PEDAGOGICAL CONTENT KNOWLEDGE OF INQUIRY: AN INSTRUMENT TO DOCUMENT IT AND ITS APPLICATION TO HIGH SCHOOL SCIENCE TEACHERS

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Abstract:

Authors of this study pursued to document and assess Pedagogical Inquiry/Content Knowledge (PICK), that is, the knowledge necessary to teach a particular topic effectively through inquiry.
It is argued that the lack of consensus on what constitutes an inquiry-based approach makes the generalization about it difficult, because the concept is relatively unspecific and vague. This problem can partially be solved by constructing a set of activities promoted by inquiry, therefore defining the inquiry objectives for classroom and laboratory teaching.
High school teachers' PICK can be documented and assessed by means of a Loughran *et al.* (2004) Inquiry Content Representation (I-CoRe) developed by the authors through a proposal of a set of seven inquiry activities. Five inquiry experienced high school and college teachers answered the questions of the Inquiry Content Representation for each one of the activities and they were also interviewed to construct the Professional and Pedagogical Experience Repertoires, a second tool by Loughran *et al.* to document PICK. It was observed that all teachers interviewed have used inquiry to modify their students' way of thinking, mainly through question posing. Some of them employed research as their main tool to promote scientific inquiry but others mentioned the lack of time to do it. It is interesting to notice that in spite of the fact that inquiry is out of the curriculum, the teachers made use of it to improve their teaching practice.
According with their answers, their activities were classified within the three general approaches expressed by Lederman (2004): implicit, historical and explicit. It is shown that a given teacher cannot be classified exclusively in one of them, because in his/her activities one general approach overlaps the others. The authors conclude that Lederman's classification has to be taken into account as an orientation to characterize a given activity of one teacher, even though the same teacher may use another activity characterized by other general approach. That is, Lederman's classification applies to characterize activities, not persons.

Pedagogical Content Knowledge

Introduction

Shulman (1986, 1987) coined the term Pedagogical Content Knowledge (PCK) as one type of knowledge that teachers should possess, because they do not only have to know and understand the subject matter knowledge (SMK), but also how to teach that specific content effectively. Skilful teachers transform the subject matter into forms that are more accessible to their students, and adapt it to the specific learning context, thereby developing their PCK.

After Shulman introduced PCK, his student Pamela Grossman (1990; P. 5), indicated that "Four general areas of teacher knowledge can be seen as the cornerstones of the emerging work on professional knowledge for teaching: general pedagogical knowledge; subject matter knowledge; pedagogical content knowledge; and knowledge of context".

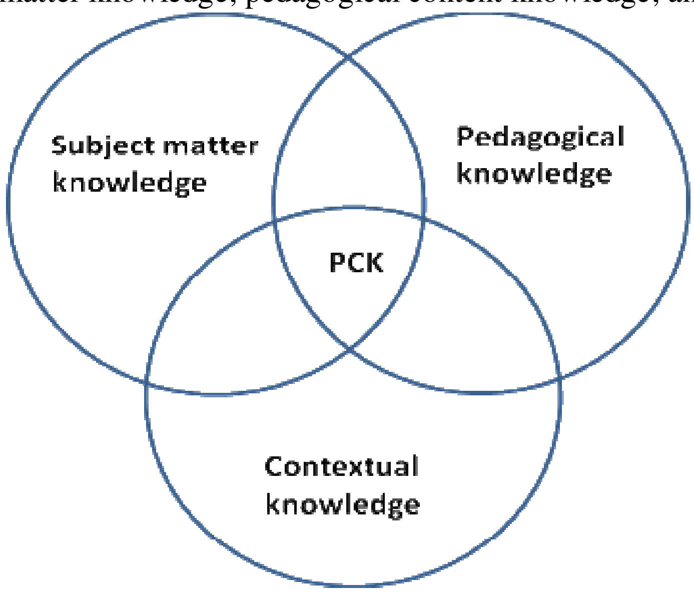

Illustration1. The intersection represents PCK.

Those kinds of knowledge interact exceptionally well with each other, making it difficult to implicitly distinguish each one of them. PCK lies overlapped inside the other three types of knowledge, according to illustration 1 by Gess-Newsome (1999).

Magnusson, Krajcik and Borko (1999) have defined PCK as consisting of five components (and several subcomponents for each one):

(a) Orientations toward science teaching;

(b) Knowledge and beliefs of science curriculum, including national, state, and district standards and specific science curricula;

(c) Knowledge and beliefs of student understanding of specific science topics;

(d) Knowledge and beliefs of assessment in science;

(e) Knowledge and beliefs of science instructional strategies for teaching science.

Recently Park and Oliver (2008) said that the development of one component of PCK may simultaneously encourage the development of others, and ultimately enhance the overall PCK. They included a sixth component element of PCK named "Teacher efficacy" drawn from the concept of self-efficacy that evolved from Bandura's (1986) social cognitive theory, and includes teachers' beliefs in their ability to affect student outcomes, that is, an affective component of PCK.

The ability to solve quantitative problems does not necessarily indicate the strong command of the concepts, reasoning, and representational skills needed for effective teaching in high school. Evidence from research indicates that many preservice and inservice teachers — even physics majors— often have the same difficulties with the material as any other student. To be effective in helping their students in similar situations, teachers must have pedagogical content knowledge —the knowledge necessary to teach a particular topic effectively (McDermott, 2006).

How to document PCK?

There are several ways to document PCK (Baxter and Lederman, 1999; Loughran, Mulhall, & Berry, 2004). The authors have decided to document PICK (Pedagogical Inquiry/Content Knowledge) with the Loughran *et al.* (2004) scheme, due to successful experiences (Garritz *et al.*, 2007; Padilla *et al.*, 2008; Garritz & Velázquez, 2009) with their framework, which is detailed in the Content Representation (CoRe) questionnaire of table 1. Loughran *et al.* promote that eight questions be answered for each one of the central concepts or ideas of the topic. They use the term 'central concepts or ideas' to mean those concepts that are at the core of understanding and teaching the topic; those that belong to the disciplinary knowledge which it is usually used by the teacher to split the teaching topic. The clue is that those ideas sharply reflect the most important issues of the theme.

Table 1. Original Loughran *et al.* (2004) Individual CoRe frame.

1. What you intend the *students* to learn about this idea?
2. Why is it important for students to know this?
3. What else do *you* know about this idea? (That you do not intend students to know yet)
4. What difficulties/limitations are connected with teaching this idea?
5. What do you know about students' thinking which influences your teaching of this idea?
6. What other factors influence your teaching of this idea?
7. What teaching procedures do you use to engage with this idea? (Give particular reasons for these).
8. What specific ways do you use for ascertaining students' understanding or confusion around this idea? (Include likely range of responses).

In our case, instead of letting the interviewed teachers fill the central concepts or ideas of the topic, we constructed and developed a set of students' abilities promoted by inquiry, based on a bibliographic search. This set has been included in the section of this work named "The search of abilities necessary to do scientific inquiry".

A second tool proposed by Loughran, Mulhall, & Berry (2004) to zoom the answers given in the CoRe by interviewed teachers is the Pedagogical and Professional experience Repertoires (PaP-eRs). The PaP-eRs refer to teaching a specific content in a given context and they help to illustrate aspects of PCK in action. PaP-eRs are developed from detailed descriptions offered by individual teachers, and/or as a result of discussions about situations/ideas/issues pertaining to the CoRe, as well as classroom observations.

Inquiry: an elusive concept.

Historical development of inquiry

Before 1900, most educators viewed science primarily as a body of knowledge that students were to learn through direct instruction. One criticism of this perspective came in 1909, when John Dewey contended that science teaching gave too much emphasis to the accumulation of information and not enough to science as a way of thinking and an attitude of mind (NRC, 2000; Arons, 1997, chapters 12 and 13).

As it is well known, teachers usually start teaching in the same way they received their classes, so in the case of teachers training, listening passively to lectures does not develop the competence or confidence necessary for teaching science as inquiry —in contrast to science as information.

The educator Joseph Schwab (1960, 1966) was an influential voice in establishing the view of science education through inquiry. At his time, the implications of Schwab's ideas were profound. He suggested that teachers should present science as inquiry and that students should use inquiry to learn science subject matter. To achieve these changes, Schwab (1960) recommended that science teachers look first to the laboratory and use experiments to lead rather than to follow the classroom phase of science teaching. That is, students should work in the laboratory before being introduced to the formal explanation of scientific concepts and principles. Evidence should build to explanations and the refinement of them. McDermott (2006) says in relation with the training of physics teachers "Not enough attention is devoted to the development of scientific reasoning. If there is a laboratory component, it often consists of hands-on activities that lack coherence."

Gordon E. Uno (1990) defined inquiry as "a pedagogical method that combines hands-on activities with student-centered discussion and discovery of concepts".

The National Science Education Standards (NRC, 1996, it will be referred as NSES in what follows) put inquiry in the formal educational arena, as a requisite for good teaching:

> Scientific inquiry refers to the diverse ways in which scientists study the natural world and propose explanations based on the evidence derived from their work. Inquiry also refers to the activities of students in which they develop knowledge and understanding of scientific ideas, as well as an understanding of how scientists study the natural world.
>
> Inquiry is a multifaceted activity that involves making observations; posing questions; examining books and other sources of information to see what is already known; planning investigations; reviewing what is already known in light of experimental evidence; using tools to gather, analyze, and interpret data; proposing answers, explanations, and predictions; and communicating the results. Inquiry requires identification of assumptions, use of critical and logical thinking, and consideration of alternative explanations (NRC, 1996, p. 23 of NSES).

It has been until recently that European Union has recognized the virtues of inquiry based science education (Rocard *et al.*, 2007).

Multiple definitions of inquiry

After mentioning that "many educators misunderstand what is meant by inquiry", Martin-Hansen (2002) insists that inquiry either refers to the work scientist do to study the natural world or to the activities of students that mirror what scientists do. She defines several types of inquiry:

Open or full inquiry: Can be defined as a student-centered approach that begins with a student's question, followed by the student (or groups of students) designing and conducting an investigation or experiment and communicating results. This approach most closely mirrors scientists' actual work.

Guided inquiry: The teacher helps students develop inquiry investigations in the classroom. Usually, the teacher chooses the question for investigation.

Coupled inquiry: Combines a guided-inquiry investigation with an open-inquiry investigation.

Structured inquiry: Sometimes is referred to as direct inquiry. It is a guided inquiry mainly directed by the teacher.

The research literature on inquiry tends to lack precise definitions, as illustrated in a large-scale meta-analysis of the science education literature done nearly 27 years ago (Anderson, 1983). The dilemma this situation poses for the person attempting to synthesize what the research has to say about inquiry teaching is that making generalizations about it becomes difficult because of varied conceptions existing of inquiry teaching. This broad category includes such a wide variety of approaches that the label is relatively nonspecific and vague. Since the NSES contains no precise operational definition of inquiry teaching— though it does contain some specific teaching examples— many and varied images of inquiry teaching can be expected among its readers. The same situation persists today, when inquiry teaching is defined differently by different researchers, or the researcher may choose to use a different term for an approach that others apparently would identify with the inquiry label (Anderson, 2002).

Buck, Bretz & Towns (2008) discuss the different definitions of inquiry and the several modifiers added to the word 'inquiry' (guided, open, full, etc.) and they arrived to the conclusion that "the uses and meanings of inquiry as modes of instruction and student investigation vary among authors and intended audiences". Brown *et al.* (2006, p. 786) describe tactfully the dilemma, and write "What makes this research difficult to understand is the lack of agreement about what constitutes an inquiry-based approach. The bulk of the research has taken place in precollege classrooms examining the outcomes of various blends of inquiry-based instruction. These studies are hard to compare given the differing meanings for inquiry that have been employed".

In order to overcome the imbroglio and the lack of definition of inquiry, this study wants to make a synthesis of the set of abilities promoted by inquiry found in the literature and to construct an instrument to investigate inquiry experienced teachers to find out how they use their PICK in the classroom and lab.

The search for abilities necessary to do scientific inquiry.

We start to search for the abilities necessary to do scientific inquiry from the NSES (NRC, 1996). There we found the following for the 5-8 grades:

1. Identify questions that can be answered through scientific investigations
2. Design and conduct a scientific investigation
3. Use appropriate tools and techniques to gather, analyze, and interpret data
4. Develop descriptions, explanations, predictions , and models using evidence

5. Think critically and logically to make the relationships between evidence and explanations

And the following for the Content standard 9-12, which is the level of education, we chose for our study:

1. Identify questions and concepts that guide scientific investigations
2. Design and conduct scientific investigations
3. Use technology and mathematics to improve investigations and communications
4. Formulate and revise scientific explanations and models using logic and evidence
5. Recognize and analyze alternative explanations and models
6. Communicate and defend a scientific argument

The two first abilities of both educational levels related with posing questions and designing and conducting scientific investigations, which make emphasis on research, whether are present or absent in the rest of the consulted approaches to inquiry.

For example, in *Inquiry and the National Science Education Standards* there are reported the following five “Essential Features of Classroom Inquiry” (NRC, 2000), none of them directly related with doing scientific research:

1. Learners are engaged by scientifically oriented questions.
2. Learners give priority to evidence, which allows them to develop and evaluate explanations that address scientifically oriented questions.
3. Learners formulate explanations from evidence to address scientifically oriented questions.
4. Learners evaluate their explanations in light of alternative explanations, particularly those reflecting scientific understanding.
5. Learners communicate and justify their proposed explanations.

With respect to the abilities for inquiring, French & Russell (2002, p. 1036-7) include several of them in this paragraph:

> Although there are variations of inquiry-based instruction (e.g., open-ended, guided, challenge), they share all or most of the following characteristics: inquiry-based instruction places more emphasis on the students as scientists. It places the responsibility on the student to pose hypotheses, design experiments, make predictions, choose the independent and dependent variables, decide how to analyze the result, identify underlying assumptions, and so on. Students are expected to communicate their results and support their conclusions with the data they collected. In inquiry-based labs, the concepts behind the experiments are deduced during the lab; the results are unknown beforehand, although predictable, because the students designed the experiments. Results that do not support the students’ hypotheses are not viewed as a failure but as an opportunity for the students to rethink any misconceptions in their understanding of concepts.

Table 2 includes summary statements of the abilities and understandings for “Science as Inquiry”, mentioned by Bybee (2004):

Abilities Necessary to Do Scientific Inquiry	**Understandings about Scientific Inquiry**
Identify questions that can be answered through scientific investigation.	Different kinds of questions suggest different kinds of scientific investigations.
Design and conduct a scientific investigation.	Current scientific knowledge and understanding guide scientific investigations.

Use appropriate tools and techniques to gather, analyze, and interpret data.	Mathematics is important in all aspects of scientific inquiry.
Develop descriptions, explanations, predictions, and models using evidence.	Technology used to gather data enhances accuracy and allows scientists to analyze and quantify investigation results.
Think critically and logically to make the relationships between evidence and explanation.	Scientific explanations emphasize evidence, have logically consistent arguments, and use scientific principles, models, and theories.
Recognize and analyze alternative explanations and predictions.	Science advances through legitimate skepticism.
Communicate scientific procedure and explanations.	Scientific investigations sometimes result in new ideas and phenomena for study, generate new methods or procedures for investigation, or develop new techniques to improve the collection of data.
Use mathematics in all aspects of scientific inquiry.	

Table 2. Science as Inquiry, Grades 5-8 (Bybee, 2004)

In Martin-Hansen (2002) the authors of this study found a table with the following set of five “Essential features of classroom inquiry”:

1. Learner engages in scientifically oriented questions
2. Learner gives priority to evidence in responding to questions
3. Learner formulates explanations from evidence
4. Learner connects explanations to scientific knowledge
5. Learner communicates and justifies explanations

Khan (2008) also mentions several processes associated with inquiry in science, and includes the following:

1. Identifying a problem and gathering information
2. Making predictions
3. Making sense of observations and finding patterns in information
4. Using analogies and physical intuition to conceptualize phenomena
5. Analyzing and representing data
6. Postulating potential causal factors
7. Working with evidence to develop and revise explanations
8. Generating hypothetical relationships between variables
9. Evaluating the empirical consistency of information
10. Formulating and manipulating mental or physical models (modeling)
11. Coordinating theoretical models with information, and
12. Sharing what has been learned from the inquiry with others.

Based in all the bibliography mentioned in this section, (Schwab, 1978; NRC 1996; 2000; Bybee, 2004; Lederman, 2004; Khan, 2007), the authors have selected seven pedagogical activities related with the inquiry process, present in Table 3.

Table 3. Pedagogical activities associated with the inquiry process:

A. Identify and consider questions that can be answered through inquiry;

B. Define and analyze properly the question to be solved and identify its relevant aspects;
C. Gather bibliographic information to be used as evidence;
D. From evidence, to develop explanations to the posed question;
E. Think about everyday problems and display relevant historical aspects;
F. Design and conduct a scientific investigation through a set of actions including those in Table 4;
G. Communicate by means of argumentation what has been learned through inquiry.

The authors have separated a set of activities considered the best related with the development of scientific research (activity 6 in Table 3) and they have written down them in Table 4 as an example of what is meant by "Design and conduct a scientific investigation".

Table 4. Scientific investigation involves:

Making sense on observations and search for patterns in the collected information;
Generating hypothetical relationships and evidence between variables;
Postulating potential causal factors;
Evaluating the empirical consistency of information;
Using analogies and physical intuition to conceptualize phenomena;
Formulating and manipulating mental or physical models (modeling);
Using appropriate tools and techniques to gather, analyze, and interpret data;
Thinking critically and logically to develop predictions, explanations and models by using the evidence;
Coordinating theoretical models with information;
Assessing the reached explanations with some scientific model;
Communicating and discussing scientific inquiry results in the classroom.

Methodology: I-CoRe and PaP-eRs

The instrument developed

The original questions of Loughran *et al.* (2004) CoRe of Table 1 were substituted in this study by those mentioned in Table 5. Questions 1 and 2 in Table 1 are partially reflected in question 1 in table 5; question 4 in Table 1 is represented by question 2 in Table 5; question 5 in Table 1 is represented by question 3 in Table 5; question 7 in Table 1 is represented by question 4 in Table 5; and question 8 in Table 1 is represented by question 5 in Table 5. There are not equivalents to questions 3 and 6 in table 1.

Table 5. Questions for each one of the pedagogical activities of inquiry mentioned in Table 3:

1. Why do you consider important for students to develop this activity?
2. What are the difficulties or limitations of teaching this activity?
3. What are the difficulties or limitations of students related with learning this activity?
4. What teaching examples and procedures do you use for engaging students with this activity?
5. What are the specific ways for ascertaining students' understanding or confusion around this activity?

A matrix was constructed where these five questions were placed in the first column and the seven activities in the first row, giving the arrangement presented in next page as illustration 2. The teachers selected which ones of the activities he/she develops with his/her pupils and answered exclusively those columns.
As has been mentioned, it is real that a novice teacher cannot fill properly (with phrases that make sense) the 35 cells of the I-CoRe, so this instrument can be used to identify the expertise of a given teacher in dominating the interviewed topic's PCK.

Questions/inquiry pedagogical activities	A. Identify and consider questions that can be answered through inquiry	B. Define and analyze properly the question to be solved and identify its relevant aspects	C. Gather bibliographic information to be used as evidence	D. Develop explanations to the set out question, from evidence	E. Think about everyday problems and display relevant historical aspects	F. Design and conduct a scientific investigation	G. Communicate by means of argumentation what has been learned through inquiry
1. Why do you consider important for students to develop this activity?							
2. What are the difficulties or limitations of teaching this activity?							
3. What are the difficulties or limitations of students related with learning this activity							
4. What teaching examples and procedures do you use for engaging students with this activity?							
5. What are the specific ways for ascertaining students' understanding or confusion around this activity?							

Illustration 2. The matrix form of I-CoRe with 35 cells that have to be filled by inquiry experienced teachers.

PaP-eRs by interviewing

As it will be analyzed in the results section of this study, sometimes the answers given in some of the cells of the I-CoRe were not explicit enough, so that it was necessary to develop interviews to zoom in some aspects. In that way, the PaP-eR obtained was the speech verbatim. The interview was conducted with specific questions pointing to the place where an extension was desired. Follows an example of questions used in the interviews:

> What type of question you pose to your students to start a process of inquiry? Can you give us an explicit example? To what part of the curriculum belongs?
> What is the condition to accept a question of inquiry proposed by students? Could you give us an example?
> Can you show an example of some topic of everyday life that you use to engage inquiry in your students?
> What about some historical event necessary to think about the inquiry question? Could you give an example?
> In the column headed by 'Define and analyze properly the question to be solved and identify its relevant aspects' you criticize how students use to participate with an encyclopedic and rote learning instead of one about problem solving. How could you guaranty the elimination of that encyclopedic and rote learning? Do you have a successful example where you can manage to avoid it? Could you give us some details?

Description of the experienced inquiry teachers

In the following description we will use fictitious names of the interviewed teachers in order to protect their privacy.

Archibald works teaching Chemistry in a public high school institution from the National Autonomous University of Mexico that has the lemma 'Order and progress', phrase of Auguste Comte, father of French positivist thought, because it was founded in 1867 by Gabino Barreda, a distinguished Mexican positivist. He has the seniority in teaching because he has been doing it for the last forty five years.

Elizabeth also works in an autonomous public university in Mexico City for the last seven years, and she has another five years of previous teaching experience. The students at this university are special because they are often rejected from other universities, so their academic level is precarious. She studied undergraduate physics. She prides herself on using guided inquiry in her classes, as it has been defined by the Physics Education Group of Washington University at Seattle, USA.

Margaret also works in a public high school from the National Autonomous University of Mexico. She also teaches Chemistry and she has done it for eighteen years. She studied a Master in Organic Chemistry and she also has three diplomas. For more than five years she was an administrative coordinator in her school.

Olivia works in the same institution as Archibald and Margaret. She said she was not an expert in inquiry teaching, because she did not know it was denominated like this. Nevertheless she considers that such strategies are very important because they promote organized and articulated thinking processes. She uses question posing as her main way of teaching.

Rufus works in a recently created public high school institution in Mexico City, which declares as its objective the use of academic methods that promote the development of higher intellectual abilities to convert high school in a space of authentically human interactions to enhance moral, intellectual and social values. He studied undergraduate Chemical Engineering and studied a Master degree also in the same discipline. He is now finishing his Open University pedagogy studies, and has recently been proposed and accepted as administrative coordinator in his school. He has completed 16 years of teaching experience.

Each one of the teachers answered different columns of the I-CoRe, as it has been gathered in Table 6. Archibald and Olivia answered all the activities, and the other three made a selection.

Teachers/inquiry activities reported	A. Identify and consider questions that can be answered through inquiry	B. Define and analyze properly the question to be solved and identify its relevant aspects	C. Gather bibliographic information to be used as evidence	D. Develop explanations to the set out question, from evidence	E. Think about everyday problems and display relevant historical aspects	F. Design and conduct a scientific investigation	G. Communicate by means of argumentation what has been learned through inquiry
Archibald	X	X	X	X	X	X	X
Elizabeth	X					X	X
Margaret		X	X		X	X	
Olivia	X	X	X	X	X	X	X
Rufus		X	X		X		X

Results

By asking teachers to respond the I-CoRe, the authors of this study realized that at the beginning the teachers were showing some concern about it, because they were a little confused about what was meant by inquiry. However, when they read the questionnaire in which scientific inquiry definition was included according to the NSES, they were entirely willing to collaborate and share their experiences. After answering the I-CoRe each of the teachers agreed that inquiry is very important in the course they teach; despite some of them recognized that they had made use of inquiry without knowing it was called that way. An interesting set of answers was received, all of them highlighting scientific inquiry as a formative process where students play the central role. Teachers' declarations show that via their inquiry they expect students to improve their rational cognitive structure and to know how scientific knowledge is constructed. Besides, it was observed that all teachers interviewed have used inquiry to modify students' way of thinking.
Some of the teachers employed research as their main tool to promote scientific inquiry and some others mentioned the lack of time to do it. All of them used posing questions as an important aid to develop their classes centred on inquiry.

According to the responses and comments made by the five teachers through the I-Core and the additional interview, it can be appreciated the great interest they have to improve the traditional teaching of subjects like physics and chemistry. They are convinced that inquiry goes beyond a purely informative activity towards a dynamic way of teaching. And that to give a plausible answer to the questions posed it is necessary to propose a design that allows logically structured responses to the hypothesis. They also agree that it is essential to find information in the literature, which may serve students to make a comparison and set a relationship with their conclusions.

Importance of inquiry

We included an additional question to the I-CoRe frame: What is the importance of inquiry in the course you are teaching?

The following sentences show what teachers understand by inquiry and, as we can observe, they manifest different conceptions of what should be done when inquiry is used as a teaching plan of action:

> Inquiry practiced in classroom, in the lab and in everyday life is very formative and stimulating because it helps students to develop the habit of observing, of reasoning and of relating different concepts in this and other courses with his/her personal experience (Archibald).

Without saying it explicitly, Archibald considered some of those abilities that characterize scientific activity and that are quite important for students to develop logical and rational way of thinking. We could say that this teacher uses open inquiry activities.

> From the Piagetian perspective, many students entering the university are situated between the concrete and the formal operational stages. We think that abilities underlying scientific thinking require a cognitive development corresponding to the formal stage so it is necessary that students achieve the transition. This may occur through the student's active mental involvement, which can be reached by guided inquiry in experimental work (Elizabeth).

To Elizabeth the transition from concrete to operational stages is quite important to develop students' way of thinking through a guided set of experimental strategies.

> I think that teaching through inquiry mainly follows two goals: first, it lets us to establish some relationships among theory, practice and human daily life activities, and second, it lets us to practice some strategies with which it is possible to make science and research (Margaret).

> Inquiry pedagogical activities I carry out in my lectures are important because they lead to organized and articulated thinking, basic for the understanding of chemistry. This kind of thinking is also useful to face other type of problems in everyday life. To pose questions and to ask for consulting books and other sources of information is part of my Chemistry teaching style. Other activities as analyzing and interpreting data and communicating the results are fulfilled in lab activities discussion or in presentations on some research. Nevertheless, is rare to do formal research in my course (Olivia).

> Inquiry is of fundamental importance because we try to develop a constructivist approach in chemistry learning using it, that is, we try the student to get involved in

> teaching-learning activities as the central work strategy. This allows the student to recognize how scientific knowledge is constructed and inquiry is strongly related with that. I have to clarify that inquiry is not the unique working strategy employed, but it is one of the most often used by me (Rufus).

For the last two teachers, inquiry allowed them to make relationships between the desired scientific way of thinking and those events which are closer to students, and inquiry helps them to develop the thought and abilities more related to the scientific activity.

The following subtitles correspond to one of the seven main inquiry activities and contain the commented answers of the five inquiry experienced teachers.

Posing questions

Some examples of questions employed by the five teachers to start an inquiry activity are:

> What do I need to know in order to predict whether a certain object sinks or floats in a given liquid? This construction is guided by the teacher based on two strategies 1) reveal previous ideas, confront and resolve and 2) Socratic dialogue (Elizabeth).
>
> Can we cheat on the breathalyzer? (Olivia).
>
> When you have heartburn what medicine do you take? Which is the best one? (Olivia).
>
> What's the content in the carton juices you consume regularly? How do you know its composition? (Rufus).

As we can observe, to answer all these questions it is necessary to develop a small research which can be done by gathering bibliographic data or by means of lab experiments, besides the questions are asked in a very simple way. Nevertheless, a question can take more than 100 hours of classroom and lab activities to get a final answer, as for example the one asked by Elizabeth.

In the case of Rufus' question, among other activities students have to make a bibliographical research to find out what kind of mixtures are there, which are their separation methods, and so for, in order to arrive to the discussion of how to separate the main components of a commercial juice. The groups arrive to acceptable results when they face the experimental separation.

Developing explanations from evidence

Only two of the five teachers answered positively that they employed this activity, and both insist in the importance of doing it:

> This is the main purpose of inquiry and I think that is the way of acquiring knowledge rather than memorizing definitions of concepts. (Archibald).
>
> To formulate explanations from the evidence is a fundamental element of problem solving. The exercise requires analyzing information, building relationships, immersing into the wealth of knowledge, incorporate information gathered in the literature search, organize all the data and generate a plausible explanation. (Olivia).

As Bybee (2004) says, explanations are central to knowing about the natural world, and are ways to learn about what is unfamiliar by relating it to what is already familiar. This means to relate scientific knowledge with everyday events. In this sense, all teachers who said to make use of this activity consider that it is important because it helps students to learn without memorizing and it helps them to develop scientific reasoning.

Everyday life and historical aspects

In relation to the activity related with everyday and historical aspects, two of the teachers emphasize the difficulties, but stress its importance:

> The greatest difficulty one faces is precisely the search, or design, or selection of problems arising from a credible situation of daily life, consistent with the reality of the student, which it is both easily understood for him or her but at the same time it has some degree of difficulty, making attractive the solution (Margaret).

> The problem to be addressed should be as close as possible to the student's daily life, in order to facilitate meaningful learning. In addition, the student must realize that building science is a historical process (Rufus).

These two teachers consider quite important to relate the subject with the context and for the latter the closer to students' daily life the better. In this case, the context used by both is quite different because Margaret looks for problems related to students' daily life focused on making science easier to students, and without taking into account history of science or Nature of Science (NOS). On the other hand, Rufus tries to find problems related to students everyday life, but pointed out on NOS as well as history of science.

> I know that historical aspects show the evolution of knowledge, but I decided to touch briefly on grounds of short available class time (Olivia).

It can be seen that to Olivia, history and NOS are quite important but she prefers not to spend too much time in such subjects because of the lack of time.

Doing Research

As can be seen in Table 6, four of the five teachers considered important the activity of "Design and conduct a scientific investigation", so the authors of this research celebrated having included it in the seven central pedagogical activities of inquiry. Following there are some of the highlights of three of the teachers:

> I try to find problem situations that have connection with everyday life. For instance, this year sixth grade students and I developed a project for producing bioethanol from acid hydrolysis of cellulose paper, obtaining the monomer of glucose, which was fermented with yeast to finally obtain the biofuel. In class, given that research cannot be developed so vastly, it raises little research, preferably theoretical, which may be developed in a few classes, but that allows students to connect scientific content to everyday life (Margaret).

> The series of actions referred are essential to develop a style of thinking that leads to safe routes to acquire reliable knowledge. For example, a student team chose to investigate the effect of ultraviolet radiation on plants. The hypothesis was that UV light would cause damage and plant growth would be lowered. They designed the experiment starting from bean seeds that germinated and were transplanted into

> small pots. They split the plants into three groups: one was left at ambient conditions; another was subjected to UV light from a lamp an hour a day and the last received two hours daily of UV light. Unfortunately, results were not conclusive (Olivia).
>
> For example, to answer the question: what do I need to know in order to predict whether a certain object sinks or floats in a given liquid? involves differentiating between observations and inferences; learning how to operationally define the variables and its properties, and then learning to do experiments where some variables are controlled and investigating whether each of those variables influences or determines the behavior of sinking or floating of the object (Elizabeth).

It can be seen in those phrases the restricted type of research that high school pupils are subjected to. At undergraduate level, at least in the chemistry field, it has often been mentioned the necessity to expose students to early open research (Cruz-Garritz, Chamizo & Torrens, 1989) as an inquiry strategy to develop undergraduate students' understanding (Craig, 1999; Slezak, 1999; Lindsay & McIntosh, 2000; Hutchison & Atwood, 2002).

Approaches for inquiry

In the case of inquiry, Lederman (2004) recommends to integrate it with Nature of Science (NOS). As both are important contexts, we have the scheme detailed by Schwartz & Lederman (2002), in which inquiry and NOS occupy the Contextual Knowledge space in illustration 1. The relations among these three elements provide insight into the development of PICK.

Over the years, three general approaches have been clearly evident in the science education literature when it comes to the enhancement of students' and teachers' understandings of NOS and/or scientific inquiry.

The first approach, the *implicit* one, suggests that by "doing science" students will also come to understand NOS and scientific inquiry. That is why the curriculum of the 60s and 70s emphasized hands-on inquiry-based activities and/or process-skills instruction.

The second approach, the *historical* one, suggests that incorporating the history of science (HOS) in science teaching can serve to enhance students' views of NOS. Some authors include this approach inside the third one (Acevedo, 2009).

Lederman (2004, P. 312) suggests a third approach that he calls the *explicit* one. Explicit instruction should not be equated with didactic instruction. Rather, the term *explicit* is used to emphasize that teaching about inquiry or NOS should be treated in a manner similar to teaching about any other cognitive learning outcome: "should be planned for instead of being anticipated as a side effect or secondary product".

Usually, in curriculum reforms NOS and inquiry are not taken into account as contents to be learned, and are considered only as strategies. If students are expected to develop more adequate conceptions of scientific inquiry then, as any cognitive objective, this outcome should be planned for, explicitly taught, and systematically assessed. NOS and scientific inquiry are instructional objectives of primary importance that permeate all the aspects of curriculum and instruction. The pedagogical content knowledge must include understanding the organizing theory of science along with its modes of inquiry (Eick, 2000).

Classification within the three approaches of Lederman

The answers given by the five teachers have been classified as *implicit, historical* and *explicit*. It is suggested that teachers who could be classified as *implicit* mainly use A and F activities in table 2. The *historical* teacher, incorporates history of science (HOS) to enhance students' views of NOS and inquiry, mainly with E activity in table 2. As a cognitive consequence it is proposed that *explicit* teachers be related with almost all of the activities in table 2.

Two of them, Margaret and Elizabeth seem to be implicit teachers, because they mostly use the activities F, and G in Table 2. Nevertheless, mainly by their objectives, it is clear in both cases that they can be also classified as explicit, because of the planned way in which they develop the inquiry activities, so inquiry can be taken into account as content to be learned.

On the other hand, Archibald and Olivia seem to be explicit teachers because they answered all (A to G) activities in table 2. Olivia gave more examples of her inquiry approach in the PaP-eR interview afterwards. One of them stresses the explicit character of her inquiry, by an activity that was thought as an extended guided one:

> They put forward two large test tubes (4 L) almost filled with water. In one of them is introduced a closed can of regular Coke and in the other a closed can of Diet Coke. The regular goes to the bottom and the Diet floats. Students were asked to give an explanation of what they observed. Among the many explanations finally appears that related to the density. They are asked to calculate the density of the liquids; for this purpose they have to design a procedure, request the material they will require and proceed. The numerical value obtained should be analyzed to see whether it is consistent with what is observed. Some make mistakes, and they are asked to identify them. Finally, each can choose to read the ingredients list and find the differences (Olivia).

She also mentions in her I-CoRe something that can be classified as explicit because she participates in a program called 'Youth towards Research' and this is emphasized in the interview with her:

> To raise questions and ask students to review other books and information sources is part of a kind of lecture style in a chemistry course. Others, like analyze and interpret data, and communicate results are made in discussions related to laboratory activities or presentations related to some simple research. However, activities such as research planning and review what is known today, only apply when students are participating in specific research project, which is not taken by the whole group, just by those students who have particular interests because they belong to the program 'Youth Towards Research' or they have shown their wish to participate in Scientific competitions like Science Fair (Olivia).

Only one of the teachers, Margaret, seems to be an historic one, because of the emphasis given in activity E in table 2, where she includes the following consideration:

> In the historical level I place what happened as a reference and I establish a relationship with everyday life. The purpose is to contextualize scientific facts and knowledge to construct the history not as isolated events but as part of the

phenomena resulting in the conditions of human scientific development. In this way the student realizes, for example, that the impressionist trends in picture modified all the art (music, literature, etc.) of the end of XIX Century or that the work of Perrin was connected with Einstein's explanation of Brownian motion in the realm of the particulate nature of matter.

So, she considers important the historical moment in which scientific findings were developed; and she uses to mention that the construction of science knowledge should not appear as an isolated event, completely absent from the present reality, but as part of its historical moment.

As can be read from this analysis there are reasons to consider Margaret as an implicit teacher, but also to classify her as an historic one or as an explicit teacher. The authors conclude that Lederman's classification has only to be taken into account as an orientation to characterize a given activity of one teacher in one of the three general approaches to inquiry, even though the same teacher may use another activity characterized by other general approach. That is, Lederman's classification applies to characterize activities not persons.

PaP-eRs

The PaP-eRs this study has developed were performed through interviews with the inquiry experienced teachers. An example of a small section of a verbatim captured in the interview to Elizabeth is presented in Appendix 1. Here is presented only a summary of its highlights: Elizabeth is involved with a group of teachers in the course "Introduction to Physics" for Health Promotion career, in which they give a lot of importance to the active involvement of students in the process of constructing knowledge, which leads them to a proposal of experimental work. They use a "guided-inquiry" approach based on the work of McDermott & Physics Education Group (1996) from Washington State University. Their objective is that students can develop some knowledge and reasoning skills to get functional understanding of physics and other disciplines. Arons (1997) called "critical thinking" to those scientific skills and knowledge. The curriculum in Washington State explicitly addresses specific difficulties that research has shown may preclude a functional understanding. Even when teachers do not have these difficulties themselves, it is likely that their students will. *Physics by Inquiry* helps teachers develop the type of knowledge necessary to be able to teach a given topic effectively —pedagogical content knowledge (McDermott, Heron, Shaffer & Stetzer, 2006). McDermott's group has assessed the effectiveness of teachers' PCK-training with students by means of pre and post tests. Elizabeth bases her work in attaining the following three critical thinking abilities in students mind: to differentiate between observations and inferences; to operationally define the involved variables; and to establish experiments of variables control to be able to predict the behavior of a given system.

Assessment of inquiry activities

In relation to assessment of inquiry activities, the five teachers coincide in using several tools as: written reports; concept and mental maps, oral and written questions, analysis of everyday problems, construction of logical assertions on the problem, review of bibliographical information, among others. Some verbatim phrases of four of them are transcribed:

> To identify and pose problems I stop constantly during the class or the lab activities to ask students (orally and written) for their conclusions up to that moment, insisting them to write the evidence they have gathered in their notebook and the reasoning employed. I explore if students: 1) distinguish among the different operational definitions (of mass, volume, density), 2) recognize the design of correct and simple experiments where variables are controlled to determine its influence in the results, 3) write in their notebook a report where inquiry process on the question of floating and sinking of an object in a liquid can be followed (Elizabeth).

> I assume that the activity has been developed properly. If students are able to construct logical assessments helping to describe the problem and go with the research further. Also, if they are able to establish, document and report the relationship between the everyday problem and the scientific concepts that explain or are related to it (Margaret).

> I can assess what has been done by revising some of the bibliographic sources the students quoted, asking them on the reliability of the source, verifying that collected data are related with the problem stated and the way in which they were joined to constitute evidences" (Olivia).

> I assess the work by asking students to develop a multimedia presentation in front of the group, and also a written report of the results (Rufus).

Conclusions

Given the relative confusion existent in relation to the term 'inquiry', the authors of this study made a bibliographic search trying to find a proper definition of it, by means of the activities that inquiry must promote in students. A set of seven activities constituted the final goal and were considered as the central concepts proposed by Loughran *et al.* in their Content Representation. An Inquiry-CoRe was constructed as a framework for capturing and documenting the pedagogical inquiry/content knowledge of teachers that follow an inquiry way of teaching.

An interesting set of answers was received by applying the I-CoRe to five high school and college teachers, all of them highlighting scientific inquiry as a formative process where students play a central role. The I-CoRe was complemented with interviews from which Pedagogical and Professional experience Repertoires —the second tool proposed by Loughran *et al.*— were constructed. These Pap-eRs were useful to zoom on several points where the I-CoRe was insufficient or suggestive of a deeper insight.

It could be observed that all teachers interviewed have used inquiry to modify their students' habits of mind, mainly through posing questions. Some of them employed research as their main tool to promote scientific inquiry but others mentioned the lack of time to do it.

It is interesting to notice that in spite of the fact that inquiry is out of the curriculum, some teachers —like those participating in this study— made use of it to improve their teaching practice. All of them recognize that inquiry is fundamental to make students start thinking

more like scientists, that is, to acquire 'critical thinking' abilities. The problem they have is the lack of time to cover the whole curriculum, which is why they use inquiry to teach only part of the content, or to develop exclusively a limited number of laboratory experiences. At the same time, because of the same reason, history is not easily included into inquiry experiences, and as a consequence NOS becomes difficult to be tough. But what all of them try to exploit is the context to make science closer to students.
The instrument developed has been useful to evaluate PICK activities of teachers. For example, Margaret has been mainly explicit in her I-CoRe mentioning the way in which she assess her PICK before, during and after the course she lectures:

> I consider inquiry has a central importance in my teaching. It takes most of my time: Before the course I use it to think and plan new possible learning experiences. During the course, I use it to test a given experience deciding to include it or to omit it. After the course, I reflect on the possible success or failure of the inquiry system, analyze its pros and cons, and adjust those improvable activities and cancel those unsatisfactory for the students as well as for the teacher (Margaret).

Something very important is how teachers lead students to ask questions. To develop inquiry in classroom, asking questions becomes a fundamental item, but asking questions depends on how open or close the strategy is. In this case, none of the teachers mentioned the importance of this subject.
According with their answers, each one of them could be classified within the three approaches expressed by Lederman (2004): implicit, historical and explicit. However, all made use one or several different Lederman's approaches, making some emphasis in one of them at each moment, and these particularities make the difference among those teachers. In particular, implicit, explicit, and history-based approaches are shown in one (Margaret) of the teachers' different expressions and activities.
The conclusion is that Lederman's classification of three general approaches has not to be taken to the letter, but only as an orientation to systematize certain pedagogical activities of a given teacher in a specific moment. It is shown that a given teacher cannot be classified simply in one of them, because his/her activities in one general approach lap over to the other two.
As usual, the final conclusion of a study like this is the recommendation to use the documented PICK in the teachers' training process, by commenting and arguing the sentences and conclusions of experienced teachers with the in-service or pre-service ones.

References

Acevedo-Díaz , J. A. (2009). Enfoques explícitos *versus* implícitos en la enseñanza de la naturaleza de la ciencia [Explicit *versus* implicit approaches in teaching Nature of Science], *Revista Eureka sobre Enseñanza y Divulgación de las Ciencias*, **6**(3), 355-386. Can be dowloaded from URL http://www.apac-eureka.org/revista/Larevista.htm.

Anderson, R. D. (1983). A consolidation and appraisal of science meta-analyses. *Journal of Research in Science Teaching*, **20**(5), 497-509.

Anderson, R. D. (2002). Reforming Science Teaching: What Research says about Inquiry, *Journal of Science Teacher Education*, **13**(1), 1-12.

Arons, A. B. (1997). *Teaching Introductory Physics*, U.S.A.: Wiley.

Bandura, A. (1986). *Social foundations of thought and action: A social cognitive theory*. Upper Saddle River,NJ: Prentice-Hall.

Baxter, J.A. & Lederman, N.G. (1999). Assessment and Measurement of Pedagogical Content Knowledge. In Gess-Newsome, J., Lederman, N. G. (eds.), *Examining Pedagogical Content Knowledge*, (Chapter 6; Pp. 147-162), Dodrecht, The Netherlands: Kluwer Academic Publishers.

Brown, P. L., Abell, S. K., Demir, A. & Schmidt, F. J. (2006). College Science Teachers' Views of Classroom Inquiry, *Science Education,* **90**(5), 784-802.

Buck, L. B., Bretz, S. L. y Towns, M. H. (2008). Characterizing the Level of Inquiry in the Undergraduate Laboratory, *Journal of College Science Teaching,* **38**(4), 52-56.

Bybee, R. W. (2004). Scientific inquiry and science teaching. En Flick, L. B. y Lederman, N. G. (Eds.), *Scientific inquiry and nature of science: implications for teaching, learning, and teacher education* (Chapter 1; pp. 1-14). Dordrecht, The Netherlands: Kluwer Academic Publishers.

Craig, N. (1999). The Joys and Trials of Doing Research with Undergraduates, *Journal of Chemical Education,* **76**(5)**,** 595–598.

Cruz-Garritz, D., Chamizo, J. A. & Torrens, H. (1989). Early research, *Journal of Chemical Education*, **66**(4), 320-321.

French, D. & Russell, C. (2002). Do Graduate Teaching Assistants Benefit from Teaching Inquiry-Based Laboratories? *Bioscience*, **52**(11), 1036-1041.

Garritz, A., Porro, S., Rembado F. M. & Trinidad, R. (2007). Latin-American teachers' pedagogical content knowledge of the particulate nature of matter. *Journal of Science Education,* **8**(2), 79-84.

Garritz, A. & Velázquez, P. (2009). Biotechnology pedagogical knowledge through Mortimer's conceptual profile. 18 pages. Proceedings of the NARST 2009 Conference, Garden Groves, CA, USA, April.

Gess-Newsome, J. (1999). Pedagogical Content Knowledge: an Introduction and Orientation. In J. Gess-Newsome & N. G. Lederman (Eds.). *Examining pedagogical content knowledge* (Chapter 1; Pp. 3-17) Dordrecht: Kluwer.

Grossman, P. L. (1990). *The making of a teacher: teacher knowledge and teacher education*. New York: Teachers College, Columbia University.

Hutchison, A. R. y Atwood, D. A. (2002). Research with First- and Second-Year Undergraduates: A New Model for Undergraduate Inquiry at Research Universities, *Journal of Chemical Education*, **79**(1), 125-126.

Khan, S. (2007). Model-Based Inquiries in Chemistry, *Science Education,* **91**, 877–905.

Lederman, N. G. (2004). Syntax of nature of science within inquiry and science instruction. In L. B. Flick, y N. G. Lederman, (Eds.), *Scientific inquiry and nature of science: implications for teaching, learning, and teacher education* (Chapter 14; pp. 301-317). Dordrecht, The Netherlands: Kluwer Academic Publishers.

Lindsay, H. & McIntosh, M. (2000). Early Exposure of Undergraduates to the Chemistry Research Environment: A New Model for Research Universities, *Journal of Chemical Education*, **77**(9), 1174–1175.

Loughran, J. J., Mulhall, P., & Berry, A. (2004). In search of pedagogical content knowledge in science: Developing Ways of Articulating and Documenting Professional Practice. *Journal of Research in Science Teaching*, **41**(4), 370–391.

Magnusson, S., Krajcik, J., & Borko, H. (1999). Nature, sources, and development of the pedagogical content knowledge for science teaching. In J. Gess-Newsome and N. G. Lederman (Eds.), *Examining pedagogical content knowledge* (pp. 95-132). Dordrecht, The Netherlands: Kluwer Academic Publishers.

Martin-Hansen, L. (2002). Defining inquiry. *The Science Teacher,* **69**(2), 34-37.

McDermott, L. C. &the Physics Education Group (1996). *Physics by Inquiry*, New York, USA: John Wiley & Sons.

McDermott, L. C. (2006). Editorial, *American Journal of Physics*, **74**(9), 758-762.

McDermott, L. C., Heron, P. R. L., Shaffer, P. S. & Stetzer, M. R. (2006). Improving the preparation of K-12 teachers through physics education research, *American Journal of Physics*, **74**(9), 763-767.

NRC (1996). National Research Council *National Science Education Standards*. Washington, DC: Academic Press.

NRC (2000). National Research Council, *Inquiry and the National Science Education Standards*. Washington, DC: National Academy Press.

Padilla, K., Ponce-de-León, A. M., Rembado, F. M. & Garritz, A. (2008). Undergraduate Professors' Pedagogical Content Knowledge: The case of 'amount of substance'', *International Journal of Science Education*, 30(10), 1389-1404.

Park, S. & Oliver, J. S. (2008). Revisiting the Conceptualization of Pedagogical Content Knowledge (PCK): PCK as Conceptual Tool to Understand Teachers as Professionals. *Research in Science Education*, **38**(3), 261-284.

Rocard, M., Csermely, P., Jorde, D., Lenzen, D., Wallberg-Henriksson, H. & Hemmo, V. (2007). *Science Education now: a Renewed Pedagogy for the Future of Europe*. Brussels: European Commission, Directorate-General for Research.

Schwab, J. (1960). What Do Scientists Do? *Behavioral Science*, **5**(1), 1-27.

Schwab, J. (1966). *The Teaching of Science*. Cambridge, MA: Harvard University Press.

Schwartz, R. & Lederman, N. G. (2002). "It's the nature of the beast": the influence of knowledge and intentions on learning and teaching nature of science. *Journal of Research in Science Teaching*, 39(3), 205-236.

Shulman, L. S. (1986). Those who understand: knowledge growth in teaching, *Educational Researcher*, 15, 4-14.

Shulman, L. S. (1987). Knowledge and Teaching; Foundations of the New Reform. *Harvard Educational Review*, 57 (1), 1-22.

Slezak, J. (1999). Student-Inspired Undergraduate Research, *Journal of Chemical Education*, **76**(8), 1054-1055.

APPENDIX 1 Pedagogical and professional experience repertoire of Elizabeth (extract from a longer interview)

Could you tell us the frame in which you base your inquiry perspective? Is it documented?

The theoretical framework of our inquiry approach corresponds to McDermott work in Washington University in Seattle, which is based in: 1) the ideas of Arnold Arons, a former professor of that university, 2) Piaget proposition of cognitive development, and 3) constructivism as a didactic proposal. Arons considers a series of abilities he called "abilities of critical thinking" that are part of scientific thinking and required for "functional or operative learning" of disciplines; you appropriate some knowledge and apply it to circumstances different from those you learned it and this appropriation is more than understanding some facts; it is, being able to explain where all comes from.

The Physics education Group has made work only for university physics?

Not only. They have 4 branches of work: 1) For college physics students, where they complement the traditional classes with curriculum materials called *Tutorials in Introductory Physics*, 2) For college students majoring in other disciplines different to the scientific ones, 3) For students starting scientific careers but with limited background, and 4) To train physic teachers for elementary and secondary school, according to the inquiry standard required by the *National Science Education Standards*. The curriculum material developed for the last three branches is called *Physics by inquiry*. They realized that most of the problems of university students come from previous levels so they decided to tackle that problem by appropriately preparing basic education teachers in physics.

Which is the profound objective of using guided inquiry in the course of Introduction to Physics in the Health Promotion career?

Adopting the constructivist proposal implies the active involvement of students in the learning process; implies that one as a teacher finds the way to induce a cognitive conflict and leads them to attain meaningful learning, let's say. The congruent pedagogical way with that objective is the inquiry approach, because it is the scheme in which students intellectually involve in their own learning. The teacher is a guide in the learning process and does not act in the traditional way, but by means of a Socratic dialog, making more questions than giving answers. The teacher must conflict, involve, and confront students by means of inquiry, trying that they construct their knowledge by attaining critical thinking abilities and scientific reasoning processes. And this applies for Health Promotion as well as for other careers.

Could you give us an example of an inquiry of a physical concept?

A big question we make to students, that they last the whole course of 100 hours in answering is: what do you have to know in order to predict if a given object floats or sinks in some liquid? The first answer of some students is about some of the properties of matter, but the question is not on that point but how do you inquire about it? Which is the procedure? We pretend students to answer how this must be investigated, how do we finally arrive to the conclusion that we need to know the density of the object and of the liquid and compare them. The intention is that this inquiry serves students to solve other kind of problems related with the differentiation between observations and inferences; to operationally define the involved variables and to establish experiments of variables control in order to predict the behavior of a system. Physics allows working with simpler systems. The problem of determining the floating or sinking problem is easier that any public health one. The advantage of our course is that students start this methodology with a more reliable problem.

[One examples is] the mass… the first thing that you do is to work with scales, which can be built in an easy way. You just have to use a universal bracket and a piece of wood with a lot of holes (this is called perfocel©). You place the wooden board on the bracket as the arms of the scale and hang one tray at each extreme or at two points at the same distance from the pivot.

They (students) arrive to the conclusion that a standard is needed. To do so, the first thing you ask them is that they compare objects in terms of the property the scale registers. The first thing they mention is 'weight', "the scale is registering weight". Then, you ask them, but how do you use it in order to make a classification, to establish a hierarchy in terms of which object has a larger or a smaller portion of that property? Tell me the most efficient way to make a comparison; how do you do it? Tell me the procedure. This implies, as Piaget says, the ability of comparing one object with another and then with another. What you are doing is putting things in order. Once they do that, you ask them how they can quantify this relationship. This leads them to establish a standard such as a coin, for example, or nuts, as we use for that purpose. They decide that the nuts allow you to measure this property by comparing the mass with a set of nuts. Afterwards you can work as you please. For example, I like to mention that nuts are equivalent to grams. This unit is like an entelechy to them and they are very much surprised to realize that it is something so conventional; that certain number of grams is equivalent to another number of nuts. And that you can establish a new standard and define the equivalence…