out. Data emerging from the answers to the questionnaire are correlated with those obtained from the tutorial worksheets completed during the PCK lab, the portfolios of the prospective teachers and the discussions in large groups on the educational path. Results evidenced a relevant and generalized increase in the CK, as well PCK.

1. INTRODUCTION

The building of teachers’ professional skills in science education requires the development of different competencies integrating disciplinary and pedagogical content to develop Pedagogical Content Knowledge (PCK) (Shulman 1987; Viennot, 1997; Magnusson, Krajcik, & Borko, 2001; Michelini, 2004; Davis, Petish, & Smithey, 2006; Appleton, 2006). A reconstruction of the contents in the research perspective of the Model of Educational Reconstruction (Duit 2005) contributes to the clarification of the subject aspects and activate the process of linking common sense ideas and a scientific description of the world, which is crucial in scientific learning (Viennot 2004; Millar 2005; Gilbert 2005; Enhgag, Niedderer 2005). In the case of prospective teachers the development on the disciplinary level has to be integrated with the building of competences in the transformation of contents in educational proposals, examples, problems and in all the knowledge that constitutes the professional baggage of an expert teacher (McDermott, 1991; Nersessian, 1995; Viennot, 1995; Kouhilla, 2000). This process is particularly hard in the case of future primary school teachers, who generally have very weak disciplinary, methodological and formal competences (Michelini, 2003; 2004; Guile 2003; Mikeska, Anderson, Swartz 2009).

Research experimentationations on pre-service teacher education show that an effective improvement of professional competencies occurs when the development is resonant with the methodological
strategy to be adopted in the classroom with students. Moreover the involvement of future teachers in project based activities and in the reflections on micro-steps or elements of teaching and learning proposals are the conditions to transform knowledge on content and pedagogical aspects of professional competencies (Holbrook 2002; Griffiths, Guile 2003; Michelini 2004; Corni et al. 2004).

To develop prospective primary school teacher in the concept of Energy two different orders of problems have to be overcome:

- The lack of disciplinary knowledge (Kirkwood, et al. 1989; Kruger 1990; Spirtou, Koumaras 1994) and in particular the identification of energy as a state property of a system;
- The way of thinking of the pedagogical approaches related only to forms of Energy and to Energy sources, typically adopted in the textbooks.

To this aim the Formative Intervention Module on Energy (FIME) was presented to two groups of perspective teachers in the two academic years 2007/2008 and 2008/2009.

Here we present the FIME, the main results of the two experimentations, analyzing the prospective teachers’ ideas and knowledge before and after the first experimentation, discussing how we re-design the module and the results obtained in the second year of the experimentation. Particular attention is given to the role of the didactic laboratory, based on the analysis and reflection on PCK on energy. To evaluate CK and PCK a questionnaire based on the main questions emerging from the literature was presented as a final examination. The relative results give an overview of the improvement in the professional competencies of the future primary teachers on the concept of energy.

2. Research Questions

This work aims to give answers to the following research questions:


RQB: Why types of contribution to PCK formation on Energy in perspective primary teachers is produced by a strategy based on: 1. the exploration of an innovative teaching and learning proposal on energy? 2. the personal involvement in the analysis of conceptual knots and learning questions combined with a peer to peer discussion? 3. What kind of PCK?

RQC: What kind of instruments and methods are useful to evaluate PCK?
3. THE CONTEXT

A Formative Intervention Module on Energy (FIME) was offered to two groups of Perspective Primary Teachers (PPT) in the two academic years 2007/2008 and 2008/2009. In the two years two groups of trainees (21-22 years old) are involved attending the course of Physics Education in the second year of the Degree in Science of Education at Udine University). The sample was composed of N=101 PPT in the first experimentation and by 143 PPT in the second one. The additional Conceptual Lab activity involve 37 of the PPT of the second group.

In each of the two years, the FIME covered 12 hours integrating lectures, interactive activities based on inquiry and problem posing methods, a didactic laboratory based on the analysis of the reference proposal on teaching and learning for primary level. A task of personal reflection on the contents and on the pedagogical aspects was assigned to the two groups of trainees. The discussion on the rationale of the research based proposals on energy gives to the prospective teachers a reference to develop personal educational paths. A personal portfolio containing all the materials of FIME was required at the end of the activity. A final oral and written examination on energy was included. The structure of the FIME was the same in the two years, but significant differences were introduced in the second year as a consequence of the research results obtained at the end of the first year, as discussed in the following.

4. A FIRST EXPERIMENTATION (07/08)

In the academic year 2007/08 a first course on energy was presented to N=101 trainees (21-22 years old, attending the course of Physics Education in the second year of the Degree in Science of Education at Udine University). It was organized in the following parts:

1. Pre-questionnaire (1h)
2. Discussion on the foundation in physics of the concept of energy in the traditional way and analysis of the main concepts and consequences related to: kinetic energy theorem; energy conservation principle; the first thermodynamic principle (4h)
3. Collection of the questions posed by PPT on energy and learning (at distance) and related discussion (1h)
4. Presentation and discussion on the rationale of the research based proposal on energy (Heron et al 2008), with illustration of the simple everyday experimental apparatus and explorative activity (4h)
5. Post-questionnaire (1h)

5. THE EDUCATIONAL PATH

Educational paths with different rationales were discussed. The educational path for primary learners presented and discussed in detail in the 4th part of the FIME is the result of a research based curriculum proposal (Heron et al. 2008, 2009), produced by means of action - research
experimentation in primary school (Colonnese et al 2008). It is based on an inquiry learning strategy by means of minds-on simple experiments proposed as a situation-problem. At each step attention is placed on a new type of energy, analyzed in forms of a transformation between types of energy. The analysis is carried out on three plans: actions - phenomena - energy description. The types of energy discussed are internal, kinetic, potential energy (initially introduced as “falling energy”) and the energy associated to light.

The approach is in the familiar context for pupils of “human body energy’’ and “food energy”: a generic internal energy of the human body and foods is introduced. Pedaling with a bicycle, part of this energy can be transformed to rotational kinetic energy of the bicycle pedals and wheels. The rotational kinetic energy is re-discovered using a toy turbine. The form of energy that was transformed into the rotational kinetic energy of the wheel is referred to as “falling” potential energy. Looking at pictures of other moving systems, such as windmills and turbines set in motion by flowing water, they were expected to make the connection that non-animate objects, water and air, could have the same effect as an animate object (a person) and therefore reasonably be said to have energy as well. The experiments with a Newton’s cradle apparatus suggest, but do not address the idea of energy conservation (or better the idea that energy can be remain constant in a system). Different ways to transform falling potential energy to different types of energy of the same or other systems are considered. In particular the spring-mass system is a relevant context to introduce elastic potential energy. Toys and common apparatuses, as a simple dynamo and a flashlight that is activated by shaking, are proposed to analyze the transformation of different forms of energy to those associated with light. The following different situations are considered to recognize internal changes from related macroscopic changes and to recognize the different forms of internal energy with the relative transformations: the increase in temperature, heating a system as a mass of water; the change in internal structure, in a phase transition as the ice-water one; the change in the shape, for instance deforming a plasticine ball with a hand; the changes in chemical processes, as dissolving salt or sugar in water.

6. DATA FROM PRE-QUESTIONNAIRE 07/08

The previous ideas of PPT directly correlated to the educational path on energy are well described by the data obtained from the following three questions included in the pre-questionnaire:


Q1 data reported in Fig.1 shown that more frequently energy is identified with a quantity that is compared in different forms or has different properties. When we consider the more quoted forms (fig. 2-left), we recognize that these are mainly related to the sources and the ways of “production” (for instance solar, electrical, wind ...). The forms defined in physics (kinetic, potential, internal, associated with light, here indicated as type of energy) only in 2 cases are quoted alone; in the large majority of case (66/101) are quoted without any hierarchy in a miscellany of forms.

When we consider the attributes of energy we can recognize that in the majority of cases the idea that energy is created or destroyed prevails. The idea that energy is useful for life and it can be transformed are other relevant classes of ways of thinking of energy (fig.2 right).
Figure 1: Q1 - Identification of energy: not exclusive categories (left); exclusive categories (right). NA) No answer; A) Forms of energy; B) Properties of energy; AB) Forms and Properties; C) Sources of energy/creation from sources; D) Involved in interaction or movement; E) Related to/produced by work; F) related to/produced by heat; G) Related to machine working; H) Energy = force; I) Diffuse entity.


The answer to questions Q4 and Q5 permit us to go deeper on this point.

For Q4, 74/101 sentences state that energy is conserved: without explanation (11); recalling the conservation principle or the slogan “nothing is created, nothing is destroyed” (13); “... because it is transformed” (22); quoting examples as: “it is stored in batteries ...”, “in power centres ...” (33). In the remaining 27/101 cases the answers assert that energy in not conserved, because: “it is dispersed ...” (15), “it is transformed” (7) or “it is partially destroyed in the transformation, but a part remains” (3). It is evident that the conceptions of the majority of the PPT are a long way off the scientific meaning of Energy conservation. In addition for not all PPT is
the transformation of energy correlated to its conservation: in some cases a transformation and dispersion of energy are even correlated. This is more evident when we consider the answers to Q5 in which it is required that the meaning of transformation be made explicit giving two examples. Almost all PPT prospective teachers (95/101) affirm that energy is transformed, including 148 explanations, classified in the following not exclusive categories: A) From a form to another form (47 - only this answer category: 27); B) It transforms into movement or comes from movement (“muscular energy transform to movement”) (20); C) It is transformed to heat (“solar energy transform to heat”, “the eaten food transforms to energy and produces heat” (19) or to light (4); D) It is transformed in a system (“solar energy is transformed to something essential for life”) (17); E) It transforms to a force (“the force of wind transforms to energy”) (4). The meaning of energy is associated to its transformation: A) It produces transformation in things (“solar energy transforms through fusion of atoms”, “the food transformed in the body”, “the movement of wind is transformed to electricity/current” (11); B) It is produced in the processes (“water produces energy” -10). Less than 1/3 of the sample (27/101) express the idea that energy transforms from one form to another. For the majority of the prospective teacher when energy is transformed it changes nature, for instance becoming another physical quantity as electric current, movement, a transformation in a system, a system itself.

7. RESULTS FROM THE PORTFOLIOS AND FINAL EXAMINATION AFTER THE FIRST EXPERIMENTATION IN 07/08

The Content Knowledge results emerging after the first year experimentation comes from the PPT portfolios analysis, the data from examinations, the content offered in the educational paths developed by PPT at the end of the module. More than 87% of the trainees recognized the types of energy and used these types to give an appropriate description of simple processes in terms of kinetic, potential, internal energy; only in few cases 30-35% are difficulties present in distinguishing potential energy and internal energy and in some case the energy associated with light. Analogous percentages were obtained for the identification of energy as a quantity that is transformed from one form to another and that is conserved. Concepts of transformation and conservation are often associated (“because it is transformed”). For a group of PPT (about 40%) transformation is in any case associated to a dispersion or a loss of energy. This result shows an important modification in the initial conception of energy, documented in the previous paragraph.

Another picture emerges, when we consider the Pedagogical Content Knowledge, collected by analyzing in particular the teacher plans on how to introduce energy to pupils, how they organize the topic for school, and ideas expressed in oral examinations. A large majority of PPT recover the initial ideas and conceptions when they have to think of educational activity and paths for pupils. For instance about 72% mentioned as a first goal the wrong definition of energy, frequently proposed in the textbooks: “Energy is the capacity to do work”. At the same time one of the most diffused aim was to teach to pupils that “It exists in different forms: nuclear, kinetic, thermal …”, without any distinction between type and forms. About this point the more evident change was that a large majority includes forms of energy: kinetic, potential, internal and the usually quoted energy forms related to sources solar, hydroelectric, nuclear, wind energy. Also an ambiguous language was used in some case (for example “it is
These results confirm that a reconstruction of the concepts and a proven CK do not produced effective changes in the pedagogical organization of the educational proposals.

8. THE FORMATIVE MODULE BASED ON ENERGY PCK - LAB 08/09

The same FIME was implemented in 2008/2009 for 143 PPT, 21-22 years old: the CK results differ for a not significant percentage. A successive PCK laboratory (PCK-lab) was organized by splitting by thematic group the PPT. It was based on individual and cooperative work activated by questions on situations by means of worksheets. The PCK-lab included a personal reflection activity on CK aimed to discuss pedagogical aspects. At the end there is a questionnaire on PCK.

The PCK-lab on energy provides the following steps for 37 participants:

1. Individual task in Work Sheet 1 (WS_1): Q1.1 List the concepts more relevant to energy (10 min); Q1.2 Indentify critical learning aspects in relationship with the considered concepts (10 min), explaining the choices and reasons for critical aspects.

2. Group work. The group of 37 PPT was organized in 8 groups of 4-5 persons to compare and criticize the individual answers to the Q1.1 and Q1.2 questions and formulate a second work sheet (WS_2) with shared answers (20 min).

3. Individual analysis of a specific conceptual knots and the related learning problems (WS_3) (15 min). Five different questions with a similar structure were presented on the following conceptual knots documented in literature: 1) Conservation and transformation from kinetic to internal energy (Q3a: reposted example); 2) Energy associated to a system (Q3b. As far as you know, are there things that have/posses energy?); 2) Conservation of energy (Q3. naïve meaning of conservation vs scientific one); 3) Transformation of energy (Can energy by transformed?); 4) The energy “lost” (A bicycle wheel is stopped rotating by hand. Where has the energy of the wheel gone?).

The following are examples focused on the conservation of energy and in particular on the recognition of the transformation from kinetic energy to internal energy:

WS_3 - Example 1: A Teacher (Q) recognizes that her pupils used standard sentences correctly to give answers to her own questions, but, when asked, are not able to explain the meaning of these sentences. Proposed to students this situation: The spring in a toy car was wound up and the car let go on the floor. Why did the car stop after a while?

A: Because the force acting on it ceased.

Q: Have you ever heard about the law of conservation of energy? What does it mean?
A: Energy is not created or destroyed.
Q: So what happened to the energy of the car?
A: It changed to kinetic energy, and then to potential energy.
Q: Which potential energy?
A: I don’t actually know, . . . (Goldring Osborne, 1994)

1.1 Individual part (15 min) - D1.1.1 What does the girl involved in the dialogue from Goldring, Osborne (1994) demonstrate she has understood? D1.1.2. What is vague in her answers? D1.1.3. What remain to be clarified? D1.1.4. What kind of questions should you prepare to stimulate a discussion in a classroom activity aimed at the comprehension of the unclear concepts and aspects? For each question propose the answers expected.

3.2 Collective part: construct shared answers. (15 min)

WS_3 - Example 2: Millar (2005) outlined that “energy is not a cause” and criticizes some expressions in the textbooks for primary level as the follow:

2A.1) Energy is needed to get jobs done, or to make things work
2A.2) Without energy nothing can ever happen
2A.3) You need energy to move and work

Or

2B.1) a ball keeps moving because it has kinetic energy
2B.2) Petrol makes a car go because petrol has energy

2.1 Individual part (15 min) Discuss each question, indicating part to be considered correct, part to be modify, and how. 2.2 Collective part: construct shared answers. (15 min)

4. Group work (each of 5-6 persons) of PPT working on the same Q3 question to compare, to discuss and share the different analysis made, writing notes on the group’s activity. (20 min)

5. Group work adopting an “expert” modality of cooperative learning to share specific competencies. The new groups are formed with 5 PPT, each of them expert in a Q3 question, because they analyzed it in the previous work (in the 3rd - 4th steps). (15-20 min).

6. Homework. The PPT were request to re-organize Knots and Concepts about energy and to analyze a primary school textbook in the light of their list, specifying which concepts and knots are treated in a satisfactory way and which need to be integrated. A final comment on the PCK-lab is requested on the following questions: 1) what do you think you have learnt in the laboratory on energy (contents and concepts)?; 2) which specific elements for professional competencies of a teacher are developed?
9. **THE PCK - QUESTIONNAIRE**

A post-questionnaire composed of 15 open ended questions was given to the PPT after the instruction to evaluate the PCK, during the final examination. The questionnaire was designed on the following main conceptual knots emerging from the literature: energy associated to human or living beings, as a fuel-like substance which is possessed by living things; energy possessed only by moving objects (Stead 1980; Watts 1983) or as a product of some process and existing only during this process (Nicholls & Ogborn, 1993; Watts 1983; Duit 1984); energy as force or power (Trumper 1983, Driver, Warrington 1985); different forms of energy and recognition of the form associated with standing objects (Brook, Wells 1988; Carr & Kirkwood 1998); conservation of energy (Duit 1981; Watts 1983; Black & Solomon 1983; Brook & Driver 1984; Driver & Warrington 1984, Solomon 1985); transformation of energy and process (Carr & Kirkwood 1998; Gilbert & Watts 1983; Duit 1984; Trumper 1993; Dawson-Tunik 2005).

The following questions exemplify the format:

**Q1.** In a student group pupils say that energy is the force that makes things function. How it is possible to face in the classroom the distinction between force and energy?

**Q2.** A group of pupils analyze the situation: “A bicycle wheel initially moving, is stopped by activating brakes”. For the question: “where has the energy possessed by the wheel gone?”, the pupils answer:

A: Alessia: “the energy of the wheel disappeared”,
B: Deborah: “a part of the energy disappeared, in thermal energy”
C: Francesco: “The kinetic energy transform to internal energy”
D: Giovanni: “The kinetic energy transform to potential energy”
E: Sara: “The kinetic energy transform to heat”
F: Melissa: “The kinetic energy transform to energy passing to the hand or to the air”

2.1 *Discuss each answer of the pupils. 2.2 What aspects are relevant to be addressed in a classroom activity?*

10. **DATA FROM POST-QUESTIONNAIRE 08/09**

When we analyze the post-questionnaire filled at the end of the course in 2008/2009, the following data emerge (N=37).

11. **Q1. FORCE VERSUS ENERGY**

Concerning question Q1 we can consider the CK and the PCK answers. Fig. 3 shows answer categories concerning the distinction between energy and force concepts of the PPT attending
Figure 3: Q1 - Content Knowledge related to the distinction between Force and Energy: exclusive categories of answers: A) E is a property of states of systems/F describes an interaction; B) F is a vectorial quantity/E no; C) F requires a displacement/E in some case no; D) Energy exist in different type; E) F is a form of energy; F) E is associate to displacement/F is not associated to a displacement; NA) No answer.

the whole course (N=37). It emerges that: A) the majority was able to give a specific characterization of the two quantities or at least of one of the two A1) distinguishing Energy as property of state of a system and force as descriptor of the interaction (the main category - 15/37), A2) identifying Force as a vector quantity (4/37), A3) identifying Energy as quantity existing in different types (1/37); B) those (30%) not distinguishing force and energy B1) consider force as a form of energy (6/37), B2) associate to the existence of a displacement (4/37 energy and 2/37 force). 4/37 do not answer the question.

In Figure 4 concerning the PCK categories on this distinction there emerges the reluctance of PPT to plan for pupils’ activities related to conceptual knots and energy concepts (see C and D). The preferred approaches are for explorative activities or for formal definition. PPT appear to not be conscious that definitions do not solve the learning problem of concepts.

12. Q2. A MOVING BICYCLE WHEEL, STOPPED BY RUBBING A HAND

When we consider the energy transformation in a bicycle we observe that a good result is obtained in recognition of the transformation of kinetic energy to internal energy (pupils answer C: from kinetic to internal, figure 5).
In 6/18 of the cases enriching comments in the answers were included: Francesco “understands the possible transformation, but does not specify if the internal energy is of the wheel or is of the brake”, “The kinetic energy transforms to internal energy, that we perceive as heating”. Some problems emerged with forms and transformation, between a form into another: “Kinetic energy does not transform only to internal energy and to potential energy” (8). In some cases we observe excessive attention to details and loss of capacity to choose (5).

13. RESULTS FROM EXPERIMENTATIONS IN 2008/09

Analyzing the portfolios of the PPT, the data confirm those reported for the previous year concerning the enrichment in CK related to the concept of Energy and those in PCK emerging from the questionnaire. The portfolios give also an overview on the use of expressions like conservation of energy, transformation of energy, energy loss coherent with scientific meanings. A share of meaning was reached in relation to using the concept of energy in analyzing simple everyday life situations as well as simple experimental phenomena.

Correlating data emerging from the questionnaire and from the PPT portfolios, we can summarise the following results. The CK data confirm in many ways that the PPT have competences in the identification of the Energy concepts, as a state property of a system, recognition
that energy exists as different types that can transform from one form to another. The meaning attributed to Energy conservation and Energy transformation is coherent with those of physics, applied in general terms to processes. Less than the 20% evidenced problems in the clear distinction of internal energy and potential energy, analyzing the case of bouncing a ball.

Results concerning PCK are obtained correlating data from the answers to the questionnaire, the portfolios analysis, and the written educational plan proposed by the PPT as request in the final examinations. The prevalent approach adopted by the PPT is to involve pupils in experimental explorative activities aimed at an operational identification of the energy concept. 26/37 PPT appear to be aware of typical learning problems on the topic and 23/37 discuss in an exhaustive way how it is possible to face these learning problems in the school classroom.

14. Conclusions

A Formative Intervention Module on Energy (FIME) was experimented in two successive academic years (2007/2008 and 2008/2009) with Perspective Primary Teachers (PPT). The FIME was centered on a subject oriented foundation of the concepts and a discussion of a research based proposals and related tutorials based on explorative activities and simple experiments. To evaluate the competencies produced with the FIME during formative paths, different tools were used: questionnaires, portfolios, work-sheets, written and oral examinations, notes collected by researchers.
We summarize the main results obtained giving answers to our research questions as follow.

Before instruction the prospective teachers identify Energy prevalently with different forms and “properties” (as transformation, conservation or more often creation/destruction) (RQA1). They assign meaning to expression like Energy conservation, Energy transformation, Energy dissipation with common sense ideas not coherent with the scientific ones. From a number of PPT, for example, energy is conserved when or because is stored as in batteries. For others energy is not conserved because it changes (conserved foods are those that do not change at all!). At the same time, for almost all the sample energy is transformed, from one form to another (for 1/3 of PPT), changing nature (in movement, in an object, in a transformation) for 2/3 of PPT (RQA2). The spectra of energy types or forms mentioned by the PPT is very large, but no hierarchy or distinction emerges between the physics types and the forms associated to the sources or to the means of production of electric energy (RQA3).

The strategy applied in FIME includes reconstruction of the foundation of the energy concept in physics, the presentation and discussion of different approaches in the literature and an operative, innovative proposal for primary school, based on inquiry learning exploration. It produced a good CK, but does not produce effective PCK on energy (RQB1). From an intermediate questionnaire it emerged that improvement was obtained in the CK: Energy is identified as a state property of a system, that can be transformed and the process is described in terms of actions and in terms of energy. A great personal involvement is needed to transform the content competences to professional attitudes. In this process the role of peer collaboration and of comparison of ideas is relevant. In particular a personal involvement in the analysis of PCK questions combined with a peer to peer discussion build gradually effective PCK on energy for a small group of PPT (37). A relevant contribution comes from the knowledge of students’ typical learning problems on the topic and how it is possible to face them in the school classroom (RQB2).

The way this work was carried out to monitor the PCK competencies and to act for their improvement for PPT appears to be fruitful in the identification of the way of thinking. The integration of research results in the FIME offers the opportunity to enrich the formative module not only with respect to the CK competences, but also for those of PCK.

The format proposed is effective for an multilayer evaluation (RQC1).

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