Sci & Educ
DOI 10.1007/s11191-011-9387-7

Heuristic Diagrams as a Tool to Teach History of Science

José A. Chamizo

Abstract The graphic organizer called here heuristic diagram as an improvement of Gowin's Vee heuristic is proposed as a tool to teach history of science. Heuristic diagrams have the purpose of helping students (or teachers, or researchers) to understand their own research considering that asks and problem-solving are central to scientific activity. The left side originally related in Gowin's Vee with philosophies, theories, models, laws or regularities now agrees with Toulmin's concepts (language, models as representation techniques and application procedures). Mexican science teachers without experience in science education research used the heuristic diagram to learn about the history of chemistry considering also in the left side two different historical times: past and present. Through a semantic differential scale teachers' attitude to the heuristic diagram was evaluated and its usefulness was demonstrated.

> *If we just show the findings and products of science,*
> *no matter how useful and inspiring they may be,*
> *without communicating its critical method,*
> *how the average person can distinguish*
> *between science and pseudoscience?*
> *Both are presented as baseless assertion*
> C. Sagan (1997, p. 39)

1 Introduction

It is evident that information about knowledge is nowadays available from many places: libraries, CDs, webs and electronic nets remind us the omnipresence of information.

Partial and preliminary versions of this paper were presented at *10th International History and Philosophy of Science Teaching Group International Conference*, South Bend, Indiana (Chamizo 2009a) and *8th International Conference for the History of Science in Science Education* in Maresias, Sao Paulo.

J. A. Chamizo (✉)
Facultad de Química, Universidad Nacional Autónoma de México, México, México
e-mail: jchamizo@servidor.unam.mx

Today, in the age of computers, the challenge about information is not only quantitative but also qualitative. Generally speaking currently we process more information in 24 h than the average person would process in a lifetime 500 years ago, when the fundamental structure of today's university was solidly established (Rodgers et al. 2006). In this context the aim of education can not be only informing. The idea will be to help students to reason through scientific thinking rather than to regurgitate the conclusions of science. Generally speaking, scientific content is taught, but Schwab's (1962) interpretation of science teaching as a dogma or as "*a rhetoric of conclusions*" remains.

Chemistry education practice has not been driven to any great extent by research findings (for example, common misconceptions, modelling, problem-solving, history and philosophy of science) nor to accomplish professional ideals (van Berkel et al. 2000). Chemistry teachers generally ignored that chemistry is, among all other sciences, the most productive (Tague et al. 1981). The growth of chemical information in the last century has been outstanding. Thus, being up-to-date, being universally informed has become a mere fiction for many decades (Schummer 1999). However the changes that have occurred in textbooks during the past three decades do not show any real recognition of the growth in scientific knowledge. Despite all this, and once the majority of chemistry teachers all over the world used textbooks as the main (sometimes the only) source of information, we became, without wanting to… *history teachers!* (Chamizo 2007b).

The importance of teaching history of chemistry in general or specific courses has been widely accepted. For example Wandersee and Baudoin (2002) considers:

> We think the history of chemistry can help chemical educators to develop, use, and investigate materials and strategies that promote learning in chemistry that is both meaningful and mindful. We agree with D. B. Gowin's definition that learning is a change in the meaning of experience. The overall objective of chemical education is to help students to construct a meaningful and mindful understanding of the nature of matter and changes in matter. If this is so, then knowing from whence these ideas came, how they were constructed over time, how the record of human 'struggles to understand' can illuminate how we know what we know today, will only help learners. They will be enabled to link newly-learned chemical concepts and principles both to their prior knowledge and to the collective historical knowledge of the global chemistry community.

However, the way to help students construct a meaningful and mindful approach to chemistry's history has been difficult, to say the least. In a traditional course there are many and different kinds of obstacles to confront, some deeply rooted in chemistry teaching practices. Recently Höttecke and Celestino Silva (2011) recognized another three obstacles: teachers' skills, epistemological and didactical attitudes and beliefs; institutional framework of science teaching, and available textbooks. Again Schwab's (1962) interpretation of science teaching as "*a rhetoric of conclusions*" appears to be fundamental. It means that if scientific competence is not worked out, we cannot say that scientists are being trained. On this subject there are different positions, but it is possible to recognize that scientific activity requires more reflection and less memory (Hodson 1994). One way to do that it is to scaffold teachers in open-inquiry teaching (Valk and Jong 2009). That is, try to reduce, at least, two of the obstacles mentioned above.

This paper attempts to help the above by introducing a new graphic organizer, called heuristic diagram (through which a large amount of information, usually from an inquiry, can be synthesized and displayed), following the original proposal of Gowin's Vee modified according to the characterization of concepts originally proposed by the English philosopher S. Toulmin.

2 Philosophy, History, Science and Education

The American philosopher L. Laudan began his well-known book *Progress and its Problems* (1977) with the claim: *science is essentially a problem-solving activity*. In a very precise paragraph he adds (p. 12):

> If we take seriously the doctrine that the aim of science (and of all intellectual inquiry activities, for that matters) is the resolution or clarification of problems, then we shall have a very different picture of the historical evolution and the cognitive evaluation of science.

Hence, at least for him and in opposition to the traditional and positivistic view of science, quite common in science courses (McComas 2000) problems and problem-solving are central to scientific activity.

If one of the objectives of science education is to help students become problem solvers because this is the activity of scientists, then the current activities that occur in the science classroom under the guise of 'problem-solving' must change dramatically to become much more based on inquiry (Gabel 1989). One of the options is Problem-Based Learning (PBL). Beyond self-direct learning, PBL requires students to be active. Traditional modes of classroom learning—often characterized by memorizing information, solving exercises and mirroring the views of teachers—do not prepare students for the type of learning they will encounter in the real world. As De Berg (1989) showed the overemphasis on quantitative calculations in most science textbooks may be the cause of students' low level of conceptual understanding. Because most teachers rely very heavily on textbooks, it is reasonable to suspect that this emphasis has a great impact on teachers' instruction and assessment methods.

One of the major reasons why students find problem solving difficult is students' failure to construct meaning from the problem statements (Frazer 1982). Hence it is necessary to construct and relate personal knowledge to problem solving. Also, a close connection between students' understanding of the nature of science and their problem solving strategies has been recognized (Lin and Chiu 2004).

Learning in the real world is a product of problem solving. Students who are actively engaged in the educational process make substantial connections with course content. These connections promote a deep level of processing (Knowlton 2003). Recognizing the enormous variety in types of problems Watts (1991) divided problem-solving in two different categories that can be roughly characterized like: PS1 as a purely intellectual process and PS2 as an implementation task—translating concepts into practical outcome. Problems in the PS1 category are usually presented at the end of science' textbooks. This is a clue that they are all somehow related and require for their solution the same kind of mathematical manipulation or repertoires. On the other hand problems in the PS2 category are real world rooted problems, with different possible solutions. Related with these ideas research results from the dichotomy *successful/unsuccessful problem solvers* showed (Herron and Greenbowe 1986) that successful problem solvers have among other characteristics a good command of basic facts and principles; have general reasoning strategies; construct appropriate representations; and apply a number of verification strategies.

Here, requiring students to ask questions, generate ideas and provide explanations to support those ideas promotes learning (Dominowski 1998). This is a new teaching culture where the capacity to form questions is more valued than that of giving unasked, or simple answers. In accordance with the French philosopher G. Bachelard (1979, p. 16):

> And say what you will, in the scientific life problems do not arise by themselves. It is this sense of the problem that indicates the true scientific spirit. To a scientific mind all knowledge is the answer to a

> question. If there was no question, there can be no scientific knowledge. Nothing is spontaneous. Nothing is given. Everything is built.

In last decades many philosophers have questioned the traditional basic assumptions about the nature of science (Chalmers 1978; Hacking 1983; Laudan 1990; Latour 1999). For example Giere (1999) considers that science does not need laws. For him (p. 23):

> From the bits and pieces available, I have concluded that the original view of science as discovering universal laws of nature had little basis in the actual practice of science, but was imported largely from theology.

And more important to this work is his acceptance that the content of science changes with time; its aims and methods change as well. This is because (p. 6):

> Science does not deliver to us universal truths underlying all natural phenomena; but it does provide models of reality possessing various degrees of scope and accuracy.

However, the models are constructed in a specific historical moment with the intention of explaining or predicting a particular phenomena and should therefore be recognized explicitly. Is to say, as indicated by Justi (2000, p. 213) there are, also, historical models:

> A historical model is considered as a consensus model developed in a specific context. Within this definition, a context is taken to mean a system of philosophical, scientific, technological and social beliefs. This implies that a historical model is not necessarily a model developed by an individual scientist, nor that its production and use is situated within a specific time period. The most important issue is that it achieved consensus status within a particular context.

So is reached the issue that matter most to us. Of that it is for students get an open question, a question that defines a specific problem in a particular historical moment. To try to resolve that question they will have to be placed in such historic moment and to compare or evaluate it from the present time.

The Vee heuristic is a graphic organizer developed years ago by Gowin (Novak and Gowin 1984) with the purpose of helping students (or teachers, or researchers) to understand their research. Gowin indicates (p. 55): *A heuristic is something employed as an aid to solving a problem or to understand a procedure*. This instrument has been used for understanding knowledge in different fields (Calais 2009; Keles and Özsoy 2009; Fox 2007; Sillitoe and Webb 2007; Gowin and Alvarez 2005) and also for diagnostic, formative, and summative assessment (Doran et al. 2002).

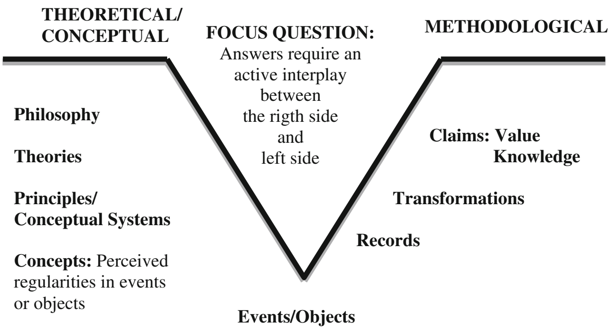
Graphic organizers represent thinking processes, they are a "cartography of cognition" (Wandersee 1990). Gowin recognized the initial difficulty of students in producing Vees, particularly the time necessary for them to become competent, but also (p. 113):

> In spite of the relatively challenging nature of Vee making, our experience has been that students react positively to this task. Especially when compared with more traditionally written reports, Vee making is a shorthand approach to exposing students' understanding of a topic or area of study and also helps them to organize ideas and information. Students recognize that Vee making, besides being less tedious than writing reports, helps them to gain understanding of the subject matter.

It is clear that students must learn to build these graphic organizers and it takes time and requires a kind of skill which are not used to. Educational processes generally get little emphasis on synthesis capacity and such is one that must be developed here. That is despite their initial, for unknown, complexity, Gowin Vee allows students to organize their ideas and identify the information they need to solve a problem (Escudero and Moreira 1999).

As is well known (Fig. 1, Novak and Gowin 1984, p. 3) Vee heuristic consists of five parts: events or objects in the bottom, a focus question in the center, a methodological rigth side where it is shown what must be done to answer the question, a theoretical-conceptual

Fig. 1 Gowin's Vee (Novak and Gowin 1984 p. 3)



left side, it means the frame of reference for interpreting it, and finally the response, not necessarily incorporated into the Vee. However the left side, the thinking side, became sometimes difficult because it is not clear for all the users (and also the experts) what is the relationship among philosophy, theories, principles (laws, as Giere indicated above) and concepts. In this paper a modification of this, not so clear, left side was introduced following Toulmin's philosophical approach.

The work of the English philosopher S. Toulmin (2003), *The uses of Argument*, has provided a valuable foundation for science education. Many research works have been inspired from his proposals (Osborne et al. 2004; Chamizo 2007a, b; Erduran and Jiménez-Aleixandre 2008). However, Toulmin's work provides an overview of science that has not been sufficiently explored; it entails the dynamic view of scientific knowledge, with attention to the social environment. This could be extremely useful if we consider that learning science is also a dynamic process in which new knowledge emerges.

Toulmin (1972, p. 35) defines a concept through the historical-social interaction, this is one reason why here utilize his characterization of the development of science:

> Each of us thinks his own thoughts; our concepts we share with our fellow-men

Science is not a static enterprise; rather its concepts, interest, presuppositions, and theories are dynamically evolving. It is also complex (1972, p. 161):

> In order to do proper justice to the 'complexity' of scientific concepts, we must distinguish three aspects, in the use of those concepts: namely (i) the language, (ii) the representation techniques, and (iii) the application procedures of science. The first two aspects or elements cover the 'symbolic' aspects of scientific explanation –i.e. the scientific activity that we call 'explaining' –while the third covers the recognition of situations to which those symbolic activities are appropriate. The 'linguistic' element embraces both nouns –technical terms or concept-names- and also sentences, whether natural laws or straightforward generalizations. The 'representation techniques' include all those varied procedures by which scientist demonstrate –i.e. exhibit, rather than prove deductively- the general relations discoverable among natural objects, events and phenomena: so comprising not only the use of mathematical formalism, but also the drawings of graphs and diagrams, etc.

So recognizing that each scientific concept requires for its full understanding of three different aspects: applications, language and representation techniques can be clarify its development over time. Toulmin's analysis considers the growth or evolution of concepts and their collective use by disciplines and indirectly the growth of scientific knowledge. A few examples of the implementation of this approach in teaching the history of chemistry, particularly in Spanish speaking countries, have been published (Henao et al. 2009; Camacho and Cuéllar 2007; Estany and Izquierdo 1990). For Toulmin the continuity of science rests in the problems by which successive generations of scientists (from any specific discipline) were faced… and problems, like the Vee heuristic considered, start with questions.

Finally, I should indicate which of the different ways to interpret and understand history (Chamizo 2007b; Kragh 1987) is most appropriate for this work. Here it is useful to consider Husbands' approach (2003, pp. 133–134):

> It will be clear by now that knowing about the past is never just about knowing "when things happened". If pupils cannot begin to explain why they happened, with what consequences and effects, if they cannot explain why some historical periods and events have a significant and resonance for them if, in short, they cannot develop a interpretative framework for their understanding of the past, then knowing about the past is reduced to a sort of quiz game…Nonetheless, the past once existed. History is not simply an enterprise in fiction because it involves procedures of dialogue with evidence, with the voices, however imperfectly mediated, of the past. We, and our pupils, have to establish a relationship with the past and with the way in which we, and they, make sense of the experience of other people in different settings…[…]…This means that we need to establish a more subtle, less absolutist understanding of the way in which knowledge is created. Our knowledge of the world and the language with which we describe it is not simply in our own heads, nor is it a given feature of the world in which we are living. It needs to be developed through the process of inquiry in classrooms, by teachers and learners in classrooms working to create meanings.

In short, what students need to do to solve a problem from the standpoint of the history of science and as proposed by Bachelard and Toulmin, is to have an open question related to science, perform a research of historical sources, taking care to explicitly recognize the applications, the language and the model used in the past to address this issue and compare them with the applications, the language and model of the present. They are studying the evolution of concepts that interest them personally to answer a particular question. They create meanings.

3 Heuristic Diagrams as a Tool to Teach History of the Sciences

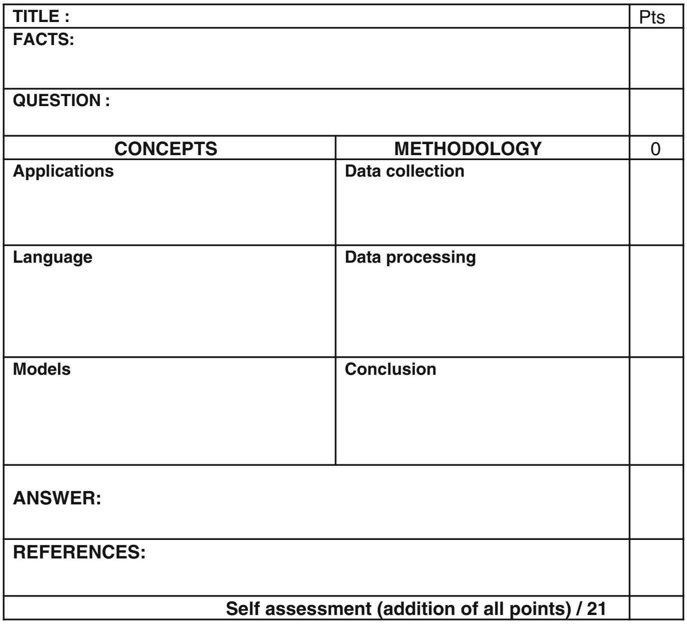
Problem-Based-Learning and open—inquiry teaching, require a change in the role of teachers, from the usual instruction-oriented role to a more guidance-oriented role and here heuristic diagrams can be useful, not only for them but also for their students.

Despite its virtues, one of the greatest difficulties in the use of Gowin's Vee is due to the ambiguity of its left side, one that regards thinking. For example sometimes a concept map can be included (Doran et al. 2002) sometimes not, and most important Gowin does not recognize the difference between terms and concepts (2005, p. 56)

> We define concept as a name (e.g., label, sign, word or signifier) for a regularity in events or objects. The word "wind" is a name for an event or some kind of regular motion of the air. The word "chair" names an object, a thing we sit on. Concepts are events and objects of our experience.

The heuristic diagram as an improvement of Gowin's Vee, following Toulmin's philosophical approach was initially proposed in open-inquiry laboratory work (Chamizo and Izquierdo 2007; Chamizo 2009a, b) Fig. 2, but also in teaching history of chemistry (Chamizo 2009b). Now the left side agrees with Toulmin's concepts (language, models as representation techniques and application procedures). The events or facts that induce the question must be recognized through literature references and the answer to the question must be explicit. The left column allows students self-assessment in accordance with a specific rubric Table 1.

To begin working with this graphic organizer it is necessary to construct a question, as proposed by Bachelard, from facts or events. This is not an easy task and teachers should learn how to do it. Therefore after reviewing several taxonomies (Cordova et al. 2007;



TITLE :		Pts
FACTS:		
QUESTION :		
CONCEPTS	**METHODOLOGY**	0
Applications	**Data collection**	
Language	**Data processing**	
Models	**Conclusion**	
ANSWER:		
REFERENCES:		
	Self assessment (addition of all points) / 21	

Fig. 2 Heuristic diagram

Hofstein et al. 2005; Otero and Graesser 2001; Chamizo and Hernández 2000) about the kinds of questions we established our own (Rios 2011). So we recognize two extreme types of questions, closed and open that can be characterized as follows:

- Closed. Request information from one source and the answer is short and in one place.
- Open. Evidence and information requests from two or more sources, the answer is broad, refers to analysis, appeals for the organization of ideas, concepts and facts and establish relationships among them.

Hence asking requires, from the person doing it, mobilizing knowledge and skills, and recognizing the depth of his own knowledge. Questions should be well formulated (precise and clear), unambiguous, contextualized (in time and space) and feasible (that can be answered by the person who asks). Asking is a property of scientific thinking, and does not belong to a rhetoric of conclusions.

The left side of the heuristic diagram can be used in research that require only one type of concepts, such as those used in experimental research (Chamizo and Colsa 2009 but can also be divided into two columns depending on whether you want to consider two different sets of concepts. In this research, two different historical times are considered. This amendment also changes the number of points associated with the self-assessment. Hence the scoring rubric of Table 1 must be changed with the addition of the appropriate points.

4 Methods

The context of this case study is a specific new masters degree science curriculum (chemistry oriented) in the Autonomous National University of Mexico designed for high

Table 1 Scoring rubric for heuristic diagrams

Points	Characteristics
Facts	
0	No facts
1	Some facts are recognized
2	Facts are recognized and some concepts
3	Facts and concepts are recognized and also some methodological aspects
Question	
0	No question
1	There is a question related (supported) with facts
2	There is a question related (supported) with facts that includes concepts
3	There is a question related (supported) with facts that includes concepts and suggests some methodological aspects
Methodology	
0	No methodology
1	There is a procedure that allows data collection
2	Data processing (tables, graphics)
3	A conclusion has obtained through data processing
Concepts	
0	No concepts
1	Applications are identified
2	Applications and language are identified
3	Applications and language are identified and also models capable to explain the question
Answer	
0	No answer
1	Answer is quite similar to methodology's conclusion
2	Answer besides methodology's conclusion includes facts
3	Answer besides methodology's conclusion includes facts and concepts (models particularly)
References	
0	No references
1	There are references related only to facts, concepts or methodology
2	There are references related to facts, and concepts or methodology
3	There are references related to facts, concepts and methodology

school in-service school teachers without previous experience in educational or historical research. The study was carried out in two complete, mainly women (two-thirds on average) successive and separated by a 2 years different cohorts of teachers engaged in a History of Chemistry course starting a master degree syllabus. In the first one the sample was five chemistry teachers coming from two different public Mexican high schools. In the second one the sample was six chemistry teachers coming from four different Mexican high schools (private and public). In both cases they studied a traditional science history

Table 2 Models used in the past and in the present related to specific questions

Question	Model used in the past	Model used in the present
Why Boyle believes that the experiments on the elasticity of air are a way to overcome the prejudices of reason?	Hobbes	Hacking
What impact did the social situation of Mendeleev, in the popularization of the periodic system of elements?	Logical positivism	Mulkay
Why Soddy with all the experimental evidence gathered during its investigation did not suggest the existence of another atomic particle?	Rutherford	Liquid drop
Why is not possible to say that with their experiments with acids and metals the English H. Cavendish, in the second half of the eighteenth century, discovered hydrogen?	Phlogiston	Quantum chemistry

course for 16 weeks and also performed a process of continuous research and inquiry on the specific issue that they selected freely and whose final product is a heuristic diagram. The first step of their research was devoted to choose the episode and clarifying the question that guide the specific inquiry of each student related to the history of chemistry using Gowin's Vee and learning how to ask open questions (Rios 2011). Around the fourth week the heuristic diagram was introduced and the second step required the construction of one of them following the specific instructions to do it (see "Appendix"). A scoring system adapted from Novak and Gowin (1984) has been used where the main idea was to relate the five sections among them (Table 1) and also students' self-assessment. At this point in their research students already identify some of the difficulties in accessing historical primary sources, which leads them to modify their own questions. In the third step, 4 weeks later, the students along with the instructor discussed their heuristic diagrams together noting any deficiencies (and here self assessment is very important) and finally producing a form for evaluation at the end of the course (Table 2; Fig. 3).

To have an idea of student-teachers' attitudes towards the heuristic diagram, a semantic differential scale without a neutral alternative was designed (Robson 2002). It means that a person must choose, to a certain extent, one or the other adjective. Ratings on bipolar adjective scales tend to be correlated, and three basic dimensions of response account for most of the co-variation in ratings. Items belonging to a previously identified three-dimensional scale have been labelled Evaluation, Potency, and Activity (EPA) (Heise 1970). A 15 item scale has been tested previously with another chemistry teachers group (pilot study). The reliability of instrument was calculated as Cronbach alpha ($\alpha = 0.88$). An improved 12 items version was answered (paper script) by the two cohorts of teachers-in service that participated in our research at the end of their course.

5 Results

The course of history that in-service teachers study (all of them chemists), considers; aspects of language (Crosland 1978), of the historical evolution (Jensen 1998), experimental development (Chamizo 2009a, b), chemistry method (Bachelard 1976; Jacob 2001), some of its main ideas (Knight 1992) as well as the winners of the Chemistry Nobel Prize (nobelprize). So instead of a one-dimensional chronological account, are discussed several at a time. This helps in-service teachers to define their subject and make their own question at the beginning of the course.

<table>
<tr><td colspan="3">TITLE: HABER´S AMMONIA SYNTHESIS</td><td>Pts</td></tr>
<tr><td colspan="3">FACTS: In 1909 F. Haber synthesized 80 g of ammonia per hour from H_2 and N_2 to a pressure of 175 Bar, and 600ºC with osmium finely distributed as catalyst. (1). In 1913 C. Bosch and A. Mittasch produced the first industrial unit (3 to 5 ton) of ammonia to a pressure of 200 atm and a temperature between 500 and 600ºC with iron as catalyst (2).</td><td>3</td></tr>
<tr><td colspan="3">QUESTION: Why were different catalysts chosen in the two cases?</td><td>3</td></tr>
<tr><td colspan="2">CONCEPTS</td><td rowspan="2">METHODOLOGY</td><td rowspan="2">0</td></tr>
<tr><td>PAST</td><td>PRESENT</td></tr>
<tr><td>Applications
Fertilizers’ industry
Explosives’ industry</td><td>Fertilizers, explosives, plastics, refrigeration, pharmaceutical and metallurgical industry, among others (1)</td><td>Data collection
Haber`s Nobel Prize conference
Documents on Fritz Haber and the synthesis of the ammonia (1) (4)
Documents on Bosch and the synthesis of the ammonia. (2) Documents on current and ‘back then’ catalysts (4)(5)</td><td>3</td></tr>
<tr><td>Language
Catalyst. Substance that changes the speed of a chemical reaction given without modifying the energetic factors of the reaction.</td><td>Catalyst. A substance that increases the speed of a reaction without modifying the global change of Gibbs’ free energy. It is so much a reagent and a product of the reaction. (3)</td><td>Data processing
<table>
<tr><th>Catalyst</th><th>Yield</th><th>Conditions</th></tr>
<tr><td>Fe, Mn</td><td>Low</td><td>750ºC, ordinary P</td></tr>
<tr><td>Fe, Mn</td><td>Low</td><td>T>700ºC, 200 atm</td></tr>
<tr><td>Cr, Mn, Fe, Ni</td><td>Med</td><td>T<600ºC, 200 atm</td></tr>
<tr><td>U, Os</td><td>High</td><td>600ºC, 175-200 atm</td></tr>
</table>
Haber only used Fe as catalyst. Bosch-Mittasch, a mixture of Fe, Al_2O_3, CaO and K_2O</td><td>3</td></tr>
<tr><td>Models
Of the intermediate reactions (Clement and Desormes). Stocks on the participation of the catalyst in the reaction that really happens, but in which the catalyst does not turn out to be involved, though the partial reactions have the catalyst as a chemical principal component of the process (5)</td><td>Surface reactions. The chemical nature of a surface determines its skill to act as catalyst for a certain type of reaction</td><td>Conclusion
Of all the catalysts tried by Haber under the conditions necessary for the production of ammonia, pure Iron was not a good catalyst in comparison with Osmium or the mixture used later by Bosch and Mittasch.
.</td><td>3</td></tr>
<tr><td colspan="3">ANSWER. According to his experiments Haber concludes in 1909 that to obtain high yields of ammonia in his synthesis certain conditions of temperature and pressure (500-600 ºC and 175-200 atm), are necessary besides a catalyst. Of those tried by him U and Os are those who have a better catalytic action in comparison to pure Fe. The mixture that contains Fe, aluminium oxide, calcium and potassium oxides like it they did Bosch and Mittasch had obtained similar yields. That is to say, the pure Fe is not a good catalyst.</td><td>2</td></tr>
<tr><td colspan="3">REFERENCES: (1) Modak, J. <i>Haber Process for ammonia synthesis</i> in Resonance. August 2002, pp 69-77. (2) Perutz, M.. <i>Friend or foe of mankind</i>? in <i>I wish I’d made you angry earlier: Essays on science and scientists.</i> Cold Spring Harbor Laboratory Press, 2002. (3) IUPAC. <i>Compendium of Chemical Terminology</i>, 2nd ed. (the "Gold Book"). Compiled by A. D. McNaught and A.Wilkinson. Blackwell Scientific Publications, Oxford (1997). (4) Haber, F. <i>Thermodynamics of technical gas-reaction</i>. Longman Green and Co. London, 1908. (5) Nobel Lecture. <i>Wilhelm Ostwald, The Nobel Prize in Chemistry 1909</i>. Dieciembre 1909. http://nobelprize.org</td><td>3</td></tr>
<tr><td colspan="3">Self assessment (addition of all points)/21</td><td>20</td></tr>
</table>

Fig. 3 Heuristic diagram about Haber’s ammonia synthesis

Graphic organizers, like the heuristic diagram, were introduced as research tools a few years ago (Trowbridge and Wandersee 1998). In relation to the Vee diagrams (that could be applied also to the heuristic diagrams) these authors consider (p. 115):

> Vee diagrams may at first be tedious to construct because of the need to identify all the elements of the investigation. Many times these elements are implicit or missing. However, the basic steps to construct a Vee diagram are surprisingly simple and easily taught. When constructing a Vee diagram start with the focus question and then decide upon the events you must study, elaborate the methodological or "doing" side" of your study. Next, develop the theoretical side and you will be able to see how theory (concepts) affects and modify practice. However, once the research is done you will be able to see even more how doing or practice affects theory and vice versa.

Besides this, which is not a simple or easy subject, the heuristic diagram introduced another difficulty or challenge. In the "concepts" section the relation between two different times, with their three characteristics (language, models as representation techniques and application procedures) appears. Students do not have trouble setting the research topic but find it hard to build a proper open question about it. The second difficulty is in recognizing when the question is social, psychological, or scientific. Clarifying this properly allows identifying the models that can be used in response. However these models produced in specific historical contexts (one of the few examples published were in chemical kinetics by Justi and Gilbert 1999) and later superseded for many research purposes are known as historical models. Merging some characteristics of each of several distinct scientific and historical models forms a hybrid model. It is used for classroom teaching purposes as if it were a coherent whole. They appear frequently in many chemistry textbooks and as Justi (2000, p. 223) showed they must be avoided:

> The identification of hybrid models provides a new insight through which teaching can be discussed. The existence of hybrid models in teaching means that no history of science is possible because it implies that scientific knowledge grows linearly and is context independent.

The above is a serious issue. The way science is taught usually reduces history, the best, to purely anecdotes, so finding this information is not necessarily easy. The point is that students identify the model that enabled scientists to that particular historical time, to interpret a given set of facts. Table 2 shows examples of models corresponding to different historical moments identified by in-service teachers in their respective questions. Identifying them is one of the most complex tasks in research, in part because the bibliographic sources are not readily accessible. In this as in other parts of the research process, using the heuristic diagram clearly helped to identify the theoretical aspects to be considered to have a better understanding of the historical development of scientific concepts.

After several attempts and with the aid of the "Instructions for completing heuristic diagrams" ("Appendix") and the scoring rubric (Table 1) very satisfactory heuristic diagrams have been produced (Figs. 3, 4). The criterion to identify the final version is established for themselves at a predetermined date in accordance with the self-evaluation that are assigned. These figures show heuristic diagrams of the in-service teachers from each of the cohorts. As has been reported rubrics can clarify the assignment and help students reach its learning objectives and also provide an effective, efficient, equitable self-assessment method (Schneider 2006). Finally the importance of self-evaluation should be noted in the rightmost column in the heuristic diagrams. Filling it requires students to reflect on what is needed in each part of the diagram. Hattie recently reported (2009) student's estimates of their own performance as the single most important factor related with achievement.

<table>
<tr><td colspan="3">TITLE: THE RELUCTANCE TOWARDS ACCEPTING BOLTZMANN'S STATISTICAL MODEL.</td><td>Pts</td></tr>
<tr><td colspan="3">FACTS: Justification of physical chemistry and reactivity, excluding the concept of atom by Ostwald. Boltzmann' suicide in 1906. Perrin's experiments. Acceptance of the statistical model proposed by Boltzmann</td><td>3</td></tr>
<tr><td colspan="3">QUESTION: What were the positions and / or ideas, which supported the position of the nineteenth century scientific community that argued against the statistical model proposed by L. Boltzmann?</td><td>3</td></tr>
<tr><td colspan="2">CONCEPTS</td><td rowspan="2">METHODOLOGY</td><td rowspan="2">0</td></tr>
<tr><td>PAST</td><td>PRESENT</td></tr>
<tr><td>Applications
Justification of chemical reactivity, and thermodynamic properties of a reaction.
Prevalence and fall under the atomistic model of energy' conservation and stoichiometric laws.</td><td>Theoretical justification of the thermodynamic properties and chemical reactivity, from atoms.
Confirmation of the atomistic approach</td><td rowspan="2">Data collection
Review of secondary texts.
Review of articles in the Internet.
Identification of opposite epistemological positions.
Identification of models they support.
Identify their differences

Data processing
Positions in opposition to the Boltzmann model:
- Dogmatism, conservatism and orthodoxy, identification of theory with the object. Rationale for the chemical reactivity of conservation principles and stoichiometric laws, excluding the existence of atoms, not to accept its existence.

Boltzmann epistemological positions held:
-A theory is a representation of nature, nature can be represented by different theories, even opposite, a theory can be better than another, but not truer. Therefore the existence of atoms is not essential, if not its utility to represent nature better. Theoretical pluralism

Decisive events in time order:
- Lack of acceptance of the statistical thermodynamic theory.
- Boltzmann's suicide
- Perrin experiments demonstrating the existence of atoms.
- Acceptance of atomism by Ostwald (however it is clear the permanence of his dogmatism).</td><td>3</td></tr>
<tr><td>Language
Micro-and macrocosm.
Atom.
Molecule.
Statistical distributions.
Thermodynamics.
Energy' s conservation.
Microstates.
Stoichiometric Laws</td><td>Micro-and macrocosm.
Atom.
Molecule.
Statistical distributions.
Statistical thermodynamics
Energy' s conservation laws and related stoichiometric atom and its quantum states</td><td>3</td></tr>
<tr><td>Models
Ostwald' s physicochemical model.

Boltzmann's statistical model, which justified the thermodynamics from the existence of atoms.</td><td>Ostwald's model is correct and valid, is included in the interpretation of thermodynamics of the macro cosmos but is limited compared to statistical model…</td><td>Conclusion

Boltzmann's epistemological view supports his model. However, the dogmatism of Ostwald never ceased, and only until Perrin's experiments proved the existence of atoms, Ostwald accepted its existence. Unfortunately this fact was consummated a few months after Boltzmann's death, so that the latter never got to see his theory accepted.</td><td>3</td></tr>
<tr><td colspan="3">ANSWER. The position that was argued against Boltzmann model was represented by Ostwald, which attempt to justify the thermodynamics and reactivity only from the principle of conservation of energy and partners, regardless of the concept of atom (he does not accept its existence) which was the tool more simple and powerful concept with which they had to support chemical phenomena. This position was reversed experimentally in 1906 with the experiments of Perrin, who in turn showed that the Boltzmann model was valid with respect to dogmatism and better than Ostwald regarding explanatory power and universality. Unfortunately, the late acceptance of Ostwald came when Boltzmann had already died.</td><td>2</td></tr>
<tr><td colspan="3">REFERENCES: The World of Physical Chemistry, Keith J. Laidler Oxford University Press. Kaplan, I. G. Intermolecular Interactions: Physical Picture, Computational Methods, and Model Potentials, Wiley. http://www.filosofiacuba.com/articulo.html, PORTAL DE LA FILOSOFÍA IBEROAMERICANA Y CUBANA, physics / 9806011 - 8 Jun 1998.</td><td>3</td></tr>
<tr><td colspan="3">Self assessment (addition of all points)/21</td><td>20</td></tr>
</table>

Fig. 4 Heuristic diagram about Ostwald-Boltzmann's dispute

The semantic differential scale (SDS) is a scaling tool which has been used frequently for measuring social attitudes, particularly in the fields of linguistics and social psychology, but also in education. It is concerned with assessing the subjective meaning of a specific subject to the respondent, instead of assessing how much they agree, as Lickert scale does. The semantic differential scale is designed to explore the ratings given along a series of bipolar rating scales (often adjectives) and factor analysis have shown that such ratings typically group together into three underlying dimensions:

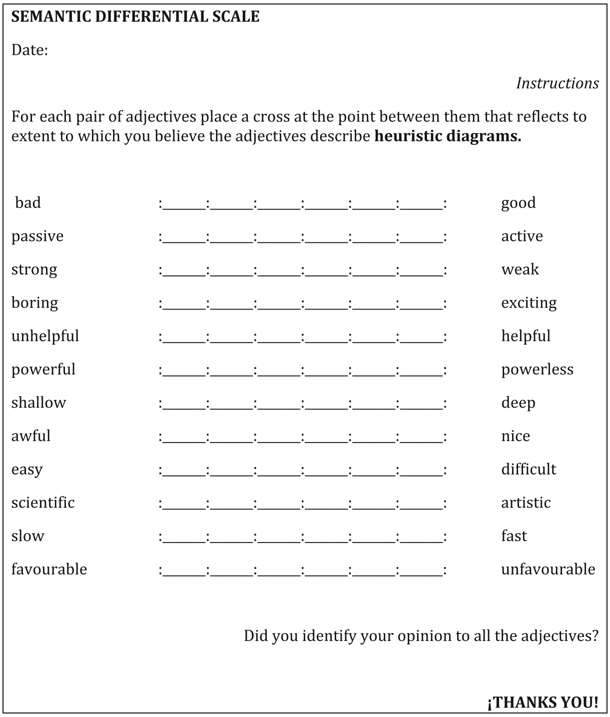
- Evaluation refers to the overall positive meaning.
- Potency refers to its overall importance.
- Activity refers to the extent to which the subject is associated with action.

In this research a six-point scale was used. It forces the subject to lean towards one evaluation or another (Fig. 5). Also the pilot study was crucial to both elicit and test adjectives and help to avoid ambiguous antonyms.

The semantic differential is a useful technique for measuring attitudes toward specific situations or also objects. The technique is extremely flexible and simple to construct, administer, and score. Validity studies show correlation coefficients of approximately 0.80 between the semantic differential ratings and Thurstone, Likert, and Guttman scales.

Related to in-service teachers' attitude caution needs to be taken when interpreting the data due to the relatively small sample size in both cohorts. However overall, participants were positive about the value of the heuristic diagram, with a mean of 4.4 (scored 1 for inactive negative or undesirable boundary to 6 for active, positive or desirable boundary),

Fig. 5 Semantic differential scale



SEMANTIC DIFFERENTIAL SCALE

Date:

Instructions

For each pair of adjectives place a cross at the point between them that reflects to extent to which you believe the adjectives describe **heuristic diagrams.**

bad	:______:______:______:______:______:______:	good
passive	:______:______:______:______:______:______:	active
strong	:______:______:______:______:______:______:	weak
boring	:______:______:______:______:______:______:	exciting
unhelpful	:______:______:______:______:______:______:	helpful
powerful	:______:______:______:______:______:______:	powerless
shallow	:______:______:______:______:______:______:	deep
awful	:______:______:______:______:______:______:	nice
easy	:______:______:______:______:______:______:	difficult
scientific	:______:______:______:______:______:______:	artistic
slow	:______:______:______:______:______:______:	fast
favourable	:______:______:______:______:______:______:	unfavourable

Did you identify your opinion to all the adjectives?

¡THANKS YOU!

Table 3 Semantic differential scale results

Adjectives			Results	
Inactive, negative, or undesirable boundary (1)	Active, positive, or desirable boundary (6)	Dimensions	Intensity average (2008, N = 5)	Intensity average (2010, N = 6)
Bad	Good	Evaluation	5.2	4.7
Passive	Active	Activity	5.2	5.0
Weak	Strong	Potency	4.8	5.0
Boring	Exciting	Activxity	4.6	4.0
Unhelpful	Helpful	Evaluation	5.0	5.5
Powerless	Powerful	Potency	4.4	4.2
Shallow	Deep	Potency	5.2	4.3
Awful	Nice	Evaluation	4.6	3.5
Difficult	Easy	Activity	2.2	2.2
Artistic	Scientific	Potency	4.4	4.5
Slow	Fast	Activity	3.6	2.7
Unfavourable	Favourable	Evaluation	5.2	5.5
Total average			4.5	4.3

Table 3. Eleven of the chosen adjective pairs, have values higher than 3 and only one (difficult-easy) has an average less than 3 (however their interpretation is complex but indicates that for science teachers, is not a simple matter to find and interpret historical data).The EPA analysis gave a detailed picture of the in-service teachers' attitude about the heuristic diagram. Evaluation is associated with the adjective contrasts: good-bad, helpful-unhelpful, nice-awful, and favorable-unfavorable. Their mean value was 4.9 (SD = 0.7). Hence the value of the instrument as a tool to teach history of science is without doubt. The scales that define the Potency dimension (obtained mean value 4.6 with an SD of 0.4) are strong–weak, powerful-powerless, deep-shallow and scientific-artistic. Again the importance of the heuristic diagram appears to be high. Activity scales refer to the extent to which the heuristic diagram is associated with action. They are active–passive, exciting-boring, difficult-easy and fast-slow. Their value was 3.7 (SD = 1.2). This dimension is more difficult to interpret than the other two, particularly the scales easy-difficult and slow-fast. In general Evaluation scales are always found to be more reliable than Potency or Activity scales (Heise 1970).

With the precautions outlined above it is possible to say that for in-service science teachers involved in their first historical research project, the use of an instrument called heuristic diagram was well evaluated, the instrument seemed powerful and interesting. Thus a small book on the history of experimental chemistry using this instrument has recently been published (Chamizo 2010).

6 Conclusions

In agreement with the obtained results, the new instrument called heuristic diagram, where Toulmin's concepts have been introduced and also his main idea of science development through problem solving in an open-inquiry scenario answering an open question, helps to improve in-service science teachers' ideas about the history of sciences and their competences to teach about it. As indicated by Tiles (1984, p. 12) in her study of Bachelard:

> Scientific progress is demonstrable and has been demonstrated. Moreover, the demonstration of this progress is an indispensable part of science teaching. This sense of progress is integral to the dynamics of scientific culture, i.e. current science includes within it, as an integral part, a perception of its own history, a perception which grounds its sense of the direction of its own progress…[…]…Thus this scientifically internal history of science is necessarily evaluative.

Teachers learned how to use the heuristic diagram to perform an historical investigation and were encouraged to use this tool with their own classes as part of science lessons. Somehow they learned to be successful problem solvers. It is clear that such research requires time and dedication, but there is no another way to do. Forgive the metaphor, we do not have catalytic converters! An example from the atomic structure of carbon, as indicated again by Bachelard (1976, p. 186):

> To say that the carbon atom is a small pyramid, is to give an illustration by reality, is an excess of realist philosophy. Moreover, this lack of nuance is very typical of that teaching only for results. This teaching deprives us of the awareness of problems and historical development of their difficult solutions. How to isolate in an open learning, that is a true teaching, a scientific result of the methods that lead to there and from there the problems start?

Finally, heuristic diagrams are a tool that helps to develop historical research and learning in the classroom not only in chemistry, but also in other sciences.

Acknowledgments I am grateful to Yosajandi Pérez and Alejandra García for the methodological and language discussions and also to all teachers-in training and the reviewers. All of them help me to improve the manuscript.

Appendix

Instructions for Completing a Heuristic Diagram

TITLE: (Refers to the subject of research)		Pts
FACTS: (This refers to information obtained and / or observations about something happening in the world that leads us to ask a question. Preferably should identify several of them)		
QUESTION: (Statement of an inquiry focusing on the facts. We must make sure that there is only one question)		
CONCEPTS	**METHODOLOGY**	0
Applications (Refers to applications for the issue under investigation)	**Data collection** (This refers to what we do to obtain the relevant information to answer the question. It should be pointed and detailed)	
Language (Refers to the terms we need to know to answer the questions)	**Data processing** (Refers to data management and results in tables, charts, diagrams etc. which summarize the data obtained)	
Models (This refers to the model used to give the answer to the question. It may be scientific, economic, social, etc. For example Lewis' atomic model, or Arrhenius' acid-base model, or market model, constructivist learning model, etc..)	**Conclusion** (This refers only to that obtained from the processed data)	
ANSWER: (Refers to the explanation that answers the question by bringing together the concepts and methodology's conclusion)		
REFERENCES: (This refers to books, magazine articles, websites, etc., consulted and used in every part of the investigation)		
Self assessment (addition of all points) (You need to score all the points collected and compared against possible points)		

References

Bachelard, G. (1976). *El materialismo racional*. Buenos Aires: Paidos.

Bachelard, G. (1979). *La formación del espíritu científico*. México: Siglo XXI.

Calais, G. (2009). The Vee diagram as a problem solving strategy: Content area reading/writing implications. *National Forum Teacher Educational Journal, 19*, 1–8.

Camacho, J. P., & Cuéllar, L. H. (2007). La ley periódica analizada desde el modelo de Toulmin. Aportes para la enseñanza de la historia de la química. en Quintanilla M. (comp.). *Historia de la Ciencia. Propuestas para su enseñanza*, Vol II. (pp. 107–124). Santiago: Arrayan.

Chalmers, A. F. (1978). *What is this thing called science?*. Milton Keynes: Open University Press.

Chamizo, J. A. (2007a). Las aportaciones de S. Toulmin a la enseñanza de las ciencias. *Enseñanza de las ciencias, 25*, 133–146.

Chamizo, J. A. (2007b). Teaching modern chemistry through 'historical recurrent teaching models'. *Science & Education, 16*, 197–216.

Chamizo, J. A. (2009a). Heuristic diagrams as a tool to teach history of chemistry. In: *Proceedings from 10th international history and philosophy of science teaching group international conference*. South Bend, Indiana: Notre Dame University.

Chamizo, J. A. (2009b). Los diagramas heurísticos en la enseñanza de la historia de la química. In Z. Monroy & R. León-Sánchez (Eds.), *Epistemología, psicología y enseñanza de la ciencia*. México: UNAM.

Chamizo, J. A., & Colsa M. E. (2009). Heuristic diagrams as an assessment of experimental student learning tool. In *European science education research association conference*. Istanbul, ESERA.

Chamizo, J. A. (2010). *Introducción Experimental a la Historia de la Química*. Can be downland from http://www.joseantoniochamizo.com/educacion/index.html. Accessed 11 April 2011.

Chamizo, J. A., & Hernández, G. (2000). Construcción de preguntas, la Ve epistemológica y examen ecléctico personalizado. *Educación Química, 11*, 182–187.

Chamizo, J. A., & Izquierdo, M. (2007). Evaluación de las competencias de pensamiento científico. *Alambique, 51*, 9–19.

Cordova, J. L., Dosal, A., & Feregrino, V. (2007). La importancia de las preguntas. *Alambique, 54*, 16–27.

Crosland, M. P. (1978). *Historical studies in the language of chemistry*. New York: Dover.

De Berg, K. C. (1989). The emergence of quantification in the pressure–volume relationship for gases: A textbook analysis. *Science Education, 73*, 115–134.

Dominowski, R. L. (1998). Verbalization and problem-solving. In D. J. Hacker, J. Dunlosky, & A. C. Graesser (Eds.), *Metacognition in educational theory and practice* (pp. 25–46). Hillsdale, NJ: Erbalum.

Doran, R., Chan, F., Tamir, P., & Lenhardt, C. (2002). *Science educators's guide to laboratory assessment*. Arlington: NSTA Press.

Erduran, S., & Jiménez-Aleixandre, M. P. (2008). *Argumentation in science education. Perspectives from classroom-based research*. Dordrecht: Springer.

Escudero, C., & Moreira, M. A. (1999). La V epistemological aplicada a algunos enfoques en resolución de problemas. *Enseñanza de las Ciencias, 17*, 61–68.

Estany, A., & Izquierdo, M. (1990). La evolución del concepto de afinidad analizada desde el modelo de Toulmin. *Llull, 13*, 349–378.

Fox, R. (2007). Gowin's knowledege vee and the integration of philosophy and methodology: A case study. *The Journal of Geography in Higher Education, 31*, 269–284.

Frazer, M. J. (1982). Nyholm lecture: Solving chemical problems. *Chemical Society Reviews, 11*, 171–190.

Gabel, D. (1989). *What research says to the science teacher, Vol. 15. Problem solving*. Washington: NSTA Press.

Giere, R. N. (1999). *Science without laws*. Chicago: The University of Chicago Press.

Gowin, B., & Alvarez, M. C. (2005). *The art of educating with V diagrams*. Cambridge: Cambridge University Press.

Hacking, I. (1983). *Representing and intervening. Introductory topics in the philosophy of natural science*. Cambridge: Cambridge University Press.

Hattie, J. (2009). *Visible learning. A synthesis of over 800 meta-analyses relating to achievement*. London: Routledge.

Heise, R. D. (1970). The semantic differential and attitude research. In F. Gene (Ed.), *Attitude measurement* (pp. 235–253). Chicago: Rand McNally.

Henao, B. L., Stipcich, M. S., & Moreira, M. A. (2009). "Sustancia" en el devenir de la química: Dime cómo te buscan y te dire que eres. *Ciência & Educação, 15*, 497–514.

Herron, J. D., & Greenbowe, T. J. (1986). What we can due about Sue: A case study of competence. *Journal of Chemical Education, 63*, 526–531.

Hodson, D. (1994). Hacia un enfoque más crítico del trabajo de laboratorio. *Enseñanza de las Ciencias, 12*, 299–313.

Hofstein, A., Navon, O., Kipnis, M., & Mamlok-Naaman, R. (2005). Developing students' ability to ask more and questions resulting from inquiry-type chemistry laboratories. *Journal of Research in Science Teaching, 42*, 791–806.

Höttecke, D., & Celestino Silva, C. (2011). Why implementing history and philosophy in school science education is a challenge: An analysis of obstacles. *Science & Education, 20*, 293–316.

Husbands, C. (2003). *What is history teaching? Language, ideas and meaning in learning about the past*. Buckingham: Open University Press.

Jacob, C. (2001). Analysis and synthesis. Interdependent operations in chemical language and practice. *Hyle, 7*, 31–50.

Jensen, W. (1998). Logic, history, and the chemistry textbook iii. One chemical revolution or three? *Journal of Chemical Education, 75*, 961–969.

Justi, R. (2000). Teaching with historical models. In J. K. Gilbert & C. J. Boutler (Eds.), *Developing models in science education* (pp. 209–226). Dordrecht: Kluwer.

Justi, R., & Gilbert, J. (1999). History and philosophy of science through models: The case of chemical kinetics. *Science & Education, 8*, 287–307.

Keles, O., & Özsoy, S. (2009). Pre-service teachers' attitudes toward use of Vee diagrams in general physiscs laboratory. *International Electronic Journal of Elementary Education, 1*(3), 1–17.

Knight, D. (1992). *Ideas in chemistry. A history of the science*. New Brunswick: Rutgers University Press.

Knowlton, D.S. (2003). Preparing students for educated living: Virtues of problem-based learning across the higher education. In D. S. Knowlton & D. C. Sharp (Eds.) *New directions for teaching and learning problem-based learning in the information age,* Vol. 95 (pp. 5–12). San Francisco: Jossey-Bass.

Kragh, H. (1987). *An introduction to the historiography of science*. Cambridge: Cambridge University Press.

Latour, B. (1999). *Pandora's hope. Essays on the reality of science studies*. Cambridge: Harvard University Press.

Laudan, L. (1977). *Progress and its problems: Toward a theory of scientific growth*. Berkeley: University of California Press.

Laudan, L. (1990). *Science and relativism. Some key controversies in the philosophy of science*. Chicago: The University of Chicago Press.

Lin, H., & Chiu, H. (2004). Student understanding of the nature of science and their problem-solving strategies. *International Journal of Science Education, 26*, 101–112.

McComas, W. (2000). *The nature of science in science education. Rationales and strategies*. Dordrecht: Kluwer.

Novak, J. D., & Gowin, D. R. (1984). *Learning how to learn*. Cambridge: Cambridge University Press.

Osborne, J., Erduran, S., & Simon, S. (2004). Enhancing the quality of argument in school science. *Journal of Research in Science Teaching, 41*, 994–1020.

Otero, J., & Graesser, A. (2001). Elements of a model of questions asking. *Cognition and Instruction, 19*, 143–175.

Rios, G. (2011). *Las preguntas como estrategia didáctica*. Tesis de Maestria, México: UNAM.

Robson, C. (2002). *Real world research*. Oxford: Blackwell.

Rodgers, M., Runyon, D., Starret D., & Von Holzen R. (2006).The 21st century learner. In *Proceedings from the 22nd annual conference on distance teaching and learning*, Madison.

Sagan, C. (1997). *El mundo y sus demonios*. Barcelona: Planeta.

Schneider, F. (2006). Rubrics for teacher education in community college. *Community College Enterprise, 12*, 39–55.

Schummer, J. (1999). Coping with the growth of chemical knowledge: Challenges for chemistry documentation, education, and working chemists. *Educación Química, 10*, 92–101.

Schwab, J. J. (1962). *The teaching of science as inquiry*. Cambridge: Harvard University Press.

Sillitoe, J., & Webb, J. (2007). Facilitating the active interplay between the conceptual and methodological aspects of a higher degree research project-Gowin's Vee heuristic. In *Enhancing higher education theory and scholarship, proceedings of the 30th HERDSA annual conference*, Adelaide, 8–11 July.

Tague, J., Beheshti, J., & Rees-Potter, L. (1981). The law of exponential growth: Evidence, implications, and forecasts. *Library Trends, 30*, 125–150.

Tiles, M. (1984). *Bachelard: Science and objectivity*. Cambridge: Cambridge University Press.

Toulmin, S. (1972). *Human understanding*. Princeton: Princeton University Press.

Toulmin, S. (2003). *The uses of argument*. Cambridge: Cambridge University Press.

Trowbridge, J. E., & Wandersee, J. H. (1998). Theory-driven graphic organizers. In J. J. Mintzes, J. H. Wandersee, & J. D. Novak (Eds.), *Teaching science for understanding* (pp. 95–128). San Diego: Academic Press.

Valk, T., & Jong, O. (2009). Scaffolding science teachers in open-inquiry teaching. *International Journal of Science Education, 31*, 829–850.

van Berkel, B., de Vos, W., Veronk, A. H., & Pilot, A. (2000). Normal science education and its dangers: The case of school chemistry. *Science & Education, 9*, 123–159.

Wandersee, J. H. (1990). Concept mapping and the cartography of cognition. *Journal of Research in Science Teaching, 27*, 923–936.

Wandersee, J. H., & Baudoin Griffard, P. (2002). The history of chemistry: Potential and actual contributions to chemical education. In J. K. Gilbert, et al. (Eds.), *Chemical education: Towards research-based practice* (pp. 29–46). Dordrecht: Kluwer.

Watts, M. (1991). *The science of problem-solving. A practical guide for science teachers*. London: Cassell.