ISSN 1548-6613 (Print)
ISSN 1930-1529 (Online)

From Knowledge to Wisdom

US–China Education Review

Volume 8, Number 5, May 2011

David Publishing Company
www.davidpublishing.com

US-China Education Review

Volume 8, Number 5, May 2011 (Serial Number 78)

DAVID PUBLISHING

David Publishing Company

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US-China Education Review, ISSN 1548-6613
May 2011, Vol. 8, No. 5, 599-614

Pedagogical Content Knowledge of Inquiry: An Instrument to Assess It and Its Application to High School In-Service Science Teachers

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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, thus defining the inquiry objectives for classroom and laboratory teaching. Five high school and college Mexican teachers' PICK (pedagogical inquiry/content knowledge) was documented and assessed by means of Loughran, Mulhall and Berry's (2004) I-CoRe (inquiry content representation) developed by the authors through a proposal of a set of seven inquiry activities. They were also interviewed to construct the professional and pedagogical experience repertoires, a second tool by Loughran et al. (2004) 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 in México, the teachers make use of it to improve their teaching practice. According to their answers, their actions in the classroom or the lab were classified within the three general approaches expressed by Lederman (2004): implicit, historical and explicit. It is concluded 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.

Keywords: pedagogical content knowledge, inquiry, content representation, science teaching, high school, undergraduate

Pedagogical Content Knowledge

Introduction

Shulman (1986; 1987) coined the term PCK (pedagogical content knowledge) as one type of knowledge

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that teachers should possess, because they do not only have to know and understand the SMK (subject matter knowledge), 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 (1986) 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".

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 Figure 1.

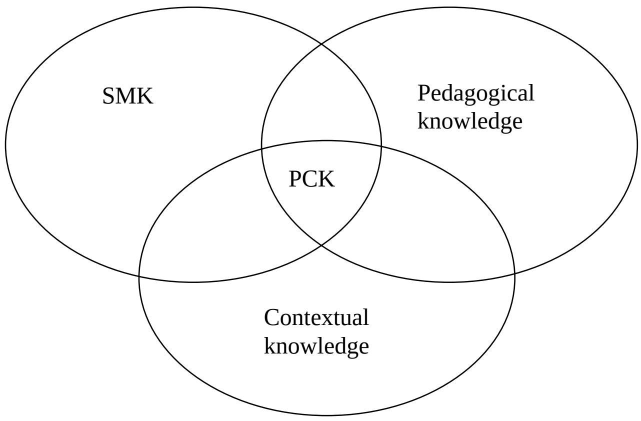

Figure 1. The intersection represents PCK.

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

(1) Orientations toward science teaching;

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

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

(4) Knowledge and beliefs of assessment in science;

(5) 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 from Bandura's (1986) social cognitive theory, and included teachers' beliefs in their ability to affect students' outcomes, that is, an affective component of PCK. One of the authors of this paper has insisted in the incomprehensible oversight of the affective domain inside PCK (Garritz, 2010).

McDermott (2006) said that evidence from research indicates that many pre-service and in-service teachers often have the same difficulties with the materials as any other students. She has emphasized that in order 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)" (p. 759).

How to Document PCK?

There are several ways to document PCK (Baxter & Lederman, 1999; Loughran, Mulhall, & Berry, 2004). The authors have decided to document PICK with the Loughran et al.'s (2004) scheme of CoRe (content representation), due to successful previous experiences (Garritz, Porro, Rembado, & Trinidad, 2007; Padilla, Ponce-de-León, Rembado, & Garritz, 2008; Garritz & Velázquez, 2009). Loughran et al. (2004) used 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.

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 et al. (2004) to zoom the answers given in the CoRe by interviewed teachers is the PaP-eRs (pedagogical and professional experience repertoires). These 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 (National Research Council), 2000; Arons, 1997, Chap. 12-13).

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) said 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".

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

The NSES (National Science Education Standards) (NRC, 1996) 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)

Multiple Definitions of Inquiry

After mentioning that "Many educators misunderstand what is meant by inquiry", Martin-Hansen (2002) insisted 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.

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 and Towns (2008) discussed 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, Abell, Demir and Schmidt (2006, p. 786) described tactfully the dilemma, and wrote "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 started to search for the abilities necessary to do scientific inquiry from the NSES (NRC, 1996). There we found the following for the Grades 5-8:

(1) Identifying questions that can be answered through scientific investigations;

(2) Designing and conducting a scientific investigation;

(3) Using appropriate tools and techniques to gather, analyze, and interpret data;

(4) Developing descriptions, explanations, predictions and models using evidence;

(5) Thinking critically and logically to make the relationships between evidence and explanations.

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

(1) Identifying questions and concepts that guide scientific investigations;

(2) Designing and conducting scientific investigations;

(3) Using technology and mathematics to improve investigations and communications;

(4) Formulating and revising scientific explanations and models using logic and evidence;

(5) Recognizing and analyzing alternative explanations and models;

(6) Communicating and defending a scientific argument.

The two first abilities of both educational levels are 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. Table 1 summarizes the abilities encouraged by inquiry suggested by Bybee (2004).

Table 1

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	

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 is 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 and Russell (2002, pp. 1036-1037) included 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.

In Martin-Hansen (2002), the authors of this study found Table 2, with another set of activities.

Table 2

Essential Features of Classroom Inquiry (Martin-Hansen, 2002)

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 (2007) also mentioned several processes that are associated with inquiry in science, and included 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;

(12) Sharing what has been learned from the inquiry with others.

Based on 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, which are presented in Table 3.

The authors have separated a set of activities considered the best related with the development of scientific research (activity F 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 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

Table 4

Scientific Investigation Involved

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 models
Communicating and discussing scientific inquiry results in the classroom

Methodology: I-CoRe and PaP-eRs

The Instrument Developed

The original eight questions of Loughran et al. (2004) on CoRe were substituted in this study by those mentioned in Table 5.

Table 5

Questions Adapted From Loughran et al. (2004) Core for Each One of the Activities of Inquiry Mentioned in Table 3

1. Why do you consider it is 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 Table 6. The teachers selected which ones of the activities he/she develops with his/her pupils and answered exclusively those columns.

Table 6
The Matrix Form of I-CoRe With 35 Cells That Have to Be Partially Filled by Inquiry-Experienced Teachers, Depending on the Activities They Develop

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 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?							

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.

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-eRs obtained was the speech verbatim. The interview was conducted with specific questions pointing to the place where an extension was desired. The following is 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 45 years.

Elizabeth works in an autonomous public university in Mexico City for the last seven years, and she has another five years of previous teaching high school experience. She studied undergraduate physics and is now finishing her master degree. 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 18 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 considered 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 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 7. Archibald and Olivia answered all the activities, and the other three made a selection.

Table 7

Activities Filled by Each One of the Five Inquiry-Experienced Teachers

Teachers/ inquiry activities reported	A	B	C	D	E	F	G
	Identify and consider questions that can be answered through inquiry	Define and analyze properly the question to be solved and identify its relevant aspects	Gather bibliographic information to be used as evidence	Develop explanations to set out question, from evidence	Think about everyday problems and display relevant historical aspects	Design and conduct a scientific investigation	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

An interesting set of answers was received, all of them highlighting scientific inquiry as a formative process in which 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, reasoning and 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 students' 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, it 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 allows 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 it 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, incorporating information gathered in the literature search, organizing all the data and generating a plausible explanation. (Olivia)

As Bybee (2004) said, 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 considered 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 students' 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 considered 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 looked for problems related to students' daily life focused on making science easier to students, and without taking into account history of science or NOS (nature of science). On the other hand, Rufus tried 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 have 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 7, 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. 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.

Approaches for Inquiry

In the case of inquiry, Lederman (2004) recommended to integrate it with NOS. As both are important contexts, we have the scheme detailed by Schwartz and Lederman (2002), in which inquiry and NOS occupy the contextual knowledge space in Figure 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 came 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 the reason 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 HOS (history of science) in science teaching can serve to enhance students' views of NOS.

Lederman (2004, p. 312) suggested 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 3. The "historical" teacher, incorporates HOS to enhance students' views of NOS and inquiry, mainly with E activity in Table 3. As a cognitive consequence, it is proposed that "explicit" teachers be related with almost all of the activities in Table 3.

Two of them, Margaret and Elizabeth seem to be implicit teachers, because they mostly used the activities F and G in Table 3. 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, Margaret, Archibald and Olivia seem to be explicit teachers, because they answered almost all (A to G) activities in Table 3. Olivia and Margaret gave more examples of their inquiry approach in the PaP-eRs interview afterwards.

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)

Only one of the teachers, Margaret, seems to be an historic one, because of the emphasis given in activity E in Table 3, where she considered important the historical moment in which scientific findings were developed; and she used 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 approaches. 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. 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 and 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's group has assessed the effectiveness of teachers' PCK-training with students by means of pre- and post-tests.

Elizabeth bases her work on attaining the following three critical thinking abilities in students mind: (1) to differentiate between observations and inferences; (2) to operationally define the involved variables; and (3) to establish experiments of variables control to be able to predict the behavior of a given system.

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 was 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 PaP-eRs were constructed.

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—make 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 the reason 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 taught. But what all of them try to exploit is the context to make science closer to students.

The instrument developed has been useful to assess PICK activities of teachers.

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 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.

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US-China Education Review
Volume 8, Number 5, May 2011
David Publishing Company
1840 Industrial Drive, Suite 160, Libertyville, IL 60048
Tel: 1-847-281-9826; Fax: 1-847-281-9855
http://www.davidpublishing.com
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ISSN 1548-6613