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JPTEO

Inside This Issue

Helpful Themes in Physics Teacher Preparation and Professional Development

Journal of Physics Teacher Education Online (JPTEO) is dedicated to investigating and documenting significant issues and challenges in the education of physics teacher candidates and in-service physics teachers. With a focus on the scholarship of teaching and learning, the *Journal* seeks to generate discussion and promulgate sustainable, long-term changes in educational research, policy and practice. Journal articles will foster deep, significant, lasting learning for physics teacher educators and improve their ability to develop teacher candidates' and in-service teachers' understanding, skills, and dispositions.

Physics teacher educators, often only one individual working within a department of physics to prepare future teachers, are frequently isolated from their peers due to a lack of a medium of exchange. As a result, those who engage in innovative acts of teaching do not have many opportunities to share their work, and to build upon the work of others. Without an opportunity to share with like-minded peers, teacher educators are likely to remain isolated, unable to benefit from or advance the work of the physics teacher education on a broader basis. Fortunately, renewed public interest in education, the development of teacher preparation standards, and some inspiring models from physics teacher education programs around the country provide hope that the time is right for change.

The work of educating future physics teachers often involves significant shifts in thought and practice. For physics teacher education faculty, physics teacher preparation is a private act, limited to the teacher and students. Such practice is rarely evaluated by professional peers, again due to a lack of a forum to exchange ideas and share procedures. *JPTEO* is a forum through which the scholarship of teaching and learning can be exchanged widely and built upon. The hope is to support the development of new models of physics teacher education that foster deep and lasting understanding, while underlining the character of teaching itself as a scholarly endeavor worthy of recognition, support, and reward.

In order to build a vibrant and useful publication, I am encouraging you - the reader - to consider writing an article for publication that will be helpful in the preparation and professional development of high school physics teachers. Here are some topics about which prospective authors might want to write:

- Nature of Science and of Scientific Knowledge
- Inquiry-oriented Instruction
- Effective Teaching and Active Learning
- Metacognition and Self-Regulation
- Critical Thinking and Problem Solving
- Curriculum Development and Instructional Planning
- Effective Classroom Atmospheres
- Class Management
- Classroom Dialogues
- The Relevance of Science
- Legal, Safety, and Ethical Concerns of Science Teaching
- Diversity/Gender Equity/Gifted/ELL/Exceptionalities
- Professional Development
- Student Teaching
- The First Year of Teaching
- The Teaching Philosophy

I hope that with such a track record of publication, *JPTEO* can serve as a resource for the preparation of new teachers, the professional development of in-service teachers and physics teacher educators. Many of the articles might well be used for reading and discussion in physics teacher education courses during the school year or in summer workshops.

The current issue of *JPTEO* deals exclusively with the topic of alternative conceptions, one of the major topics with which all physics teachers should be familiar. Now, I am not suggesting that future issues of *JPTEO* should be thematic, but that might become an interesting possibility should three of four authors offer to write about a given topic. Right now, I'm working on an article dealing with scientific epistemology and it would be great to get several "takes" on this important topic in the next issue. Should you be interested in writing about this or any other topic for *JPTEO,* don't hesitate to contact me with an idea or an abstract describing a prospective article. Looking forward to hearing from you, I am

Carl J. Wenning
EDITOR-IN-CHIEF
Department of Physics
Illinois State University
Campus Box 4560
Normal, IL 61790-4560
wenning@phy.ilstu.edu

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REVIEWERS

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JPTEO

Using different conceptual change methods embedded within the 5E Model: A sample teaching for heat and temperature

Mehmet Altan Kurnaz, Science Teacher and PhD Candidate in the Graduate School of Natural and Applied Sciences, Karadeniz Technical University

Muammer Çalik, Asssistant Professor, Karadeniz Technical University, Fatih Faculty of Education, Department of Primary Teacher Education, Trabzon, TURKEY E-mail: muammer38@hotmail.com

Because a teaching activity can be seen as a phase of conceptual elaboration, we assume that using different conceptual change techniques embedded within a 5E model might completely diminish students' alternative conceptions. By presenting a sample activity for teacher usage, we are planning to fill in a gap between teachers' theoretical knowledge and their classroom behavior in the practice of constructivism. Based on the tenets of constructivism, the purpose of this paper is to suggest a 5E model for containing students' alternative conceptions by means of conceptual change text, analogy and worksheet together. It is suggested that using these methods as a group will be more effective than using them individually so that they overcome their disadvantages and reinforce their advantages.

Introduction

Since constructivism not only stresses students' pre-existing knowledge but also engages students actively, much more research has paid more attention two issues: (a) students' alternative conceptions, and (b) conceptual change. In a conceptual complement process, Çalık and Ayas (2005) pointed out that miscellaneous conceptions may arise different from the one accepted by scientific community. These conceptions are generally called 'preconceptions', 'alternative frameworks', 'children science', 'alternative science', or 'misconception' (e.g. Baser & Çataloglu, 2005; Petersson, 2002; Rowlands, Graham, Berry. & McWilliams, 2007). In fact, determining what students think about the given phenomena is not enough to replace various student conceptions with scientific ones. Basically, as science educators, these are cases which we must endeavor to overcome.

Despite the fact that many activities have been devised to achieve conceptual change, the significance of them may be different for teachers and pupils (Osborn & Tasker, 1985). Indeed, knowing the differences between them gives teachers a chance for an excellent teaching process. Even though constructivism places emphasis on taking into account students' pre-existing knowledge and/or alternative conceptions, teachers may have difficulty knowing how to incorporate them during his/her teaching experience (e.g. Çalık & Ayas, 2005; Driver & Oldman, 1985; Fensham, Gunstone & White, 1994; Matthews, 2002).

Ever since alternative conceptions have been seen as a starting point for further learning, much research has been conducted on various subjects such as force, motion, energy, power, work, heat, temperature, mass, weight and so forth. Undoubtedly, because of the fact that students encounter these concepts in their daily lives from an early age (Baser & Çataloglu, 2005; Senocak, Dilber, Sözbilir & Taskesenligil, 2003; Paik, Cho & Go, 2007), students' ideas and alternative conceptions of heat and temperature is one of most studied areas in science education (Sözbilir, 2003). Further, these concepts are cornerstone for physics, biology and chemistry (Koh & Paik, 2002 cited in Paik, Cho & Go, 2007). These studies have reported that students hold alternative conceptions on the related concepts because of either its abstract structure (Aydogan, Gümüs & Gülçiçek, 2003; Baser & Çataloglu, 2005), or their earlier daily life experience or text books (DeBerg, 2008; Leite, 1999; Sözbilir, 2003) or cultural notions (Ericson, 1979; Harrison, Grayson & Treagust, 1999; Lubben, Netshisuaulu & Campell, 1999).

Because the first author has been working as a science teacher, we have examined his 6-13 year old students' alternative conceptions in science. (e.g. Adawi, Berglund, Booth & Ingerman, 2002; Aydogan, Günes & Gülcicek, 2003; Bulus Kırıkkaya, Güllü, 2008; Ericson, 1979; Eryılmaz & Sürmeli, 2002; Sözbilir, 2003; Niaz, 2000; Kaptan & Korkmaz, 2001; Pathare & Pradhan, 2008; Paik et al., 2007; Senocak *et al*, 2003). Alternative conceptions studied were the following: (a) the temperature of an object depends on its size (Baser and Çataloglu, 2005; Erikson, 1979, 1980; Paik et al., 2007), (b) heat is form of energy (Erikson, 1979, 1980), (c) heat is a material substance (Bulus-Kırıkkaya and Güllü, 2008; Erikson, 1979, 1980), (d) there is no difference between heat and temperature (Baser and Çataloglu, 2005; Sözbilir, 2003; Tiberghien, 1985), (e) the time necessary for cooling and heating substances does not depend on volume and mass (Baser and Çataloglu, 2005), (f) temperature can flow from one substance to another (Baser and Çataloglu, 2005; Baser and Geban, 2007), and (g) there are two types of heat, cold heat and hot heat (Baser and Çataloglu, 2005; Baser and Geban, 2007; Erikson, 1979, 1980).

Because of its importance, some studies have attempted to refute and overcome students' alternative conceptions of 'heat' and 'temperature' by means of different conceptual change strategies such as conceptual change text (Akyüz, 2004; Baser & Geban, 2007), conceptual change theory of Posner et al. (1982) (Baser & Çataloglu, 2005; Baser, 2006a), worksheet (Gönen & Akgün, 2005), a designed program (Kalem, Tanel & Çallıca, 2002), text-

Engagement	To access students' pre-existing knowledge, teacher gets students to engage in a new concept by means of short activities or questions that promote curiosity and draw out prior knowledge. The activity or question is supposed to make a connection between prior and current learning experiences so that teacher is able to organize students' thinking toward the learning outcomes of current activities.
Exploration	Students complete lab activities or group discussion or hands-on activities or role playing or analogies that enable them exploit their own pre-existing knowledge to produce new ideas, explore questions and devise and implement a preliminary investigation.
Explanation	This phase which needs a more teacher engagement, also gives opportunities for teachers to directly introduce a concept, process, or skill. Further, students address their understanding of the concept or track their correct and incorrect knowledge claims. Finally, teacher leads them to hold a deeper understanding, which is a critical part of this phase.
Elaboration	To elaborate students' conceptual understanding and skills, students attempt to extend their newly structured knowledge to deeper and broader understanding, more information, and adequate skills. Also, they can apply their understanding of the concept to additional activities.
Evaluation	This phase fosters students to assess their comprehension and abilities and gives opportunities for teachers to evaluate how their students progressed to accomplish the educational objectives.

Table 1**.** *Summary of the 5E Model Phase* (Bybee et al., 2006)

book style, textbook usage and K-W-L (What I Know, What I Want to Learn, What I Learned) (Akyüz, 2004), Microcomputer-Based Laboratories (Wiser, Kipman & Halkiadakis, 1988), an inquiry approach coupled with concept substitution strategies (Harrison et al., 1999), cognitive conflict (Baser, 2006b), meta-conceptual teaching on inducing a particularly problematic aspect of the conceptual changes (Wiser & Amin, 2001), a teaching model (Thomaz et al., 1995) and analogy (Perschard & Bitbol, 2008).

In the light of the aforementioned studies, Wiser et al. (1988) confessed that there was no evidence that computer based curriculum facilitated conceptual change even though classroom interventions have helped students at problem solving level. Further, Taylor and Coll (1997) criticized that cognitive conflict may engender to reduce student's confidence even though it has many advantages to accomplish conceptual change. Similarly, if the conceptual technique such as conceptual change text, analogy, worksheet etc. frequently use itself, students may be bored, hence, this may frustrate to achieve effective results (Çalık, 2006; Dole, 2000; Huddle, White & Rogers, 2000). Also, despite the fact that conceptual change text is effective in remedying students' alternative conceptions, a hands-on activity that students experience explicitly may sometimes be more effective (Chambers & Andre, 1997). Since a teaching activity can be seen as a phase of conceptual elaboration, we assume that using different conceptual change techniques embedded within 5E model may completely diminish students' alternative conceptions. That is, the authors recommend a new way to address alternative conceptions that the other methods (conceptual change text, change theory of Posner, worksheet, a design program, etc.) fail to properly address. By presenting a sample activity for teacher usage, we are planning to fill in a gap between teacher's theoretical knowledge and their classroom behavior in practice for constructivism as addressed by Widodo, Duit and Müller (2002).

Based on the tenets of constructivism, the purpose of this paper is to propose a 5E model on containing students' alternative conceptions by means of conceptual change text, analogy and worksheet together. The model is appropriate for grade 5-8 students.

Theoretical Framework

To facilitate applicability of constructivism, some models such as 3E, 4E, 5E and 7E are suggested. Even though the models have about similar steps, 5E is a popular version of constructivism (e.g. Hanuscin & Lee, 2007). Since each "E" displays part of the process of helping students' learning sequence experiences to link prior knowledge with new concepts, this model consist of: *engagement, exploration, explanation, elaboration, and evaluation* (e.g. Abell & Volkman, 2006; Boddy, Watson & Aubusson, 2003; Bybee, Taylor, Gardner, Scotter, Powell, Westbrook & Landes, 2006). Why we preferred 5E model can be explained with difficulty of 'elaboration' (Nas, 2008). That is, students and teachers find the step 'elaboration' difficult to devise and implement. As a matter of fact, the second author's experience also support this notion since the student teachers at the university have difficulty in designing and implementing the 5E and 7E models, especially the fourth step (elaboration) of the 5E model and the 4-6th steps (expanding, extending, exchanging) of the 7E model. Now we will outline what to do in each step.

Teaching Design

Because we prefer the 5E model, we will present each phase to clarify how we adapted the mentioned techniques.

Enter (Engaging) (5 or 10 minutes)

Before implementing the activity, all students are taken to the schoolyard and divided into small groups. The teacher should get students to confront their own pre-existing ideas. In specific, (s)he asks initial questions at the top of the worksheet and create both class and group discussion. By observing them, (s)he can capture students' alternative conceptions such as 'there is no difference between heat and temperature', 'there are two types of heat, cold heat and hot heat', and 'heat is form of energy' since concepts 'heat' and 'temperature' are very common for alternative conception researches.

Exploration (20 or 25 minutes)

Here, the teacher fosters the students to play a basketball game which is explained at the second part of worksheet (see Appendix 1). (S)he also encourages them to complete the table given in the worksheet. However, the students most probably concentrate on the game and not notice the special term as "*shooting number and the number of played ball"*. The teacher should especially emphasize this statement. In this process, even though all information is presented in worksheet, the teacher explains that *in the game, think of your teacher as a heat source, think of yourself as a substance taking heat, think of the ball given to you in the game as heat, think of your shooting number as temperature*. Then, they answer the following questions within their small groups by negotiating: *'Explain the relationships between the heat and the temperature', 'Explain the differences of the heat and the temperature'*. By doing this, students are able to make a connection between playing basketball and science in a contextual based manner. That is, the mentioned attempt intends that students say 'a-ha' moments (e.g. Metcalf & Tinker, 2004**)** since they noticed how to link their playing experience with 'heat' and 'temperature'.

Why students are asked to draw a graph result from the fact that students notice a linear relationship between shooting number and ball number so that they can acquire that such a linear relationship between 'heat' and 'temperature' is available. The targeted alternative conceptions in this step are 'there is no difference between heat and temperature', 'heat is form of energy'

Explanation (15 or 20 minutes)

In this step, overall, students are asked to present briefly their experiences of the related game (In case of shooting score and the number of played ball in particular) so that a class discussion is generated. In the following time, the teacher defines heat and temperature to students by utilizing the analogies given in the worksheets. For example, "*Similar situation is also valid for heat and temperature as in case of the game. While heat is a transferring way of energy passing from one substance to other one, temperature is its quantitative value*". By doing this, the teacher attempts to confirm or complete students' acquired ideas. In this process, representing analogy mapping (s)he affords students to discriminate the analog from targeted conception (Appendix 2).

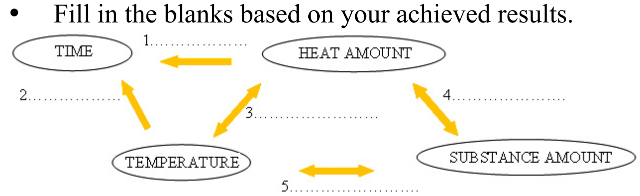
Elaboration (25 or 30 minutes)

In this stage, depending on their previous learning students are asked to produce a new concept. The first question of a narrative conceptual change text (see Appendix 4) is asked to get students create a satisfaction of their alternative conceptions. At that point, the teacher creates a class discussion environment so that (s)he can become aware of students' ideas. Further, each student learns what their peers know or consider. Then the teacher hands out the conceptual change text and allows students to read it in five minutes. Later, each alternative conception is discussed, thereon, each one is refuted. Finally, Appendix 2 and 3 are shown and discussed with students.

Evaluation (5 or 10 minutes)

After completing all activities the teacher should check the student's learning. Firstly, questions at the bottom of worksheet are asked. Secondly, the subsequent questions may be used to clarify whether or not the students have learned:

- Is there any relationship between a substance's heat and its size? Please defend your response.
- Please explain what happens when hot and cold waters are mixed.
- Fill in the blanks based on your achieved results.



- Please note what you learned today.

Implications for Learning and Research

To teach heat and temperature, especially by expressing their differences, using different conceptual change methods embedded within 5E Model is illustrated here. In such a situation it is obvious that students' perceptions may increase in a positive way since the presented materials are appeal for them as in case of our pilot-tested study. Teachers may also apply this model to devise new learning experience for the other topics or disciplines. Hence, this study is only an attempt to present alternative teaching method based on 5E model. It is sug-

Analogy (activity)	Target conceptions
An increase in the number of balls	An increase in heat
An increase in the number of shooting in regard to the number of ball given	An increase in temperature
Handing in and out the numbers of played balls	Heat that can be transferred
Not handing in or out the shooting number	Temperature that cannot be transferred

Table 2. *Analogy and target conceptions*

gested that using these methods together is more effective than using one so that they overcome their disadvantages and reinforce their advantages. But, the study has limitation that its applicability has not been investigated even though we pilot-tested it. For this reason, since we observed its applicability in our pilot-study, future research should investigate the degree to which conceptual change is achieved by designing pre- and post-test research design.

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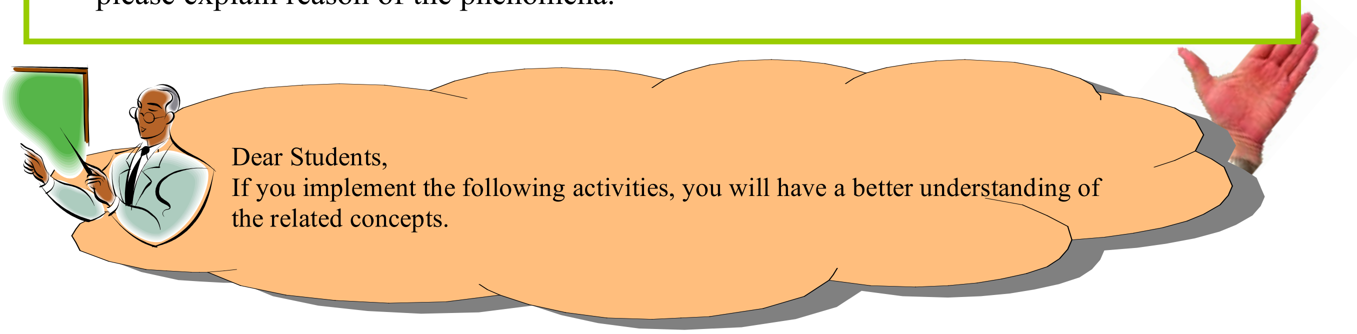
Appendix 1. Student's worksheet

Name – Surname: …….

1. Everybody witnesses that our palm gets pink and damp when we blow our respiration into it once or twice by shutting our hand. In your opinion, please explain reason of the phenomena.
2. After we blow our respiration into our palm once or twice by shutting our hand, we feel a sudden coolness if we touch our hand to the window in winter season. In your opinion, please explain reason of the phenomena.



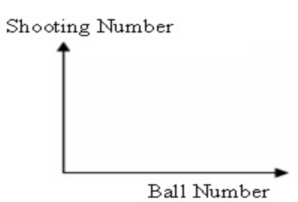
⇒ **--- All class, line up at the same distance from basketball hoop ---**

1. Shoot in an order with one ball given by your teacher. Then write your shooting number to the subsequent table after completing tour.

2. Shoot in an order with five balls given by your teacher. Then write your shooting number to the subsequent table after completing tour

3. Shoot in an order with ten balls given by your teacher. Then write your shooting number to the subsequent table after completing tour (since 12 grade 5 students were enrolled the school where the first author has been teaching science course, we used this number).

Shooting Numbers	Student 1	Student 2	Student 3	Student 4	Student 5	Student 6	Student 7	Student 8	Student 9	Student 10	Student 11	Student 12
1st Activity												
2nd Activity												
3rd Activity												



Draw a graph related by help of shooting number and ball number

Please think of your teacher as a heat source, think of yourself as a substance taking heat, think of the ball given to you as heat, and think of your shooting number as temperature. Then answer the questions below.

⇒ Explain the **relationships** between heat and temperature.

………

………

⇒ Explain the **differences** between heat and temperature.

………

……

Answer the following questions using your gained experiences from the foregoing steps

1. When I was watching TV yesterday, I encountered two different explanations. That is, while an anchor was saying "temperature of the weather is increasing", another was telling "the weather is heating". Did they mean the same thing? Please explain your response.

………

………

2. While in a TV advertisement woman says "*the detergent provides an excellent cleaning even if a lower heat exists*", in my clothes it is written "*wash at only* 30^0C *temperature*". Which one (heat or temperature) is correct? Please defend your response.

………

………

3. Fill in the blanks with suitable words in the box.

- ✓ Water taking heat ……………………………..
- ✓ Water giving heat ……………………………
- ✓ Temperature of water taking heat …………………
- ✓ Temperature of water giving heat ………………..
- ✓ While soup is getting cold, it ……………………
- ✓ A meal ………………….. for cooking.

increases
gets cold
decreases
loses heat
gets heating
needs to be heated

Appendix 2. The analogy mapping used in Explanation Phase

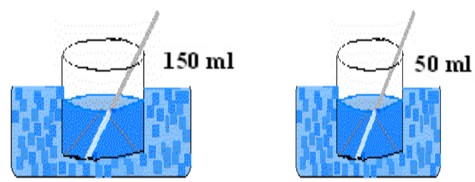
Analog Feature	Comparison	Target Feature
Passing the ball from the teacher to students	Compared to	Heat transfer from hot substance to cold one
Each student in a sequence order shoots the ball.	Compared to	Heat flows though a substance.
The more ball is available the more shooting number emerges	Compared to	The more heat exists the more temperature emerges.
Shooting number is a quantitative value.	Compared to	Temperature is a quantitative value.
The ball	Does not compare to	Heat because the ball is a physical object, but heat has an abstract structure.
Students	Does not compare to	Particulate nature of matter because we cannot see particles at sub-microscopic level. Further, there is an enormous number of particles in matter.

Appendix 3. The analogy mapping used in Elaboration Phase

Analog Feature	Comparison	Target Feature
The number of players at each group affects shooting numbers.	Compared to	The amount of substance affects the temperature.
The time necessary for shooting affects its number	Compared to	The time necessary of heating affects the temperature
Tallness of the players does not affect shooting number.	Compared to	Size of a substance does not affect its temperature.
Players	Does not compare to	Particulate nature of matter because we cannot see particles at sub-microscopic level. Further, there is an enormous number of particles in matter.

Appendix 4. A conceptual change text of heat and temperature

As seen from the two beakers- filled with water, their volumes are 50 ml and 150 ml. If we put them into ice water for a while, what do you think about heat and temperature of each beaker? Please compare them.



A famous Turkish basketball coach, Ergin ATAMAN, took his niece, Ahmet, to training. He viewed the training enthusiastically. While Ataman sent the favorite players (5 people) to a crucible, he did the spare players, majority of whom were tall, to the opposite one. Ataman took notes their shooting numbers. At that moment, Ahmet recalled a game of heat and temperature and wanted to see his uncle's schedule where all favorite players make 10 shooting per a minute and the spare players make 6 shooting per a minute. It was surprising because the number of his and his friends' shots was the same at their played game in their school. Their teacher made a comparison such as: shooting number with temperature, the ball number with heat and the students with a substance taking heat. To him, there was a discrepancy since coach gave one ball to each player group (favorite and spare). In other words, equal heat must have meant the equal temperature.

The next day, by explaining the phenomena Ahmet observed, he asked a question to his teacher: why the groups having equal heat don't possess the equal temperature. The teacher firstly addressed some explanations to his class based on Ahmet's experiences: *coach as a heat resource, favorite and spare player groups as different substances, the ball given by the coach as heat and players' shooting numbers as temperature.* Then, he expressed that some students believed that the time necessary for cooling and heating does not count on substance's volume and mass. The teacher explained that to heat a glass and kettle of water requires different time. Likewise, the time necessary for preparing a Turkish coffee and a meal differ from each other. Of course, its opposite requires the same situation.

Then the teacher said that *some students believe that temperature of an object depends on its size.* But this is wrong because temperature of the object depends on its taken heat (its own energy) instead of its size. The teacher mentioned that some students use heat and temperature interchangeably. But this is also wrong. That is, while heat is seen as a transferring way of energy, temperature is a quantitative value measured by thermometer. Further, some students thought that *heat has two types: hot heat and cold heat.* But this is incorrect as well. That is, *hot means having a higher heat whilst cold means having a lower heat.* Finally, the teacher talked about transferring of heat and temperature. S*ome students believe that temperature can flow from one substance to another. But this is wrong because what is transferred is called 'heat', not temperature.* Afterwards, refuting his discrepancy makes Ahmet become satisfactory.

Dealing more effectively with alternative conceptions in science

Carl J. Wenning, Physics Teacher Education Program, Illinois State University, Normal, IL 61790-4560
E-mail: wenning@phy.ilstu.edu

Many science teachers are aware of the existence of alternative conceptions – notions held by students that are contrary to those generally accepted by mainstream scientists. Authentic alternative conceptions are tenaciously held, and doggedly resistant to change. Only carefully managed efforts by teachers will effectively address them. The author proposes two emphases within the context of the "standard model" for more effectively overcoming alternative conceptions.

Alternative Conceptions

Seventeenth century English philosopher John Locke suggested that students come to school as "tabula rasa" (blank slates) to be "written upon" by teachers. While Hume was correct about a great number of things, this was not one of them. Students come to school with non-traditional ideas that deal with the natural world that are highly resistant to change and strongly influence new learning (Pfundt & Duit, 1991; Carmichael et al., 1990). It is these improper interpretations that are collectively know as alternative conceptions.

The children's book *Fish is Fish* by Leo Lionni (1970) illustrates this problem beautifully. Lionni tells a story about a fish that is interested in learning about life on land. Unfortunately, the fish cannot explore any place beyond the confines of a small pond. He befriends a tadpole that eventually grows into a frog and moves out of the pond onto the land. The frog subsequently returns to the pond and reports what he has seen to the fish. The frog describes all kinds of things such as people, birds, and cows. The book's illustrations depict the fish's mental representations of each of those things described by the frog; each land creature has a fish-like body that is slightly adapted to accommodate the frog's descriptions. People are imagined to be fish that walk on their tailfins, birds are thought of as fish with wings, and cows are believed to be fish with udders.

This children's story exhibits well both the creative license and dangers inherent in the fact that people construct new knowledge based on prior experiences and understandings. Research has shown that instead of remembering a host of accurate details, people tend to remember events by incorporating a few details within a schema for the event (Silva et al., 2006; Scoboria et al., 2006). Alternative conceptions often results when new experiences are interpreted in light of prior experiences, and new understandings are grafted onto prior understandings. Memories in general are retrieved by first recalling the schema and then the associated details. If a concept does not fit a pre-existing schema and is not all that salient, it likely will be forgotten or even rejected.

To give readers unfamiliar with alternative conceptions in physics a better understanding of the phenomenon, Table 1 exhibits a number of classical examples from the area of mechanics – the area most carefully studied and for the greatest period of time (e.g., Vienot, 1979; Caramaza, McCloskey & Green, 1981; Champagne, Klopfer & Anderson, 1980; Gunstone & White, 1981; Clement, 1982; Minstrell, 1982; Gilbert & Watts, 1983; McDermott, 1984; Camp & Clement, 1994).

1) When force is applied to an object, it produces motion in the direction of the force.
2) Under the influence of constant force, objects move with constant velocity.
3) The velocity of an object is proportional to the magnitude of the applied force.
4) In the absence of a force, objects are either at rest or, if moving, are slowing down.
5) An object moving under a central force will move in a curvilinear path when released.
6) The acceleration of a falling object depends upon its mass.
7) Freely falling bodies can only move downward.
8) There is no gravity in space.
9) Gravity only acts on things when they are falling.
10) An object at rest cannot be undergoing acceleration.

Table 1. *Classical examples of alternative conceptions.*

Claims Regarding Alternative Conceptions in Science

Following an extensive review of the research literature, Wandersee, Mintzes, & Novak (1994) generated eight "emerging" research-based claims relating to alternative conceptions in science. Summaries can be found in Table 2. Subsequent experiences in science teaching appear to have borne out these claims. For a thorough explanation of these claims, along with pertinent evidence, the reader is referred to the original work.

Table 2. *Research-based claims relating to authentic alternative conceptions (continued next page).*

Claim 1: *Learners come to formal science instruction with a diverse set of alternative conceptions concerning natural objects and events.* Alternative conceptions span the fields from physics and earth & space science to biology, chemistry, and environmental science. Each associated subfield within the disciplines seems to have its alternative conceptions.

Claim 2: *The alternative conceptions that learners bring to formal science instruction cut across age, ability, gender, and cultural boundaries*. No matter how gifted a group of students concerned, each group will have students with alternative conceptions regardless of background.

Claim 3: *Alternative conceptions are tenacious and resistant to extinction by conventional teaching strategies*. Students' alternative conceptions are very difficult to change; only very specific teaching approaches have shown promise of getting students to accept new explanations.

Claim 4: *Alternative conceptions often parallel explanations of natural phenomena offered by previous generations of scientists and philosophers*. Students often hold to the same views as those held by very early scientists that are frequently referred to as "Aristotelian" in nature.

Claim 5: *Alternative conceptions have their origins in a diverse set of personal experiences including direct observation and perception, peer culture, and language, as well as in teachers' explanations and instructional materials*. The many sources of alternative conceptions are at best speculative, but research and inference suggest that a student's worldview is strongly influenced by his or her social environment.

Claim 6: *Teachers often subscribe to the same alternative conceptions as their students*. It is not at all uncommon for science teacher educators to see alternative conceptions in their teacher candidates; likewise, even experienced science teachers and scientists with advanced degrees will sometimes cling to alternative conceptions that are held by their students.

Claim 7: *Learners' prior knowledge interacts with knowledge presented in formal instruction, resulting in a diverse variety of unintended learning outcomes*. Not only can alternative conceptions be a hindrance to new learning; they can also interact with new learning resulting in "mixed" outcomes. It is not unusual to see different students draw different conclusions from the same experiences and observations.

Claim 8: *Instructional approaches that facilitate conceptual change can be effective classroom tools*. Several conceptual change approaches have been developed to identify, confront, and resolve problems associated with alternative conceptions.

Table 2. *Research-based claims relating to authentic alternative conceptions (after Wandersee, Mintzes, & Novak, 1994).*

Origins of Alternative Conceptions

The origin of a given alternative conception is often difficult if not impossible to determine. Misunderstanding, miscommunication, miseducation, and even a misapplication of well-established physical principles lead to the formation of alternative conceptions.

Sometimes students can experience the same phenomenon and still draw different conclusions as in the case of demonstrations where there is a lack of critical observation and appropriate follow-up discussion. For instance, haphazardly observing the demonstration of a Lenz's law apparatus (a conducting tube through which apparently identical equal-mass magnetic and non-magnetic plugs are dropped) might lead some students to the false conclusion that weights of equal mass actually can fall at different rates under the "same" circumstances. Taylor & Dana (2003) provide several examples of students who uncritically interpreted experimental data and ended up with contradictory results. For instance, they point to problems with inappropriate conclusions based upon improperly designed experiments, misuse of instruments resulting in unreliable data, overgeneralization from the data, misinterpretation of graphs, logical fallacies in argumentation, and failure to otherwise apply critical thinking abilities. These authors also point to the existance of alternative conceptions and their influence on new learning.

In other cases, students might cling to false notions that result from one or more forms of improper teaching. For instance, students might hold alternative conceptions as a result of a parent's, peer's, or teacher's false or misleading statements, inaccurate or deceptive renderings of drawings (e.g., idealized or inaccurate depiction of physical phenomena – such as using an inconsistent scale – against a natural background, or too literally taking an analogy as real), or even a misunderstanding of technical terms (e.g. force).

In still other cases, students might misapply what correct information they do possess. A misunderstanding of underlying conditions can lead to what appears to be alterative conceptions. Teachers should be acutely aware that alternative conceptions are NOT necessarily naïve viewpoints. Sometimes they are well-reasoned explanations or over generalizations that just happen to be incorrect under certain conditions such as the realm of idealized physics (where friction is often ignored). For instance, some of the alternative conceptions in Table 1 might not appear to be incorrect at all, but actually depict real-world situations. In the absence of wind resistance, some of these alternative conceptions actually are correct. For the sake of this discussion, we will call such conceptions – sometimes correct and sometimes incorrect – paraconceptions.

Teachers who fail to recognize and make this latter distinction risk losing credibility among their students, and all hope of overcoming a particular paraconception. Without being made aware of the dual nature of some alternative conceptions (e.g., correct under certain conditions), students likely will cling to a given paraconception if they are not convinced that their understanding is either right or wrong depending on specific conditions. In this case, we don't want to eliminate paraconceptions; rather, we want to help students understand how these ideas fit in with the ideas of the scientific community and how to use them properly under various conditions. When students encounter these two explanatory paths, they must learn not to "take the best path," but to realize that both paths are legitimate under particular conditions, and to carefully analyze the situation to determine which is the most appropriate solution.

Alternative Conceptions So Called

As Clement et al. (1989) noted, "Not all preconceptions are misconceptions." And with paraconceptions, not every mistaken student expression is indicative of the presence of an alternative conception. Some mistaken expressions are nothing more than students encountering difficulties in explaining new phenomena. For instance, when presented with the question "When a small car and a large bus collide head on, is the magnitude of the force of the bus on the car greater than the magnitude of the force of the car on the bus, or are both forces equal in magnitude?" Students will naturally assume that because the car is often completely crushed in a collision and the bus relatively undamaged that the force of the bus on the car is greater than that of the car on the bus; the concept of equal but opposite forces rarely enters into the mental thought process.

Such so-called alternative conceptions do not necessarily share the characteristics of authentic alternative conceptions, but can represent "difficulties" in the formulation of scientifically acceptable explanations. This might well result from a very logical but inappropriate application of what have become known as phenomenological primitives or p-prims (diSessa, 1988). P-prims are general, irreducible knowledge structures that we all possess as a result of reflecting (perhaps subconsciously) on our experiences, and upon which we tend to rely for explanations. Examples include the principle that "more effort results in more result" and "more resistance implies less result." In the case of the car-bus collision, the greater damage to the car is suggestive of greater force.

As p-prims are refined through subsequent learning, they gradually result in expertise in the content area. For instance, in physics the common sense notion that "motion requires force" is replaced by a proper understanding of Newton's first law, "force is action" is replaced with Newton's second law, and "force is war" is replaced with Newton's third law (Hestenes, 2006).

Considering flawed student ideas to be alternative conceptions might provide a more explicit way to target those ideas that are not consistent with scientific viewpoints, and make it easier for instructors to alter their instructional approach. I am therefore adopting the alterative conceptions approach to frame the following discussion. The term "alternative conception" used in this article encompasses all types of student conceptions consistent with the research-based claims shown in Table 2.

Conceptual Change vs. Concept Exchange Models

In their landmark 1994 article, Wandersee, Mintzes, & Novak noted that instructional approaches for dealing effectively with alternative conceptions (e.g., Hewson, 1981; Posner et al., 1982, etc.) were still in "an embryonic stage of development" (p. 191). Nonetheless, the framework for addressing alternative conceptions was basically in place. For instance, Hewson (1981) proposed two models to explain how alternative conceptions are overcome. Either an alternative conception is suppressed and replaced by a correct understanding (conceptual change), or students retain both views but reject or demote the old conception and adopt the new one as more convincing (concept exchange).

The Conceptual Change Model suggests that when a new concept is learned it weakens or destroys an existing memory. Unfortunately for this model, humans don't overwrite memory as in a computer. Cognitive scientists have identified mechanisms by which memories are encoded (the establishment of new synaptic junctions), but we know of none in which memories are actively destroyed (disestablishment of synaptic junctions). Cognitive research shows that forgetting requires very specific types of actions, and the associated cognitive processes are known as proactive and retroactive interference. Efforts must be undertaken to help students forget an inaccurate conception. Teachers must help students "forget," and this involves more than just letting old memories fade. Instead, we must work to actively replace old memories with new, helping students to see how their initial ideas fit within the framework of scientific understanding.

In the Concept Exchange Model, the old conception is not modified; rather, a new conception comes to exist along side the old conception. As evidence for this model, the alternative conception often reappears after traditional instruction has supposedly banished it. It is also not uncommon when teachers press students to explain their understanding for them to respond to the inquiring teacher, "Do you want my explanation or yours?" Such queries clearly indicate that students some times hold two explanations, one that they "know to be true" based on their own experiences, and another that they "accept as true" because the course instructor told them so.

While conventional wisdom – the stuff of common teaching experiences – seems to favor the concept exchange model over the conceptual change model, similar pedagogies appear to address both models. Under both models, in order for new conceptual understanding to develop, a new conception must satisfy certain conditions stated by Posner et al. (1982). It must be intelligible (students comprehend its meaning), plausible (students believe it to be correct), and fruitful (students find it useful). To the extent that a new conception possesses these characteristics in the mind of the student, the greater the likelihood that learning of the new concept will proceed with comparative ease. To the extent that an alternative conception conflicts with new phenomena, it is modified, or is no longer considered useful, its status drops, and it is rejected as untenable.

Are Extant Models of Alternative Conceptions Flawed?

Hammer (1996, 2000), diSessa (1988), Clement et al. (1989), and Smith et al. (1993/1994), point out that problems do exist with early models of alternative conceptions and how to deal effectively with them. According to Hammer (2000), "First, [these models] provide no account of productive resources students have for advancing in their understanding. Second, descriptions of student difficulties provide no analysis of underlying mechanism, while the perspective of misconceptions cannot explain the contextual sensitivities of student reasoning."

While such criticisms of alternative conception models might well be valid, they do not constitute adequate reason to displace forty years of work in this area. When teachers encounter flawed student expressions, we can't be certain if we are dealing with flawed logic, the presence of alternative conceptions or paraconceptions, or the presence of phenomenological primitives. Assuming that students aren't merely having logic problems, both alternative conception and p-prim models can be useful in interpreting student responses.

The methods of dealing effectively with conceptual difficulties though the terminology of p-prims which includes resources and strategies that build on learners' existing ideas and extend them, through, for example, metaphor or analogy, to a new domain (Hammer, 2000; Scott, Asoko, & Driver, 1998; Camp & Clement, 1994) are not directly addressed in this article.

Pedagogies for Addressing Alternative Conceptions

A wide range of pedagogies has been developed to address alternative conceptions such as learning cycles (Karplus, 1981), Conceptual change theory of Posner et al. (1982), bridging analogies (Clement, 1988; Perschard & Bitbol, 2008), microcomputer-based laboratory experiences (Thornton & Sokolof, 1990; Thornton, 1987), disequilibration techniques (Minstrell, 1989; Dykstra, Boyle, & Monarch, 1992), an inquiry approach coupled with concept substitution strategies (Harrison et al., 1999), metaconceptual teaching on inducing a particularly problematic aspect of the conceptual changes (Wiser & Amin, 2001), and a teaching model (Thomaz et al., 1995).

These approaches tend to have in common the requirement that students encounter phenomena that run counter to their existing beliefs. Doing so, they are put in a state of intellectual disequilibrium or cognitive conflict. Becoming aware of the conflict between what they believe to be correct based on prior experiences and know to be correct based on more recent experience helps them to confront and resolve their conflicting perspectives in favor of a proper understanding. Such pedagogical approaches that emphasize conflict and resolution appear to derive from a Piagetian perspective on learning (Scott, Asoko, & Driver, 1998). In such a viewpoint, the learner's role in reorganizing their knowledge is central to overcoming the alternative conception.

These and other approaches dealing with alternative concepts typically include three fundamental steps – those identified by the University of Washington Physics Education Group: elicit/confront/resolve (McDermott, 1991). In this model a teacher first elicits a response (prediction about what will happen or an indication of agreement or disagreement with a given statement) from students, forcing them to commit to an answer in relation to a specific situation. Next, the students confront a situation that challenges their beliefs and answers, typically in an experiment that the students perform. During this second phase, if the students were incorrect in their prediction, they experience cognitive dissonance when confronting the conflict between prediction and experience. Students quickly come to realize the need for a new understanding about the concept under consideration, and are motivated to resolve the conflict with teacher assistance in phase three.

Another such strategy is that developed for the C^{3}P Project. According to Olenick (2008) overcoming alternative conceptions requires the following distinct steps:

(1) Teachers must recognize that alternative conceptions exist.
(2) Teachers probe for student's alternative conceptions through demonstrations and questions.
(3) Teachers ask students to clarify their understanding and beliefs.
(4) Teachers provide contradictions to students' alternative conceptions through questions, implications, and demonstrations.
(5) Teachers encourage discussion, urging students to apply physical concepts in their reasoning.
(6) Teachers foster the replacement of the misconception with new concepts through (i) questions, (ii) thought experiments, (iii) hypothetical situations with and without the underlying physical law, and (iv) experiments or demonstrations designed to test hypotheses.
(7) Teachers reevaluate students' understanding by posing conceptual questions.

Conjecture for a More Effective Approach

The traditional approach of overcoming alternative conceptions consists of eliciting, confronting, and resolving has not always been an effective way for teaching and learning physics as can be inferred from the results certain physics education research. Consider, for instance, instructors who use the Modeling Method of Instruction and results obtained from their use of the *Force Concept Inventory* ([FCI] Hestenes, Wells, & Swackhamer, 1992).

The FCI is regularly used with Modeling mechanics to test the progress of student learning in relation to their non-modeling peers. The FCI, a 30-question standardized exam based strongly on a traditional understanding of alternative conceptions, is used to assess teacher effectiveness for achieving a "minimal teaching performance standard: to teach students to reliably discriminate between the applicability of scientific concepts and naive alternatives in common physical situations" (Modeling website, 2002). It is conceivable that certain tentative conclusions can be drawn from data generated using this instrument in relation to novice versus expert Modelers.

According to the above Modeling website, in studies employing data from a nationwide sample of 7,500 high school physics students, "the average FCI pretest score is about 26%, slightly above the random guessing level of 20%, and well below the 60% score which, for empirical reasons, can be regarded as the threshold for understanding Newtonian mechanics…. After their first year of teaching, posttest scores for students of *novice modeler*s were about 10 percentage points higher" using data from 3,394 students of 66 teachers. "Students of *expert modelers* do much better. For 11 teachers identified as expert modelers after two years in the Project, posttest scores of their 647 students averaged 69%. Thus, student gains in understanding under *expert* modeling instruction are more than doubled (40 percentage points gained), compared to traditional instruction (16 percentage points gained)."

No explanation is given by the author(s) of this web site suggesting why it might be that the students of expert Modelers perform better on the FCI than do those of novice Modelers. However, the fact that Modelers who use the standardized FCI test – a test based strongly on alternative conceptions – show little gain in the first years of Modeling Instruction is suggestive that novice Modeling teachers, as they mature into expert Modelers, eventually come to realize that there is more to addressing alternative conceptions than a three-step method of eliciting, confronting, and resolving ideas. Something else clearly must be changing in their approach to dealing with alternative conceptions.

Based on three years of interactions with Modelers in the *Chicago ITQ Science Project,* the author presents as a tentative explanation that the reason students of expert Modelers perform better on the FCI than do students of novice Modelers is because expert modelers inadvertently have added a fourth and fifth step to their instructional practice. These steps, perhaps introduced by expert Modelers as a result of frustration, consists of identifying the existence of alternative conceptions and then reinforcing student learning in the area of the alternative conception. It is this author's contention that a poorly understood **ELICIT-CONFRONT-RESOLVE** approach fails to make a substantial lasting difference in the area of alternative conceptions because it fails to clearly **IDENTIFY** the existence of the alternative conception to students and fails to **REINFORCE** student learning in the area of the alternative conception. A better approach to dealing with alternative conceptions suggests a more clearly elucidated five-step approach that will be herein referred to as the ECIRR (Elicit-Confront-Identify-Resolve-Reinforce) model.

Including IDENTIFY and REINFORCE

Deductions from studies in the area of cognitive psychology dealing with memory and recall also serve as an additional basis of including IDENTIFY and REINFORCE in the ECIRR model.

IDENTIFY

Memory consists of both declarative and procedural components. Declarative memory is most closely associated with alternative conceptions, and consists of two components – episodic and semantic memory (Tulving, 1972). Episodic memories are memories that relate to personal experiences and take on a personal perspective. Semantic memories include abstracted facts about the world and knowledge of how things work that typically are not derived from personal experiences but, perhaps, from book learning and other forms of communication. Using a metacognitive approach - literally helping students to think about their thinking relative to what they know and how they know it - can provide an effective means for overcoming established alternative conceptions. Clearly identifying an alternative conception as such can be a powerful way to overcome alternative conceptions. Students need to know that alternative conceptions exist and should be put on notice about their pernicious effects. This knowledge enhances students' ability to better overcome existing alternative conceptions and recall new understandings. This notification, coupled with experiences that help students confront their misconceptions can activate both episodic and semantic memory.

The IDENTIFY step consists of making students aware of the fact that alternative conceptions exist and have the pernicious effects outlined in Table 2. The IDENTIFY step does NOT suggest that students are told they are wrong. To do so, especially repeatedly, can cause students to become frustrated and to shut down mentally to resist intellectual change. This step must follow the confrontation step; otherwise, it would conflict with a constructivist viewpoint under which students should draw their own conclusions based on evidence.

REINFORCE

New learning is not always retained as experience has show. Consider the fact that after instruction teachers test students' knowledge and find that an alternative conception still exists. This suggests that the alternative conception has not been replaced by a modified conception, but is temporarily unavailable for recall. While methods exist for making memories (establishment of new synaptic junctions), no method exists for easily erasing memories (disestablishment of old synaptic junctions). What makes a difference is which conception is most likely to be recalled. Cognitive understandings would suggest that there is a well-worn "highway" to the old concept making it habitually accessible during recall; the new conception has only a "footpath" leading to it and this reduces the probability of its recall. The footpath needs to be replaced by a highway, and the highway needs to become a footpath. The highway will be established only when students: (1) over learn the new conception thereby making it more accessible and more likely to be recalled than the old conception or, in the case of a paraconception, (2) learn to analyze a situation and determine which understanding is the best to apply. These approaches will help students improve their ability to retain new learning and preferentially retrieve it from memory under varying conditions.

How the ECIRR Model Works

ELICIT

The teacher probes for students' alternative conceptions through activities that make students' thinking evident such as asking questions, and conducting Socratic dialogues with whiteboarding (Wenning, 2005; Wenning et al., 2006). During such practices teachers ask students to predict, explain, and make clarify statements. Of course, this step assumes that the teacher is cognizant that alternative conceptions exist and what they are. Previous research has shown that in order for a teacher to effectively address student's alternative conceptions, they must be aware of the presence of such ideas (da Silva et al., 2007; Hewson et al., 1999).

The number of alternative conceptions possessed by students is indeed large. Secondary sources providing a collection of alternative conceptions in physics and other areas are plentiful and include such publications as *Handbook for Research on Science Teaching and Learning,* (Gabel, 1994); *Physics Begins with an M* (Jewett, 1996a); *Physics Begins with another M* (Jewett, 1996b), and online resources such as those provided by the C^{3}P program (Olenick, 2008) and *Operation Physics* (Weiler, 1998) websites. Internet searches will also provide additional resources.

<u>CONFRONT</u>

The teacher uses discrepant events to provide contradictions to students' statements or predictions and place them in a state of cognitive conflict. They confront alternative conceptions through demonstration, implications, and questions, and encourage discussion. Teachers must keep in mind that the greatest amount of learning will be achieved when the learners' motivation level is high. Motivation (as contrasted with coercion) will be highest when the students' best interests and needs are served, and the subject is relevant to students' day-to-day lives. They also must keep in mind that the greatest amount of learning occurs when the salience of the stimulus is high. Using surprise, mystery, and bedazzlement can serve to increase the salience of a phenomenon.

Taylor and Coll (1997) noted that cognitive conflict has the advantage of helping to address alternative conceptions effectively, but noted too that it might serve also reduce student's confidence in their ability to understand science. Care should be taken to ensure that this does not happen.

<u>IDENTIFY</u>

After alternative conceptions are elicited and confronted, the teacher must clearly and unambiguously identify them as such. Teachers must be careful, however, not to denigrate the value of intuition that often can lead to correct predictions. They must explain the power of alternative conceptions to mislead, and state emphatically that students must not be misled and they should divorce themselves from it because the old conception will compete with the new conception. It is not unreasonable to summarize what research says about alternative conceptions, and even to review the key findings of Wandersee, Mintzes, & Novak (Table 2). To be consistent with a constructivist viewpoint of teaching, IDENTIFY should follow confrontation and not precede it.

<u>RESOLVE</u>

The teacher should foster the replacement of an alternative conception using any of the following approaches: questions, thought experiments, interactive demonstrations, hypothetical situations, and experiments designed to test hypotheses. They should help reevaluate students' understanding by posing conceptual questions, and eliciting student source(s) of alternative conception. To overcome alterative conceptions, teachers should place as much attention on students' prior knowledge as possible, but allow students to actively resolve discrepancies by themselves because teaching by telling simply does not work.

Hestenes (2006, p. 18) points out how the active approaches of *Modeling Instruction* can be used to address pre-existing cognitive structures:

- *Modeling activities* that systematically engage students in developing models and providing their own explanations for basic physical phenomena,
- *Modeling discourse* (centered on visual representations of the models) to engage students in articulating their explanations and comparing them with [properly understood] concepts, and
- *Modeling concepts and tools* (such as graphs, diagrams, and equations) to help students simplify and clarify their models and explanations.

<u>REINFORCE</u>

When teachers help students develop a new understanding of a phenomenon rooted in an alternative conception, this does not necessarily extinguish prior learning. As experience shows, there are frequently two competing concepts in students' minds. To address alternative conceptions effectively, teachers must reinforce the pathway that leads to the new understanding and extinguish or at least suppress the pathway that leads to the old understanding, or help students to decide in the case of paraconceptions. Failure to do so can result in students recalling the alternative conception preferentially over the desired understanding.

This reinforcement should be done repeatedly, over time, and under varying conditions. This is due in part because retrieval pathways are not well established, and effort must be expended on firmly establishing the retrieval mechanism associated with the new understanding. Several important approaches from cognitive psychology can be used to do so.

<u>Employing levels of processing</u>

Encoding in relation to an alternative conception requires more than just repetition, and the desire to remember is not sufficient for appropriate encoding either. If sustained learning is to take place in order to overcome an alternative conception, then we must think about what we want to remember, we must know from experience that the prior conception is wrong, and we probably should include even some form of "desirable difficulty."

The quality of encoding associated with a new understanding can be improved through the use of levels of processing. Research has shown that the level at which information is processed, not just how long or how often, strongly influences the degree to which students retain new understandings (Craik & Lockhart, 1972). Levels of processing can be described as a continuum running from shallow processing (maintenance rehearsal) to deep processing (elaborative rehearsal). Deep processing is much more closely associated with long-term retention than shallow processing. When students are required to apply information to new situations it is much more likely to be recalled than when asked to memorize that information. Students who merely watch a demonstration are much less likely to remember its significance than those who have discussed it with friends or have been required to write about it.

Levels of processing can include desirable difficulties that are often associated with student study efforts, but can be incorporated by teachers seeking to overcome alternative conceptions. Desirable difficulties are approaches to situations that make studying more challenging and the benefits less obvious in the near term. Desirable difficulties promote long-term retention and the ability to transfer what has been learned to new situations. Teachers create desirable difficulties when they get students to think about their own thinking (metacognition) and learn subject matter using different approaches. Students create desirable difficulties for themselves when they determine the objectives of their study, organize information, and approach the subject matter from a variety of perspectives.

<u>Rehearsing under varying conditions</u>

The encoding specificity principal of cognitive psychology states that retrieval of a memory is most effective when it occurs in the same context as used for encoding. Nearly everyone has had an experience where they walk into one room to get something and fail to recall what was to be retrieved. Upon returning to the point of origin one quickly remembers what one was to pick up – an example of the context reinstatement effect. These effects are most clear when students learn about a phenomenon during a class discussion, but fail to recall it under testing situations.

The encoding specificity principal of context-specific learning comes into play when asked to recall an answer under a testing situation students fail. Still, when back in the original setting, we see the context reinstatement effect. Is this a matter, then, of forgetting where information is permanently lost from memory, or of retrieval block where information is not forgotten but not remembered either? Because memories are resilient, alternative conceptions will not just fade away. Nonetheless, memories can be weakened through the processes of retroactive interference – when concepts learned at the end of a study process reduces a student's ability to recall earlier memories. Cognitive research shows that forgetting requires action, and in the case of alternative conceptions, this cognitive process is retroactive interference.

To help overcome the problems associated with the encoding specificity principal, efforts should be undertaken to ensure that retrieval is practiced repeatedly and under a variety of conditions.

Deploying the ECIRR Model – An Example

When teaching gravitation, teachers are often confronted with the alternative conception that "there is no gravity in space." What follows is an example of how to deal more effectively with this alternative conception. Similar approaches can be used with other alternative conceptions.

Elicit – A teacher uses a historical approach to derive Newton's theory of gravitation, concluding that $F = GMm/r^2$. The teacher then asks the question how this formulation of gravity applies to objects in space – planets, the moon, satellites, the Space Shuttle orbiter… Then the teacher asks the question, "What about astronauts in space? Does gravity apply to them, too?" Students frequently will say "No!" and cite as evidence the fact that astronauts in space float around and are, therefore, weightless. According to one student's explanation, "Someone can be weightless only in the absence of gravity." Others, recognizing the limitless extent of the gravitational force, might say, "Yes, there is gravity in space but it is very small up in orbit. After all, NASA does speak about microgravity in the space environment."

Confront – To be constructivist in their approach, a teacher must allow students to come to see that their statements are not consistent with reality. Having elicited the above alternative conception, the teacher now confronts students with evidence contradicting their alternative conceptions. The teacher might talk about the parabolic aircraft flights on the NASA "Vomit Comet" that result in free floating, or what would happen to a passenger in a freely falling elevator. Clearly, while these people experience weightlessness, they are still under the influence of gravity.

Ideally, a teacher will help students confront an alternative conception by using active learning strategies that fully engage students. A teacher might have students conduct a mathematical calculation to determine the force of gravity on an astronaut, on and at different distances above the surface of the earth. Students will rapidly see that the force at the altitude of the orbit is not all that much less than near the surface of the earth. Clearly, the force of Earth's gravity must extend into space, and must be substantial even at the altitude of the Shuttle orbiter.

Identify –Following the confrontation phase, the teacher identifies the fact that students who believe that weightlessness results from a lack of gravity, or that gravity is "weak," have fallen under the influence of common alternative conceptions. The teacher notes that alternative conceptions exist, and helps the students to become fully aware of key findings about them as shown in Table 2.

Resolve – The teacher must now help students overcome their former beliefs by working with students to understand where such alternative conceptions might have come from. Following this, the teacher could go on to explain concepts such as frame of reference, and explain orbital motion is nothing but a fall toward the Earth at a rate which Earth falls out from beneath astronaut (perhaps referencing the image of "the cannon shot round the world"). Another approach would be to have students place a small weight on a string and twirl it around over their heads noting that the string plays a role similar to gravity and the weight an orbiting astronaut. Ask the students, "Upon releasing the string, what happens?" Allow students to develop their own explanations of how this analog applies to the orbiting astronaut situation. Give them an opportunity for whiteboarding as appropriate. Students will come to realize that nothing can stay in orbit with out a central force. Create a graph of acceleration due to gravity ($g = GM/r^2$) for various distances from Earth's surface out to, say, the orbital distance of the moon, and compare the ratio of g-in-orbit to g-at-surface. Computer simulations might be used to help students understand the concept. Students can also be asked to discuss or write about their alternative conceptions in relation to what they now understand to be a correct view.

Reinforce – After the resolution phase, the teacher periodically reviews the alternative conceptions under varying conditions. This might consist of periodic reviews at the end of class, interjection of questions about the alternative conceptions when related topics are discussed or by more formal formative evaluations. By periodically questioning and testing for understanding in relation to the proper understanding of gravitation under varying, teachers help students reinforce weak memories and suppress those alternative conceptions that might otherwise be more easily be recalled during summative evaluations.

In Conclusion

Effectively addressing alternative conceptions requires more than just eliciting, confronting, and resolving a false notion. Forming memories that are easily and accurately retrieved requires more than a desire to remember. Efforts must also include identifying the presence of alternative conceptions and reinforcing new learning. Forgetting takes work, and it is important to include activities that weaken memories and enhance recall of preferred understandings.

Traditional approaches for eradicating alternative conceptions fail to work because they do not implement metacognitive and reinforcement processes so necessary to deal effectively with an alternative conception. So it is with other habits such as smoking, biting fingernails, over eating, or thumb sucking. These bad habits are best broken with the use of explanations and repeated reminders. Explanations and reminders reinforce learning and are important to the habit-breaking process. Study and practice are required if students are to develop a long-lasting change in understanding and the ability to recall that knowledge accurately under a variety of new conditions.

While the EICRR model for dealing more effectively with alternative conceptions is conjectural, findings from both craft wisdom and cognitive psychology would seem to suggest that it is also important to identify alternative conceptions and reinforce student learning in this area. This EICRR conjecture could well be a fruitful area of work by physics education researchers.

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The effect of secondary education teachers' involvement in an action-research program on their students' alternative ideas on energy

Carlos Bañas-Sierra, carlosbasi6494@terra.es, and José Luis Díaz-Correa, joseluis.diaz@extremadura.es, Secondary Science Teachers, Colegio OSCUS, Badajoz, Spain.

Vicente Mellado, Professor of Science Education, vmellado@unex.es, and Constantino Ruiz, Professor of Science Education, cruiz@unex.es, Department of Science and Mathematics Education, Faculty of Education, University of Extremadura, 06071-Badajoz, Spain.

We carried out an action-research program in Spain with four science teachers in a secondary school during 2002/03 and 2003/04. During the study, the participating teachers analyzed their own students' alternative ideas on energy, and the teaching methods they themselves used as were observed in the videos of their classes. They also planned new teaching units. In the present article we will focus on the case of a teacher named Juan, and show how his teaching models and his students' ideas on energy evolved during this program. The results showed that the teacher's reflection on their students' commonest alternative ideas and on his own classroom teaching led his to plan new teaching

Introduction

The teacher is the key to qualitative improvement of education systems, and determines the success or failure of whatever curricular reform or innovation it is desired to implement (Dori & Herscovitz, 2005; Tobin et al., 1994). Understanding the processes of science teacher professional development has become one of the principal themes on the agenda of science education research (Hewson, 2007; Marx et al., 1998; Schneider et al., 2005), and is an essential element in the planning and practice of teacher education programs (Banilower, Heck & Weiss, 2007). For science teachers however, the axis of their professional development has to be science education, since the content to be taught conditions both the teacher's role and the teaching strategies (Abell, 2007; Garritz & Trinidad-Velasco, 2004; Shulman, 1986; Tobin & McRobbie, 1999).

Since the eighties, the constructivist approach has led to considerable progress in many aspects of science teaching and learning research. Constructivist studies have extensively investigated students' spontaneous ideas concerning scientific concepts. These ideas are deeply rooted, and often do not coincide with scientific theories. But having alternative ideas about scientific concepts has shown itself to be not an exclusive preserve of students. Science teachers can themselves have alternative ideas about scientific concepts, at times coinciding with those of the students (Geddis, 1993; Gunstone et al., 1993; Linder & Erickson, 1989; Mellado, Blanco & Ruiz, 1998; Sanders et al., 1993; Wanderse et al., 1994), thereby demonstrating how persistent these ideas can be. The alternative scientific ideas filter the information received, and persist and survive despite contradictions with scientific knowledge, simply coexisting with the latter in specific domains.

Science teachers too have conceptions and teaching models which are very stable and resistant to change (Jeanpierre et al., 2005; Lee et al., 2004). Science teachers' change is stimulated by successive processes of metacognitive self-regulation, based on their reflection, comprehension, and monitoring of what they think, feel, and do, and of the changes that they put into effect. Social aspects are also fundamental for science teachers' professional development. The teacher is an integral part of the community of a school, and it is very difficult for change to be individually implemented, and even more so for it to be consolidated, against the current of that school's educational culture and socially accepted norms (Bell, 1998; Mellado et al., 2006).

Sharing problems and seeking solutions in collaboration with other teachers reinforces professional skills and provides affective and emotional support (Bell & Gilbert, 1994). Action-research is a powerful procedure for the professional development of teachers, thanks to the cooperative action that it involves, and to the team work by means of which the teachers guide, correct, and assess their own problems, and take decisions in order to improve, analyze, or question their educational practice (Hanuscin et al., 2007).

Research with science teachers has found that teachers do not usually make drastic changes. Instead, they progressively put the ideas that seem to them to be important and at the same time attainable into practice (Gunstone et al., 1993; Rogan, 2007). Teachers will only change their personal theory and practice when they perceive it as being useless for their own practice, and when they have new strategies and resources available that they find useful for their everyday teaching of their specific subjects and for the learning process of their pupils (Mellado et al., 2006; Ritchie & Rigano, 2002). In this sense, previous research has shown that a fundamental factor that stimulates science teachers' reflection and change is becoming aware of the existence of the students' alternative ideas (da Silva et al., 2007; Hewson et al., 1999).

In a broader study (Bañas, 2006), we carried out an action-research program with four science teachers in a secondary school during 2002/03 and 2003/04. A constructivist theoretical framework was adopted. In the present work we will focus on the case of a teacher named Juan, and show how his teaching models and his students' ideas on energy evolved during this program.

Energy is a core topic of the science curriculum at the level of

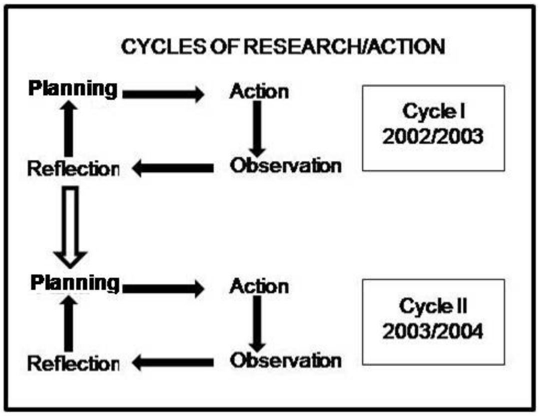


Figure 1. *Methodological cycles of action-research in the work group.*

compulsory secondary education in Spain. Due to its enormous economic, political, social, and environmental importance, there have been many studies of students' alternative ideas about energy (Bañas, Mellado & Ruiz, 2004; Domenech et al., 2003), and of different approaches to its teaching (Duit, 1987; Luera et al., 2005; Mellado, 1998; Prideaux, 1995; Trumper, 1991 & 1997).

Research questions

The research questions posed in the present study were the following:

a) How did Juan's classroom practice evolve during the two study years with his participation in the action-research program?

b) At the compulsory secondary education level, what are the students' alternative ideas about different aspects of energy?

c) And how do those ideas evolve as a result of the teachers' action-research program?

Methods

We carried out an action-research program in a secondary school during 2002/03 and 2003/04. Each school year included two cycles of action-research (Figure 1): planning, action, observation, and reflection (Vázquez et al., 2008).

In the present work we show how Juan's teaching models and the students' ideas on energy evolved during this program. Juan was a chemistry graduate with five years teaching experience. The study was conducted with students of the 4th (age 15-16) years of compulsory secondary education in a secondary school in Badajoz (Spain).

The data collection procedures were: (a) a questionnaire designed to determine the evolution of the students' ideas on energy, which was given to the students at the beginning and at the end of each year (four times in total); (b) an interview to determine the teachers' initial conceptions; and (c) class video recordings to determine the evolution of the teachers' classroom practice.

The questionnaire consisted of 45 items, open or closed multiple choice, grouped into the following fields: concept of energy, heat, temperature, difference between heat and temperature, work, conservation and degradation, and procedures and attitudes.

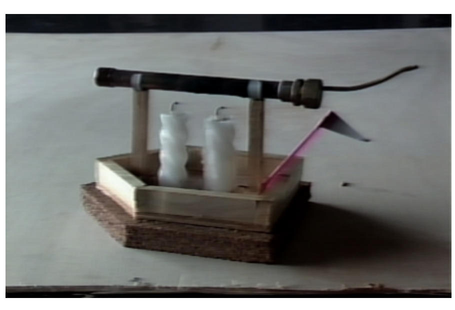
With respect to the analysis of teachers, in our study we considered two basic orientations: technical/transmissive and inquiry/constructivist. To analyze the classroom observations, these orientations were crossed with a system of categories and subcategories: planning, the methodology of teaching, pedagogical content knowledge (PCK), classroom climate, activities, resources, and evaluation. The "pedagogical content knowledge" construct due to Shulman (1986), knowledge that is specific to how each particular subject is taught, and a form of reasoning and educational action by means of which teachers transform the subject matter into representations that are comprehensible to the pupils.

During the study, the participating teachers analyzed their own students' alternative ideas on energy, and the teaching methods they themselves used as were observed in the videos of their classes. They also planned new teaching units.

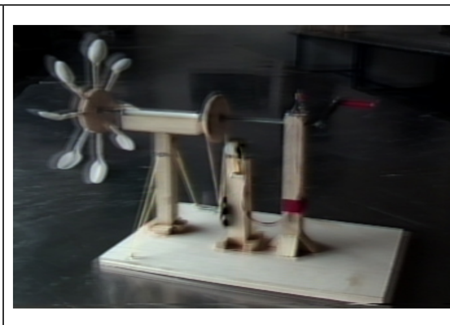
We wish to highlight the extraordinary richness of this group of teachers' work sessions. In these, among other topics, they discussed their pupils' alternative ideas about energy; the alternative ideas about energy to be found in textbooks; their teaching methods, using video recordings of classes as a basis; and planning the teaching units. In this last aspect, particular attention was paid to planning laboratory practical classes and constructing demonstration models for those classes. This led to interdisciplinary collaboration with the school's technology and computer science areas.

These models, some of which are shown in Figure 2, were found to be very useful for classroom activities. They stimulated a good working environment among the students, who worked and participated actively in the classes, doing the activities, asking questions, reflecting on what they observed, discussing, and trying to draw conclusions.

In the teacher's classroom practice, an analysis was made of the actions which reinforced (R) or generated (G) the students' al-



Transformation of chemical energy into thermal energy, and this into mechanical energy.



Transformation of hydraulic energy into electrical energy, and this into light.

Figure 2. *Practical models used in the teaching units.*

ternative ideas, or, on the contrary, fostered conceptual (F) change. At the same time, the teacher's actions which corresponded to either a technical/transmissive or an inquiry/constructivist approach to teaching were also analyzed.

Results

Juan's classroom practice in the first year was centred on the teacher and teaching, and based on educational approaches close to the technical/transmissive model. He spent most of his time on explaining the topic, and attached the greatest importance to this facet of his teaching. He only used classroom and laboratory activities as a complement, by way of occasional demonstration. He used conventional pen and paper problems for the students to apply the knowledge that he had explained. The textbook was the main mediating element of his teaching. A test was given at the end of the topic in the form of written questions which basically evaluated memory.

During the second year, for the most part Juan implemented the inquiry/constructivist oriented teaching unit that he had planned in the process of reflection with the other teachers. This was designed to facilitate the students' conceptual evolution, giving them greater autonomy and involvement in their own learning. Unlike the first year, the classes were now more student and learning centred. There was also a considerable increase in cross-discipline learning, in a Science-Technology-Society orientation, in proposing more open problem situations, in applying the knowledge to new situations, in the students' participation in class, in fostering the students' self-esteem, in small-group work, in the resources employed, and in practical activities. Evaluation took into account the starting situations, and was carried out in a continual form by means of the activity notebooks. The entire process was evaluated together with the other participating teachers.

Another aspect of the classroom practice that was analyzed was the frequency of Juan's actions that generated (G) or reinforced (R) the students' alternative ideas, or, on the contrary, fostered (R) their conceptual evolution. During the first year, there were more actions that generated or reinforced the students' alternative ideas. During the second year, however, there was a significant increase in actions fostering the evolution of these ideas, and a significant reduction of the actions generating or

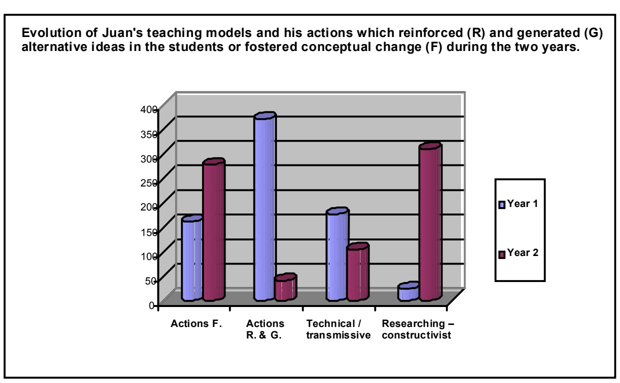


Figure 3. *Evolution of Juan's teaching practice.*

reinforcing them.

Figure 3 summarizes the results of the evolution of Juan's classroom practice. As one observes, during the first year the actions which reinforced or generated alternative ideas in the students were nearly twice as frequent as those which fostered conceptual change. During the second year, on the contrary, the actions fostering conceptual change were far more frequent. There had thus been a major degree of evolution from the technical/transmissive to the inquiry/constructivist approach to teaching.

The fundamental factor that caused change in Juan's teaching was becoming aware of the existence of their own students' alternative ideas on energy. In the group of teachers they analyzed their own students' alternative ideas on energy, the teaching methods they themselves used as were observed in the videos of their classes, and they planned new teaching units with actions that fostered the conceptual evolution of students' alternative ideas.

The analysis of the evolution of the students' ideas was carried out during the 2002/03 and 2003/04 school years, in both cases with students of the 4th course of compulsory secondary education. As these are different groups of students, we shall not present the absolute results for each year, but the evolution of the results of applying the questionnaire before and after teaching the topic of energy in each year.

In Figure 4 we show how the students' ideas on energy evolved during the two years, before and after teaching the subject of Energy. During the first year, there was a noticeable evolution in the difference between heat and temperature, and a slight evolution in the concepts of work and of conservation and degradation. Nevertheless, there was regression in the general concept of energy, the concept of heat (-18%), and in the procedural and attitudinal content. With respect to the concept of heat in particular, there was reinforcement of the students' alternative ideas, the commonest being to associate heat with an energy that bodies possess rather than a process of energy transfer between two bodies at different temperatures.

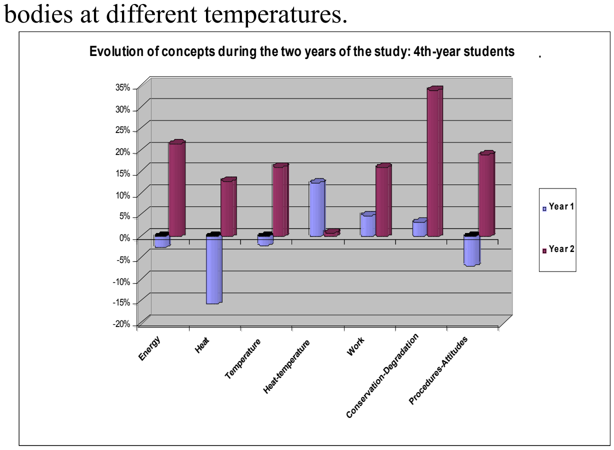


Figure 4: *Evolution of Juan's 4th-year students' ideas in the two years of the study*

In the second year, there was greater evolution in all categories except one, the exception being the difference between heat and temperature. The students better understood the overall aspects of the energy associated with transformations, reducing their reliance on the narrow definition of energy as the capacity to perform mechanical work, which is often the cause of learning difficulties (Mellado, 1998). There was a better understanding of heat and work as processes of energy transfer, as well as of the conservation and degradation of energy. But the learning difficulties were not overcome in contexts that involved the concepts of heat and temperature together. The results for these concepts are indicative of the hard core of the students' most firmly entrenched alternative ideas, and on which there needs to be further work with the teacher.

With respect to the procedures and attitudes, these were barely touched upon during the first year. But there was general improvement during the second year when many practical activities were included, and there was discussion of the implications for the planet of the current patterns of energy consumption and the possible alternatives for sustainable development.

Conclusions and implications

The teachers' reflection on their students' commonest alternative ideas and on their own classroom teaching led them to plan new teaching units which took those alternative ideas into account, and included new strategies, resources, and activities during the second year of the study. In this second year, Juan's classes included more actions promoting his students' conceptual change, and his teaching approach was close to the inquiry/constructivist model.

Comparing the first and second year results, one observes that the concepts of energy in general, work, conservation and degradation of energy, and the procedures and attitudes, improved in Juan's class during the second year. In this second year, the students had a better understanding of the overall aspects of energy associated with transformations, as against the restricted definition of energy as the capacity for doing mechanical work which frequently causes learning difficulties.

In the first year, the students reinforced their alternative idea of associating heat with a form of energy possessed by bodies rather than with a process of energy transfer between two bodies at different temperatures. In the second year, the students results improved notably. They did not manage, however, to overcome their alternative ideas on heat and temperature considered together in the second year. This result for the concept of heat and temperature is an indicator of the hard core of the students' most deeply rooted and hardest to reconstruct alternative ideas.

The action-research program has contributed to Juan's professional development, impacting significantly on the elements that form part of his teaching, and affecting positively the learning and conceptual change of his students. Despite the time and personal effort that his participation demanded, Juan showed great satisfaction and a strong commitment to continue working in this line. However, his professional development was not uniform over all of the categories and subcategories analyzed, and the influence of his participation in the program on the evolution of his students' ideas varied markedly from one concept to another. This points to the need for further work based on the information obtained so far, in order to improve those aspects that evolved least, both in the teacher's professional development and in the students' learning. In this new research, our aim is to develop a system of categories of teachers' pedagogical content knowledge (Gárritz & Trinidad-Velasco, 2004; Loughran et al., 2004; Padilla et a., 2008; Wenning, 2007) relating them with students' learning of different concept of energy.

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