Chapter 4

Review on Research done in the field

Introduction

The development of adequate student conceptions of the nature of science has been a perennial objective of science instruction regardless of the currently advocated pedagogical or curricular emphases. Consequently, it has been an area of prolific research characterized by several parallel, but distinct, lines of investigation. Presently, despite their varying pedagogical or curricular emphases, agreement among the major reform efforts in science education (e.g., American Association for the Advancement of Science [AAAS], 1990; National Research Council [NRC], 1996) centers around the goal of enhancing students' views of nature of science.

Although the belief in the importance of students' understandings of the nature of science has persisted throughout the 20^{th} century, assessments of students' conceptions did not commence until 1954 (Lederman, 1992).

In fact, there is a vast literature on education, a fraction of which reports research findings. That research literature is spread across different fields of study, grade levels, kinds of schools, and aspects of education. Studies dealing with the learning of specific science, mathematics, or technology content, while small compared to the whole body of educational literature, is growing in number and sophistication.

Among the research literature found to be very helpful for my research start, were the followings:

1. The nature of science research literature from the online report *Science for all Americans* (AAAS, 1993).
2. Duit (2002. 550 pp) and Duit & Pfundt (1991. 270 pp) of the IPN – Leibniz Institute for Science Education at the University of Kiel, Germany and;
3. The nature of science articles published in the English science education journals in 2003 and 2004, such as Science Education, Journal of Research in Science Teaching and the International Journal of Science Education.

11 Science for All Americans (SFAA) literature relative to the nature of science.

Research on students' understanding of the nature of science has been conducted for more than 30 years. The earlier part of the research investigated students' understanding about scientists and the scientific enterprise and about the general methods and aims of science (Cooley & Klopfer, 1961; Klopfer & Cooley, 1963; Mackey, 1971; Mead & Metraux, 1957; Welch & Pella, 1967). More recent studies have added students' understanding of the notion of "experimentation," the development of students' experimentation skills, students' understanding of the notions of "theory" and "evidence," and their conceptions of the nature of knowledge. The available research is reviewed in Lederman (1992). Note that this review only covers the research published in English language.

Research on the nature of science focuses mainly on the middle school and high-school grades. There are few studies that investigate what elementary-school learning experiences are effective for developing an understanding of the nature of science, although

Susan Carey's and Joan Solomon's work is a beginning in that direction (Carey, Evans, Honda, Jay, & Unger, 1989; Solomon, Duveen, Scot, McCarthy, 1992).

Research in the 1960s and 70s used multiple-choice questionnaires. Recent studies using clinical interviews reveal discrepancies between researchers' and students' understanding of the questions and the proposed answers in those questionnaires. This finding raises doubt about the earlier studies' findings because almost none of them used the clinical interview to corroborate the questionnaires. Therefore, the following remarks draw mainly upon the results of the relatively recent interview studies.

11. 1 The Scientific World View.

Although most students believe that scientific knowledge changes, they typically think changes occur mainly in facts and mostly through the invention of improved technology for observation and measurement. They do not recognize that changed theories sometimes suggest new observations or reinterpretation of previous observations (Aikenhead, 1987; Lederman & O'Malley, 1990; Waterman, 1983). Some research indicates that it is difficult for middle-school students to understand the development of scientific knowledge through the interaction of theory and observation (Carey et al., 1989), but the lack of long-term teaching interventions to investigate this issue makes it difficult to conclude that students can or cannot gain that understanding at this grade level.

11. 2 Scientific Inquiry.

Experimentation.

Upper elementary- and middle-school students may not understand experimentation as a method of testing ideas, but rather as a method of trying things out or producing a desired outcome (Carey et al., 1989; Schauble et al., 1991; Solomon, 1992). With adequate instruction, it is possible to have middle-school students understand that experimentation is guided by particular ideas and questions and that experiments are tests of ideas (Carey et al., 1989; Solomon et al., 1992). Whether it is possible for younger students to achieve this understanding needs further investigation.

Students of all ages may overlook the need to hold all but one variable constant, although elementary students already understand the notion of fair comparisons, a precursor to the idea of "controlled experiments" (Wollman, 1977a, 1977b; Wollman & Lawson, 1977). Another example of defects in students' skills comes with the interpretation of experimental data. When engaged in experimentation, students have difficulty interpreting co-variation and non co-variation evidence (Kuhn, Amsel, & O'Loughlin, 1988). For example, students tend to make a causal inference based on a single concurrence of antecedent and outcome or have difficulty understanding the distinction between a variable having no effect and a variable having an opposite effect. Furthermore, students tend to look for or accept evidence that is consistent with their prior beliefs and either distort or fail to generate evidence that is inconsistent with these beliefs. These deficiencies tend to mitigate over time and with experience (Schauble, 1990).

Theory (explanation) and evidence.

Students of all ages find it difficult to distinguish between a theory and the evidence for it, or between description of evidence and interpretation of evidence (Allen, Statkiewitz, & Donovan, 1983; Kuhn 1991, 1992; Roseberry, Warren, & Conant, 1992). Some research suggests students can start understanding the distinction between theory and evidence after adequate instruction, as early as middle school (Roseberry et al., 1992).

Nature of knowledge.

Students' ideas about the nature of knowledge and how knowledge is justified develop through stages in which knowledge is initially perceived in terms of "right/wrong," then as a matter of "mere opinion," and finally as "informed" and supported with reasons (Kitchener, 1983; Perry, 1970). This research provides some guidance for sequencing the benchmarks about the nature of scientific knowledge. For example, it suggests that students may not understand before they abandon their beliefs about knowledge being either "right" or "wrong" that scientists can legitimately hold different explanations for the same set of observations. However, this research does not say when, how quickly, and with what experiences students can move through these stages given adequate instruction. Several studies show that a large proportion of today's high-school students are still at the first stage of this development (Kitchener, 1983; Kitchener & King, 1981). Further research is needed to specify what school graduates could understand, if from a young age they were taught that different people will describe or explain events differently and that opinions must have reasons and can be challenged on rational grounds.

11. 3 The Scientific Enterprise.

When asked to describe their views about science in general, high-school students portray scientists as brilliant, dedicated, and essential to the world. However, when asked about science as a career, they respond with a negative image of scientific work and scientists. They see scientific work as dull and rarely rewarding, and scientists as bearded, balding, working alone in the laboratory, isolated and lonely (Mead & Metraux, 1957). This image of scientists has also been frequently documented among elementary- and middle-school students (Fort & Varney, 1989; Newton & Newton, 1992). Some research suggests that this image may represent students' knowledge of the public stereotype rather than their personal views and knowledge of science and scientists (Boylan, Hill, Wallace, & Wheeler, 1992).

Some students of all ages believe science mainly invents things or solves practical problems rather than exploring and understanding the world. Some high-school students believe that moral values and personal motives do not influence a scientist's contributions to the public debate about science and technology and that, scientists are more capable than others to decide those issues (Aikenhead, 1987; Fleming 1986a, 1986b, 1987).

12 Duit's bibliography on to the nature of science.

The second bibliography search was the *Students' Alternative Frameworks and Science Education*, by Helga Pfundt and Reinders Duit. Kiel, Germany: Institute for Science Education at the University of Kiel (1991. 270 pp). The bibliography documents and categorizes research into students' conceptions in science. It contains about 2000 citations to journal articles, research reports, conference papers and whole books on students' learning in physics, biology, chemistry, and earth science. Entries are classified by type of issue. Issues include general considerations concerning research on students' conceptions, relations between students' conceptions and scientific conceptions; relations between the development of student conceptions and the development of notions in the history of science, relations between everyday language and students' conceptions, methods of investigation, investigations of students' conceptions, instruction taking students' conceptions into account, investigations of teachers' conceptions, and consequences of students' conceptions research on teacher training. Investigations of students' and teachers' conceptions are further classified by content area.

Furthermore, Duit (2002) have collected in 550 pages (around 6000 references) all researches since the 1940s about *Students' and Teachers' Conceptions and Science Education* (STCSE).

The most influential reviewed literature related to the history and the nature of science that inspired my study will be presented below in details. My aim here is to present the previous researches done in the field and not to discuss them.

13 The research of Joan Solomon's group.

13. 1 A synopsis of Solomon's article about "Teaching about the nature of science in the British National Curriculum" (1991).

In her article, Solomon argued how science education in Britain became "something of a cautionary tale for modern times" after being "one of the most free and inventive enterprises in the education business". Note that Solomon research context was the implementation of the British National Curriculum.

For Solomon, it is worthwhile to examine the arguments, which have been put forward for teaching *about* science, which are: history of science, children's epistemologies, problems in teaching science, progression through the levels, methods of teaching and meta-learning.

For Solomon, little history of science has been taught in British schools. What did survive from the wave of changes in the public optional History of Science examination, was a course in Science Technology and Society (STS), that used historical examples to study the social issues of our times; for instance, living conditions at the time of the Industrial Revolution is used to illustrate the effects of industry on lifestyle and the environment.

Moreover, there is a far child-centered view that history provides a "scientist as hero" complement to classroom practice. Anecdote suggests that there is indeed much to recommend this view for the motivation that it induces.

Children's epistemologies are more substantial arguments in Solomon opinion that can be mustered for the inclusion of material, which directly addresses the knowledge on the nature of scientific knowledge. Instead of including some aspects of the philosophy of science in the curriculum, there has been the trend in curriculum rhetoric to call for more teaching of the processes of science in the hope, perhaps, that by applying observation, experiment, data analysis, and pattern-seeking in their own learning, the students would come to associate related features with scientific knowledge. Attitude research shows, that students' rate science as very difficult, and other studies show that scientists are popularly thought to be unusually clever. Solomon questioned: "would students readily assume that their own faltering attempts to learn what they see as already known, were similar to the processes by which science has advanced?"

According to Solomon, what is still unknown is how younger children, of junior high school age, who are just beginning to learn science, can be helped to take serious note of their variety of interpretations of experimental evidence, their attempts to understand and use conceptual tools, and the predictions from hypothesis from which they are urged to design further laboratory work. Solomon made an interesting question, which is: "if the meta-level of learning is made explicit to the students, will they then be able to relate it to the activities of scientists?"

Before the 1980s, many school children were taught the great theories of science – for example, Newton's laws of Motion – by first writing them at dictation speed, and then by doing experiments to "verify" them. Little snippets of history might occasionally have been added on to give more luster to the scientists and their scientific theories. But this historical gloss usually showed the students know almost nothing at all how science develops, and hence about the nature of science. By the mid-1980s science classrooms became the site of open-ended experiments, which were often disconnected from theory. The students had been busy "problem-solving" in the technological sense: which paper towel absorbs more water? Or, which surface is more slippery? There was much talk about teaching the "processes of science", as though all of these were experimental skills. The question here is: "were we equally sure that they were learning about the power of scientific theories?"

For Solomon, to understand the nature of science, it is best to confine attention to the statements of level arranged in a progression from 4 (which might be appropriate for 11 to 12-year-olds) to 10 (which only the most gifted of 16-year-olds are expected to achieve), as tabulated below. Note that the levels 4 to 10, or the expected competence levels, are mentioned in the Attainment Target related to *The Nature of Science*:

Thinking about Experimental Work	**Thinking about science Past and Present**
	Level 4: the story of a scientific advance
Level 5 … Discuss interpretations… of experiments	Level 5
Level 6 … Explanation and prediction … from a model	Level 6
Level 7: Evidence and imagination	Level 7: A change in theory
	Level 8: Science from different cultures and times
Level 9 … prediction from theory … and generalization	
	Level 10: Uncertainty and difference of opinion

Solomon thought that there are two themes running through the nature of science; one concerns reflection on school experiment, and the other is about reflecting on aspects of scientific theory in different ages. That's why it is important to discern a track and a progression for the students as they work through this Attainment Target in the science of the national British curriculum. Indeed, there are twin-teaching threads within it, which indicate two different approaches to teaching about the nature of science. One thread concerns the students' own experience of science, the other travels further afield.

Solomon suggested introducing some historical material into the work on one of the other attainment targets. It might be the story of how Blaise Pascal set up his enormous 10-m high barometers of water and wine; or how he had a mercury barometer taken up a high mountain to try out his prediction that it was atmospheric pressure, and not action connected with a vacuum, which held up the liquid. Children at the lower levels of achievement might later remember little of it except the story and the people involved in it (Level 4). At a slightly higher level they might remember the different interpretations for the space above the liquid (Level 5), or the theories, which changed due to different ways of imagining what was happening (Level 7). This kind of "stepping outside" our worldview will probably be achieved by fewer of the students (Level 8). The modeling of atmospheric pressure acting in all directions will be more advanced still. Solomon advocated that all those different levels of achievement are possible reactions to a single presentation of material.

Solomon believed that stories motivate some children and that stories from the past can add a personal element to science, which is often lacking. For instance, the hard working figure of Marie Curie will motivate the girls' students, who have rarely enjoyed school science as much as the boys. Solomon argued that by encouraging students to read in science lessons, we could inculcate a habit of reading about scientific issues that would be a most valuable outcome.

Finally, Solomon cited one of the valuable results at the teaching level, of the CLIS (Children's Learning in Science) project of Driver & Oldham made in 1985, which is, children do seem to show interest in *how* they are learning science. Solomon suspected that meta-knowledge about science, obtained in the process of learning it, is less difficult to achieve than is meta-knowledge about science education.

13. 2 Solomon's article about "Teaching about the nature of science through history: action research in the classroom" (1992).

Solomon et al. article reports on 18 months research that monitored British pupils' learning about the nature of science, using some aspects of history of science for the purpose.

This research was stimulated by the publication of the National Curriculum for England and Wales, which contained a section on the nature of science, including history of science. In fact, the aim of the historical aspect of Solomon et al. work was to observe and record how learning science through historical studies might not only affect students' understanding of the nature of science, but also their learning of scientific concepts. Because, the requirement to teach history of science found in the British school system largely unprepared and there were not only almost no classroom resources, but also it was also uncertain what the effects of teaching it might be. Worse still, it was not even clear precisely what the defects were in the students' understanding of the nature of science that this addition to the curriculum was supposed to remedy.

The researchers used elements of three different kinds of research methodologies: (a) intervention study, where a new element was introduced and its effect monitored; (b) action research, where a researcher worked alongside the teacher during the classroom sessions on a regular basis, where the researcher was a partial observer trying to recognize and bring about good practice, and (c) experimental research, where impartial observation and measurement were designed to probe and explain the progress of pupil understanding.

The first line of Solomon et al. research was in collecting students' perceptions of scientists and their work. Scientists in students' pictures had often bandages on their faces. Solomon et al. referred it to *serendipitous empiricism.* The second line of research involved free writing in response to questions about why scientists did experiments, and whether or not they knew what they expected to happen before they did an experiment based on some of Citro's work (1990). The questionnaire was administered to 400 students and the researchers found out that frequent negative responses to the second question demonstrated a thoughtless "shot-in-the-dark" attitude toward experimental investigation. The questionnaire was used as a pre- and post-course test in order to provide ancillary quantitative data for evaluating the classroom research.

The followings are the pre- and post-course questions:

1. Why do you think scientists do experiments?
    a) To make new discoveries

    b) To try out their explanations for why things happen
    c) To make something which will help people
2. Do you think scientists know what they expect to happen before they do an experiment?
    a) Yes
    b) No
    c) Don't know
3. What is a scientific theory? Is it:
    a) An idea about what will happen?
    b) An explanation about how things happen?
    c) A fact which has been proved by many experiments?
4. Sometimes in the past, groups of scientists have held different theories. Is this because:
    a) They have done different experiments?
    b) One group was wrong and the other group was right?
    c) One group made a mistake in their experiments?

Preliminary findings about the common perceptions of the nature of science held by middle school students (age 11-14 years) guided the work. The empirical study of students' progress was the main focus in Solomon et al. research, because there was little close exploration of the growth of students' understanding while the historical teaching was carried out, or of the summative effects of such a course in previous researches. The action research took place within five classrooms distributed in three different schools and involved practicing teachers who used a set of historical materials written for specially written for the study. The classroom materials consisted of 13 units and involved topics that would be needed to be taught at this stage in the National Curriculum and they taught them in an historical context. The researchers included also practical laboratory investigations, whenever this was possible.

The variety of teaching was also increased by allowing the teachers free choice of any 6 of the 13 units, so that these could be accommodated by the scheme of work with the least possible disruption. For instance, the first unit, called *Mountains on the moon*, may give some idea of the character of the materials: the story of how the telescope was discovered and then used by Galileo is set in eight short sections. The first tells how lenses were first used by medieval monks for reading, goes on through the Dutch discovery of the telescope to Galileo's improvement of its magnification, and his recommendation of it to the ruler of Venice for military use. The later sections cover how Galileo saw shadows on the moon growing longer night after night, interpreted them as evidence for mountains, and calculated the heights of these. The class reads the whole story, and then each group of pupils makes a poster to show the content of their section of it. These posters are exhibited around the classroom. A model of the moon is made from a soccer ball embellished with mountains and craters made from modeling wax. It is illuminated from one side by a projector beam and is observed by the students. Finally the pupils design and carry out their own practical investigations showing how the measured lengths of shadows are affected by the height of the object and the inclination of the light.

Before the course began, students were interviewed about their answers to the questionnaire. The researchers found that students have little or no knowledge about scientists, past or present and that they are unfamiliar with the word *theory* and, as their questionnaire shows, they can give no examples of scientific theory. The intervention materials addressed all of these problems.

After the course, the populist images of scientists still existed, but by then, students also had access to stories about real scientists, their theories and experiments.

Results of this study before and after the year's course showed that:

1. There is a significant movement away from seeing the purpose of an experiment as making a discovery, and toward seeing it for trying out explanations.
2. Significantly more students after the teaching approach think that scientists know what they expect to happen in an experiment than did before the course.
3. Far fewer now think that a theory is a fact, with both "an idea" and "an explanation" being more favored answers.
4. Both types of data collected, numerical and interview, offer substantial evidence that the units for teaching the history of science within the normal school curriculum made a valuable contribution to the students' understanding of the nature of science. In particular, there is a significant move away from serendipitous empiricism and toward an appreciation of the interactive nature of experiment and theory. Experiments are seen to be designed for trying out explanations, and hence carry an expectation about what may happen. The theories the students hold are now less likely to be just facts, but, like experiments, are related to explanation or prediction.
5. Teachers' unanimous view was that their students had learned some concepts better through studying them in the controversial situations in which they first arouse.
6. The researchers found some evidence both in the end-of-year interviews, and in responses to question which asked for recollection of a scientific theory, that helping the pupils to focus on the *reasons* for accepting one theory rather than another was more effective than just teaching accepted theory. Using the historical materials does seem to have produced more durable learning.
7. Finally, the researchers acquired new and unexpected evidence from interviews that studying the history of a change in theory may make the process of conceptual change a little easier.

13. 3 Solomon' speech "the importance of stories" at the British Society of History of Science (BSHS) conference held at the Royal Society (2000).

Solomon stressed again in her speech to let the pupils read stories. She hoped "we will have <u>stories from the history of science</u> and we will have <u>new science</u> because both these are things which have been missing very badly from school science for a long time".

She advocated that "if we can do it, it will be far better than dragging our students through explicitly-taught laws about science, and philosophical themes that they need to follow, and what we mean when we say that something is valid evidence … and then, presumably, we test it in Science and Technology in Society (SATIS). I think what we really need is stories. Because stories tell it all without pain".

Solomon believed that " if we could provide stories in a science setting – stories which raise the blood pressure, bring a tear to the eye, and provide intriguing scientific figures to follow, it would do much more than improve that rather dull thing that we call 'the public understanding of science'. It would embed our science in the shared culture we all have, and that is the important basis for all kinds of scientific literacy".

Solomon argued that " people's thirst for stories about heroes (who are just people, but writ large) must have started with the dawn of culture itself, and indeed it is stories which build up our culture. They teach us, and our children, about how things could be if only we too were heroes. They show us morality, perhaps spirituality, and they feed our ambitions.

Stories bring about almost all the ideas that we want our youngsters to absorb about human values and justice and sympathy with the wide variations of the human condition".

14 The research done in Norman Lederman's group.

14. 1 About "students' and teachers' conceptions of the nature of science: a review of the research" (1992).

The overall purpose of Lederman's article is to help clarify what has been learned about students' and teachers' nature of science and to elucidate the basic assumptions and logic which have guided earlier research efforts. Finallly, recommendations related to both methodology and the focus of future research is offered. Note that Lederman' s focus is about promoting the nature of science for K-12 students.

Lederman made a detailed review of the English language literature since the 1950s concerning the nature of science and he addressed the following questions: what have we learned? And where are we heading?

He namely mentioned the study of Mead and Metraux (1957) who made the most extensive attempt to assess students' conceptions about "what do you think about science and scientists?" and the development of the questionnaire TOUS in 1961 by Klopfer and Cooley; a paper-and-pencil test on students' understanding of science…

From the various researches, Lederman concluded that students did not possess adequate conceptions of the nature of science or scientific reasoning and that promoting accurate students' understanding of the nature of science is a primary objective of science education. Two distinct lines of research immediately followed the previous researches. Initially, student alternative conceptions were attributed to the lack of instructional procedure/approaches specifically designed to convey accurate conceptions of science. Consequently, there was a concerted effort to develop and assess the effectiveness of curricula designed to foster accurate conceptions of science. Shortly thereafter, some researchers turned their attentions to the teachers' conceptions, because it was concluded that teachers are the ones who mediate the curriculum.

The results of the initial research on the nature of science may be summarized as follows: (a) science teachers do not possess adequate conceptions of the nature of science, irrespective of the instrument used to assess understandings; (b) techniques to improve teachers' conceptions have met with some success when they have included either historical aspects of scientific knowledge or direct attention to the nature of science; and (c) academic background variables are not significantly related to teachers' conceptions of the nature of science.

Initial assessments of students' conceptions indicated that students did not possess adequate understandings of the nature of science and led to the conclusion that science teachers must not be attempting to teach the nature of science. In 1963, Cooley and Klopfer initiated a second line of research focusing around curriculum development and assessment. The results of this movement were equivocal. That is, the same curriculum was effective for one teacher with a particular group of students, but not for another teacher with a different group of students. The appropriate conclusion was that the individual science teacher must make a difference. Predictably, a subsequent line of research of research focused on the assessment of teachers' conceptions. The assessment of teachers' conceptions indicated that they did not possess the desired level of understanding, according to AAAS Standards for K-12 students. Subsequent researches indicated that the most variables that influence student's beliefs about the nature of science are those specific instructional behaviors, activities, and decisions implemented within the context of a lesson. It appeared also that continued stress on higher-level questioning within a supportive risk free environment are at least related to desired changes in students' conceptions. Debate still surrounds the issue of whether a teacher's understanding of the nature of science is directly related to the development and/or performance of any of the aforementioned variables or other aspects of classroom practice.

As a consequence of the lines of the reviewed researches, it appears to be an overt insight that teachers can not teach what they do not understand, and that simply possessing the desired knowledge does not ensure its effective communication to students.

Lederman remarked that previous researches on students' and teachers' conceptions of science (the early years between 1950-1983) were often chaotic, as opposed to coordinated and progressive.

Finally, Lederman concluded that there appears to be some consensus among researchers concerned with the nature of science that the influence of teachers' conceptions on classroom practice is mediated by a complex set of factors (such as curriculum constraints, administrative policies, teachers' attitudes about students and learning, etc.). He recommended that we must not attempt to impose a particular view of science on teachers and students as if it was more informed or unchanging. Rather, ways to communicate both the changing nature of science, as well as its various forms, must be included along with any attempt to change teachers' or students' conceptions of scientific knowledge.

14. 3 About "avoiding de-natured science: activities that promote understandings of the nature of science" (1998).

In the book edited by McComas, Lederman's opinion is that a functional understanding of the nature of science and/or scientific inquiry can be best facilitated through an explicit reflective approach. Lederman and Abd-El-Khalick proposed a set of activities designed to model an explicit approach to teaching crucial aspects of the nature of science, e.g., the tentative nature of science, difference between observation and inference. These activities have been successfully used with students at the elementary, middle, and high school levels (K-12) students and science teachers. They can be used to convey to students and pre-service or in-service science teachers adequate notions of the nature of science. Moreover, the notions advocated in these activities were designed at a level of generality that renders them virtually non-controversial. In addition, the scientific knowledge prerequisite is minimal to remove the constraints on using the activities.

Some included activities are the "Black box", "Real fossils, Real science", "Tricky tracks!" activities. The latter conveys to students the message that every idea counts irrespective of it being the 'correct' answer. Students completing this activity will gain experience in distinguishing between observation and inference and realizing that, based on the same set of evidence (observations, or data), several answers to the same question may be equally valid. This activity will be an introductory lesson of my teaching sessions, thus it will be described and discussed in details in chapter VI.

14. 4 About "views of nature of science questionnaire: toward valid and meaningful assessment of learners' conceptions of nature of science" (2002).

The authors of this article (Lederman, Abd-El-Khalick, Bell & Schwartz) have developed a new open-ended instrument, the Views of Nature of Science Questionnaire (VNOS), which in conjunction with individual interviews aims to provide meaningful assessments of learners' nature of science views. The VNOS comes in response to some calls within the science education community to go back to developing standardized forced-choice paper and pencil nature of science assessment instruments designed for mass administrations to large samples.

14. 3. 1 Description of the Questionnaire: Views of Nature of Science (VNOS).

The Views of Nature of Science Questionnaire (VNOS) has three versions, all of which are open-ended. The most frequently used versions are the VNOS–B (seven items) and the VNOS–C (ten items). Each instrument aims to elucidate students' views about several aspects of "nature of science" (NOS). These NOS aspects include the:

- Empirical NOS: Science is based, at least partially, on observations of the natural world;
- Tentative NOS: Scientific knowledge is subject to change and never absolute or certain;
- Inferential NOS: The crucial distinction between scientific claims (e.g., inferences) and evidence on which such claims are based (e.g., observations);
- Creative NOS: The generation of scientific knowledge involves human imagination and creativity;
- Theory-laden NOS: Scientific knowledge and investigation are influenced by scientists' theoretical and disciplinary commitments, beliefs, prior knowledge, training, experiences, and expectations;
- Social and cultural NOS: Science as a human enterprise is practiced within, affects, and is affected by, a lager social and cultural milieu;
- Myth of the "Scientific Method": The lack of a universal step-wise method that guarantees the generation of valid knowledge; and
- Nature of, and distinction between scientific theories and laws (e.g., lack of a hierarchical relationship between theories and laws).

The authors suggest that the VNOS–B and the VNOS–C be administered under controlled conditions (such as a classroom setting) and with sufficient time (less than one hour). They suggest that the instruments not be used for summative assessments (i.e., as a final determination of student conceptions or views) and that the users inform the students that there are no right or wrong answers. The researchers strongly recommend that administrations of the VNOS be coupled with follow-up individual interviews to insure the validity of the instrument.

The VNOS–B was tested for construct validity (i.e., capacity of the instrument to measure what it intends to measure). The researchers administered the VNOS–B to two groups of nine participants each: a novice group and an expert group. After the interviews, researchers discovered clear differences in the expert vs. novice responses regarding nature of science. The instrument was further modified and expanded for the VNOS–C. A panel of five experts examined the items for content validity and the items were modified accordingly. Profile comparisons indicated that interpretations of participants' views as elucidated on the VNOS–C were congruent to those expressed by participants during individual interviews.

14. 3. 2 The Tool.

VNOS - Form B

1. After scientists have developed a theory (e.g. atomic theory), does the theory ever change? If you believe that theories do change, explain why we bother to teach scientific theories. Defend your answer with examples.

2. What does an atom look like? How certain are scientists about the nature of the atom? What specific evidence do you think scientists use to determine what an atom looks like?

3. Is there a difference between a scientific theory and a scientific law? Give an example to illustrate your answer.

4. How are science and art similar? How are they different?

5. Scientists perform experiments/investigations when trying to solve problems. Other than the planning and design of these experiments/investigations, do scientists use their creativity and imagination during and after data collection? Please explain you answer and provide examples if appropriate.

6. Is there a difference between scientific knowledge and opinion? Give an example to illustrate your answer.

7. Some astronomers believe that the universe is expanding while others believe that it is shrinking; still others believe that the universe is in a static state without any expansion or shrinkage. How are these different conclusions possible if all of these scientists are looking at the same experiments and data?

VNOS - Form C

1. What, in your view, is science? What makes science (or a scientific discipline such as physics, biology, etc.) different from other disciplines of inquiry (e.g., religion, philosophy)?

2. What is an experiment?

3. Does the development of scientific knowledge require experiments?
   If yes, explain why. Give an example to defend your position.
   If no, explain why. Give an example to defend your position.

4. After scientists have developed a scientific theory (e.g., atomic theory, evolution theory), does the theory ever change?
   If you believe that scientific theories do not change, explain why. Defend your answer with examples.
   If you believe that scientific theories do change: (a) Explain why theories change; (b) Explain why we bother to learn scientific theories. Defend your answer with examples.

5. Is there a difference between a scientific theory and a scientific law? Illustrate your answer with an example.

6. Science textbooks often represent the atom as a central nucleus composed of protons (positively charged particles) and neutrons (neutral particles) with electrons

(negatively charged particles) orbiting the nucleus. How certain are scientists about the structure of the atom? What specific evidence do you think scientists used to determine what an atom looks like?

7. Science textbooks often define a species as a group of organisms that share similar characteristics and can interbreed with one another to produce fertile offspring. How certain are scientists about their characterization of what a species is? What specific evidence do you think scientists used to determine what a species is?

8. It is believed that about 65 million years ago the dinosaurs became extinct. Of the hypothesis formulated by scientists to explain the extinction, two enjoy wide support. The first, formulated by one group of scientists, suggests that a huge meteorite hit the earth 65 million years ago and led to a series of events that caused the extinction. The second hypothesis, formulated by another group of scientists, suggests that massive and violent volcanic eruptions were responsib le for the extinction. How are these different conclusions possible if scientists in both groups have access to and use the same set of data to derive their conclusions?

9. Some claim that science is infused with social and cultural values. That is, science reflects the social and political values, philosophical assumptions, and intellectual norms of the culture in which it is practiced. Others claim that science is universal. That is, science transcends national and cultural boundaries and is not affected by social, political, and philosophical values, and intellectual norms of the culture in which it is practiced.
If you believe that science reflects social and cultural values, explain why. Defend your answer with examples.
If you believe that science is universal, explain why. Defend your answer with examples.

10. Scientists perform experiments/investigations when trying to find answers to the questions they put forth. Do scientists use their creativity and imagination during their investigations?
If yes, then at which stages of the investigations do you believe scientists use their imagination and creativity: planning and design, data collection, after data collection? Please explain why scientists use imagination and creativity. Provide examples if appropriate.
If you believe that scientists do not use imagination and creativity, please explain why. Provide examples if appropriate.

14. 4 About "the influence of history of science courses on students' views of nature of science" (2000).

Abd-El-Khalick and Lederman' s purpose of this study was (a) to assess the influence of college-level history of science courses on college students' and prospective secondary science teachers' conceptions of nature of science, (b) to examine whether participants who entered the investigated courses with a conceptual framework consistent with contemporary nature of science views achieved more elaborated nature of science understandings, and (c) to explore the aspects of the participant history of science courses that rendered them more "effective" in influencing students' vies. Three research questions guided this investigation:

1. Do history of science courses influence students' conceptions of nature of science? If yes, in what ways?
2. Are students, including student teachers, who enter history of science courses with a conceptual framework consistent with current conceptions of the scientific enterprise

more likely to achieve, if any, more adequate and enriched understandings of nature of science?

3. To what extent, if any, do various history of science aspects influence their effectiveness in influencing students' conceptions of nature of science? These aspects included (a) course objectives, (b) instructor priorities, such as the commitment to enhance learners' nature of science conceptions, (c) teaching approach, such as explicit attention to nature of science or striving to help students develop alternate ways of reading history of science, and (d) classroom dynamics, such as large, lecture-oriented versus small, discussion-oriented courses.

The participants were 166 undergraduate and graduate students and 15 pre-service secondary science teachers. Their ages ranged from 19 to 45 years. An open-ended questionnaire in conjunction with individual follow-up semi-structured interviews was used to assess participants' pre- and post-instruction nature of science views.

The history of science courses was: "Studies in scientific controversy" that focuses on accounts of controversial scientific discoveries. Using case studies from the 17^{th} through the 20^{th} century, the course aims to highlight the rational, psychological, and social characteristics that have typified the meaning and methods of the natural sciences. The second course "History of science" focuses on the interaction of scientific ideas with their social and cultural contexts. The course covers the period from ancient civilization to the post-Roman era. The third course "Evolution and modern biology" focuses on the origin and development of Darwin's theory of evolution. The course also explores the reception and history of evolution theory from its inception to the present. The courses were taught by three history of science professors. Additionally, the history of science professors were also interviewed to generate in-depth profiles of their of their respective course, to identify the course objectives, instructor priorities, historical approach used, and the instructor's views on the relationship between history of science, science, and science teaching.

Almost all participants held inadequate views of several nature of science aspects at the outset of the study. Very few and limited changes in participants' views were evident at the conclusion of the courses.

Change was evident in the views of relatively more participants, especially pre-service science teachers, who entered the history of science courses with frameworks that were somewhat consistent with current nature of science views. Moreover, explicitly addressing certain nature of science aspects rendered the history of science courses relatively more effective in enhancing participants' nature of science views.

The results of this study do not lend empirical support to the intuitively appealing assumption held by many science educators that coursework in history of science will necessarily enhance students' and pre-service science teachers' nature of science views. However, *explicitly* addressing specific nature of science aspects might enhance the effectiveness of history of science courses in this regard. Moreover, the study suggests that exposing pre-service science teachers to explicit nature of science instruction in science methods courses prior to their enrollment in history of science courses might increase the likelihood that their nature of science views will be changed or enriched as a result of their experiences with history of science.

15 The research group of Riess on higher education and history of physics, at Carl von Ossietzky University, Oldenburg, Germany.

The aim of the Research Group on Higher Education and History of Science in Oldenburg has been twofold: first, they try to push studies of past experimental practices further ahead. They still need to learn more about different aspects of experiments and their role in the production of scientific knowledge. The group's approach is based - in most cases - on 'replications' of historical experiments. They reconstruct historical set-ups, re-do the experiments, analyse our experiences in the light of historical descriptions and compare them with other sources and documents. Secondly, the research group uses replicas in school and university education as well as in various public presentations – ranging from exhibition to film and theatre.

During the last years, the group has developed some teaching modules with an emphasis on history dealing especially with historical instruments and the way how they can be used at school. The research group promotes a so called "historisch-genetischer" (historio-genetic) approach in science teaching, i.e. modern physical concepts should be taught and learned by reflecting on their historical development. However, they put a special emphasis on experimental work. In the workshop, the participants could experiment with replicas of historical experimental set-ups, mainly from the history of electricity, for instance, replicas such as the Leyden jars, the rotation apparatus of Faraday (Höttecke, 2000).

These instruments may serve to demonstrate some connections between scientific cultures and wider cultural fields of meaning and meaning production. Their approach serves again a twofold purpose: It is a plea for an alternative way to present instruments and experiments in a public space and, on the other hand to study the history of science and the opportunities they offer to popularise science and the history of science.

In summer 1998, the group set up an exhibition at a local museum (The *Museum of Natural History and Pre-History* in Oldenburg). It was entitled 'Welt erforschen - Welten konstruieren: Physikalische Experimentierkultur vom 16. bis 19. Jahrhundert (Exploring the World, Constructing Worlds: Cultures of Experimental Physics from the 16^{th} to the 19^{th} Century). Remarkably, most of these projects were organised and realised mainly by students of the physics and the history department.

Selected replicas were shown together with original instruments, which were supplied by museums in Austria, the Netherlands and Germany. Additional material - furniture, historical costumes, books etc. - came from local museums and other institutions. One characteristic of research on electricity (as well as in other fields) in France in the 18^{th} century was the *public demonstration* of experiments – which were, consequently, specifically adapted for such performances. This way of doing science has to be seen as part of the broader Enlightenment movement. The purpose of an experiment was not only to entertain the audience: the audience had to be present in order to witness the effect of scientific experimentation, to improve their understanding of natural processes and to accept the apparent ability of enlightened scientists to manipulate nature and human bodies via electrical discharges. These performances presented natural phenomena such as lightning as being under the rule of scientific demonstration and explanation.

The thematic leitmotif of both, exhibition and catalogue, was to present historical experiments as a cultural activity. The research group aim was to show how instruments and experiments carry and embody meanings transgressing purely scientific descriptions and disembodied concepts.

In order to illustrate how this way of doing science shaped the conceptual development of electricity and the application of these concepts and practices as philosophical as well as political tools, the group discussed some issues concerning physical practices in revolutionary France. Around 1800 one can find a new ”professional” attitude among scientists accompanied by a demand for quantitative measurement and mathematical analysis. Instruments were therefore constructed as sensitive as possible and a high standard of precision was claimed for the measurements made. Consequently, such instruments or experiments were very susceptible to disturbances and were withdrawn from the public.

Another experimental culture in the exhibition, was a section on the *Romantic understanding of Nature*, which can be seen as an effort to overcome the just mentioned “new” French way of doing science. Seeing and experiencing with one’s own senses were important aspects of the romantic way of doing science. This is, for example, true for Goethe’s experiments on optics, for Faraday’s experiments to establish a close connection between electricity and magnetism as well as for Ritter’s experiments on electrical sensation. In some experiments Ritter even used his own body to investigate the action of electricity.

It was therefore important that visitors were at least able to do some of those experiments themselves and make some experiences with their own senses. They were enabled to use a water-prism and other optical devices described by Goethe, test a so-called ‘crown-of-cups’.

16 Lin et al. article about “using the history of science to promote students’ problem-solving ability” (2002).

The purpose of the study is to investigate the efficacy of promoting students’ problem-solving ability through the history of science teaching. Two classes in Taiwanese schools of Grade 8 (N= 67) participated in this exploratory study. The experimental group (N= 30) was taught with two packages of historical-rich supplementary materials were developed, as hands-on activities analogous to previous scientists’ experiments such as, Toricelli’s mercury- and Boyle’s J-tube experiments, and an attempt was made to emphasize the development of a scientific concept or theory. The details of how previous scientists discussed, debated and hypothesized, as well as how they conducted and set up their experiments, were explained to students. In this way, students were put in the same situation as these scientists and went more or less through the same steps of their scientific speculations and inquiries. In this way, they are taught implicitly about the nature of science.

The second package described the development of atomic weight and how earlier scientists distinguished the difference between atoms and molecules. With the historical description about Dalton hypothesis that every substance consisted of very small particles, students are introduced to the theory that atomic weight is a relatively compared value.
Three conceptual problem-solving tests were used in the one-year study. The first test included five items focused on the concepts of density, pressure, water pressure and heat capacity. The second test consisted of three items mainly related to the topics of atmospheric pressure and gas properties. The third test comprised four items, ranging from the concept of atom, molecule, atomic weight, and molecular weight to a variety of chemical reactions. Conceptual understanding and applications are emphasized in all these items. Most of the items were developed and pilot tested. Moreover, there are little or no mathematical calculations required solving the problems.

The control group (N= 37) was taught as usual, using a regular physical science textbook. Both groups were taught by the same teacher and had the same instruction time.

The teacher's classroom teaching was mainly based on the package and she used the textbook as the main reference for the control group. When the teaching about atmospheric pressure and gas properties was finished, all students were asked to take the second conceptual test. At the beginning of the second semester, the second package of the historical-rich material was taught to the experimental group. Finally, the third conceptual test was given to both group students.

The experimental group were taught with small group discussions, student presentations, teacher demonstrations, and hands-on activities. Students were required to predict possible outcomes of an experiment, to explain the reason of their prediction, to make a hypothesis of a problem, and to stimulate previous scientists' experiments.

After one year of teaching, using the statistical procedure of the analysis of covariance (ANCOVA) to compare the difference of the two groups on their conceptual test achievement, it was found that the experimental group students outperformed their counterparts in the chemistry conceptual problem-solving ability.

Finally, the researchers believe that the slow-acting effect of history in science teaching reminds teachers and educators to be patient while they are implementing this teaching approach.

17 Ryder et al. articles about "undergraduate science students' images of science" (1997, 1999).

In the United Kingdom, university science undergraduates specialize in a single science subject for the entire 3-4 years of study. Those students entering university straight from school will graduated at age 21-22 years. This study examined images of the nature of science held by students in their final year at university. Data were drawn from a longitudinal interview study of 11 students engaged in open-ended project work at the university of Leeds, England. This sample showed a range of ability, gender and project type was selected from four science departments at the University of Leeds – Biochemistry & Molecular Biology, Chemistry, Earth Sciences and Genetics.

Images of science expressed during interviews are characterized and coded using a framework involving three distinct areas of epistemological and sociological reasoning: 1. the relationship between data and knowledge claims; 2. the nature of lines of scientific inquiry; and 3. science as a community of scientists.

The findings of this study were, students tended to view knowledge claims as provable solely on empirical grounds, though some students mentioned social factors as also being important. Many students showed significant development in their understanding of how lines of scientific inquiry are influenced by theoretical developments within a discipline. Issues relating to scientists working as a community were underrepresented in the students' discussions about science. Rather than a single image of science, individual students drew upon a range of profile of positions in each area of the framework, depending on the scientific context being discussed.

The research questions that guided this study were the followings:

1. What range of images of science do undergraduate science students use?
2. Are students' approaches to learning science influenced by their images of science?
3. In what ways do curriculum contexts influence students' images of science?

Students have a range of ideas about science depending on the context. For instance a student's views about how scientists decide which questions to investigate may depend on whether the scientist is involved in university research or research within the laboratories of a multinational pharmaceutical company. In order to provide a context for discussions about science, the researchers decided to probe students' ideas about science whilst they were heavily involved on a specific teaching task, which were the final year undergraduate research projects. These research projects take up to eight months to complete, and involve the student working alone under the supervision of a science lecturer.

An interview-based case study was here used in order to build up a picture of the *range* of images of science drawn upon by an *individual* student in response to a variety of contexts. Moreover, case studies help to address the second and third research questions concerning the interaction between images and teaching context.

To address the first research question about students' images of scientists, the researchers used interviews in which students were encouraged to talk about their images of science with reference to particular activities on their project. These images are 'images in action', because they may be transitory and are not articulated by the student at the time and in specific contexts. In fact, each student was interviewed three times. Piloting with two students from the study showed that the questions were effective in encouraging students to talk at length about science. The researchers aim during the interviews was to get the students to talk about science in their own terms – an ideographic approach.

Discussions about the nature of science using the following questions were included in the first and last interview. The following questions were designed to encourage the student to address the following issues: the purposes of scientific work, the nature and status of scientific knowledge and science as a social enterprise:

1. How do scientists decide which questions to investigate?
2. Why do scientists do experiments?
3. How can good scientific work be distinguished from bad scientific work?
4. Why do you think that some scientific work stands the test of time whilst other scientific work is forgotten?
5. How are conflicts of ideas resolved in the scientific community?

The interviews were coded and categorized using three frameworks: students' epistemological and sociological reasoning about science, the nature of scientific lines of inquiry, and science as a community of scientists. This framework was generated by an iterative procedure.

The findings of this study were:

- Students made no distinction between data and knowledge claims. Moreover, the endpoint of scientific investigation is seen as reliable data, which serves to explain phenomena.
- The majority of students focused on empirical data as the sole grounds for proof. University students tend to advance a Popperian view in which scientific ideas are either accepted or falsified on the basis of empirical data.
- A minority of students made statements such as creative insights, hunches, inspiration or a strong personal commitment to an idea. These students came from the Department of Earth Sciences.
- Overall, the discussions of student sample emphasized the importance of obtaining reliable, valid data. This view was strengthened in the third interview after the students had completed their project work.
- The increasing emphasis on lines of inquiry being influenced by theoretical developments within the discipline was encouraging, and indicates that many of the

students in the sample are being brought 'inside science'. However, solely 'personal interest' and/or 'utilitarian' views of scientific inquiry have persisted for many students through to the beginning of their final year of study.

- The institutions of science such as professional science organizations, research journals, major science conferences and funding bodies were rarely mentioned in the interviews, particularly the role these institutions have in influencing the direction of scientific inquiry and the validation of knowledge claims through processes such as peer review. This is perhaps not surprising given that undergraduate students are not expected to attend conferences or make grant applications for research funding. However, from the perspective of the 'cultural' argument, this lack of sociological awareness may handicap those students whose graduate jobs involve interacting with the world of science. The data of this study shows that many of the students in the sample will carry into their professional lives images of the nature of science, which do not fully reflect the actual practices of science.
- In some cases students made specific reference to incidents, which had developed their ideas about science. For example, discussions about incidents from the history of science and videos about the work of modern scientists. In addition, the nature of the student's discipline, the form of curriculum and teaching they are exposed to and the type of project they were working on, are all potentially important influences on the development of the student's images of science. For example, the researchers found that students whose project had an epistemological focus - relating data to knowledge claims - tended to show developments in their epistemological reasoning. By contrast students whose projects involved making experimental techniques work with novel materials tended to show limited development in their reasoning about data and knowledge claims.
- Many of the influences on students' images of science in this study can be described as *implicit curriculum messages*.

18 Carey et al. study about "An experiment is when you try it and see if it works: A study of junior high school students' understanding of the construction of scientific knowledge" (1988, 1989).

Developing a constructivist view of scientific inquiry and knowledge is considered to be important to the training of future scientists, as well as to the understanding of scientific information by all citizens.

The research reported targets the junior high school grades. Curricular materials that introduce 7th graders (12-year-olds, N= 76 students in five 5 classrooms) to the constructivist view of science have been developed and implemented. Students' initial epistemological stance concerning scientific knowledge is that knowledge is a passively acquired, faithful copy of the world, and that the inquiry process is limited solely to observing nature, rather than constructing explanations (i.e., theories) of phenomena in nature.

The assumption guiding this curricular intervention is that if students are to gain a better understanding of the nature of scientific inquiry and knowledge, they must be actively involved in constructing and evaluating explanations for natural phenomena, and they must be engaged in metaconceptual reflection on that process. Thus, the researchers have designed an instructional unit that engages students in scientific inquiry – in the tentative groping toward a deeper understanding of the world, in the cumulative and intellectual process of theory construction.

Carey et al. research reported on several working assumptions that motivate a curricular approach, which emphasizes theory building and reflection on the theory building process:

(1) Process skills will be more easily and better learned if they are embedded in a wider context of meta-conceptual points about the nature of scientific knowledge.
(2) Such meta-conceptual knowledge is important in its own right.
(3) Metaconceptual understanding of the nature of scientific inquiry and scientific knowledge can be gained only by actively constructing such knowledge and reflecting on this process.
(4) As in any case of science education, curricular materials must be aimed at the students' beginning conceptions.

The two goals of the study are (1) to probe junior high school students' initial understanding of the nature and purpose of scientific inquiry, and (2) to explore whether it is feasible to move students beyond their initial conceptions with a relatively short classroom-based intervention. Students were taught during the three-week-long nature of Science Unit by their regular teacher. Twenty-seven of the students were randomly selected to be interviewed both prior and after participating in the Unit. The individual clinical interviews were administered by research assistants. They half-hour clinical interview probes students' understanding of the following: (1) the nature and purpose of science; (2) the main elements of scientific work, including ideas, experiments, and results/data; and (3) the relation among these elements. In addition, follow-up questions probe what students mean when they use key words or phrases, such as "discover", "try out", "proof", "explanation". The pre- and post-interview questions were grouped into six sections: (1) nature/purpose of science and scientific ideas; (2) nature of a hypothesis; (3) nature/purpose of an experiment; (4) guiding ideas and questions; (5) results and evaluation, and (6) relationships (between particular elements of scientific work, e.g., ideas and experiments).

Furthermore, the researchers developed a 24-item, multiple choice, written pre/posttest which attempted to evaluate students' understanding of the nature of scientific inquiry and knowledge, and of experimental design.

The responses to the questions on the interview were coded into codes that reflected three general levels of understanding. For instance, in Level 1, the students make no clear distinction between ideas and activities, especially experiments. For Level 2, there is a clear understanding that experiments are tests of ideas. In Level 3, students make a clear distinction between ideas and experiments, and understand the motivation for activity as verification or exploration, in addition to this, an understanding that the modification of an idea may entail reorganizing and reinterpreting the data on which the idea was originally based.

The teaching unit is formed of an introductory lesson to orient students (the main points of this lesson were that the basis for scientific inquiry is mental work, and that experiments are tests of ideas), the videodisc lessons about animal mimicry, the black box problem lesson with the videodisc segment "how do students study things they can't see?", which shows Linus Pauling verbalizing his thought process while he works on the black box problem, and finally the two-weeks yeast lessons, that engage students in constructing an ever-deepening theoretical understanding of a natural phenomena – in this case, the phenomenon of bread dough rising. The students make and test hypotheses, perform experiments, reflect upon what they are doing, and reflect on *why* they are doing what they are doing. And finally, the wrap-up lesson, which concludes the unit with a general discussion about the interplay of thought and experimentation in science. Overall, the students were motivated and enjoyed the lessons, especially the yeast lesson.

The main findings from the clinical interview were the followings:

- All of the students interviewed moved beyond their initial Level 1 understanding of scientific knowledge.
- The results support the suggestion in the literature that pre-adolescent children have a different epistemological stance towards scientific knowledge than do scientifically literate adults. Initially, most of the grade 7 students of the sample thought that scientists seek to discover facts about nature by making observations and trying out things. This Level 1 understanding of the nature of science might be called a "copy theory" of knowledge: knowledge is a faithful copy of the world that is imparted to the knower when the knower encounters the world. By this view then, the only way scientists can be wrong about some aspect of nature is through ignorance that is, by not having looked at that aspect of nature.

18. 1 The clinical interview questions of Carey et al.

Words to unpack during the interview (what do you mean by ____?)

Answer	**Helps**	**Theory**
Conclusion	**Learn**	**Truth**
Discover	**Procedure**	**Try again**
Equipment	**Proof**	**Try out**
Explanation	**Test**	**Understand**

Introductory questions:

1. What do you think science is all about?
2. What do you think the goal of science is?
3. Which statement do you think is a better description of the goals of science?
   a. The goal of science is to discover new things in the world and the universe.
   b. The goal of science is to build a better understanding of the world around us.

Why? Can you give me some examples? (of new things, or the kinds of things we try to understand)

4. How do you think a scientist does this work?

I. Ideas:

1. Where do scientists get their ideas?
2. What kinds of ideas do scientist have?
3. Do scientists do anything with their ideas? What do they do with them?

4a. If **Test** then:

4b. How do scientists test their ideas?

4c. What happens to the ideas once they've been tested?

1. Is there a relationship between a scientist's ideas and the rest of the work a scientist does? What is the relationship?
2. Do scientists change their ideas? Why (when) or why not?

II. Hypothesis

1. What is a hypothesis?
2. Where does a scientist get a hypothesis?
3. Is there a relationship between a scientist's hypotheses and the rest of the work a scientist does? What is the relationship?

III. Experiment

1. What is an experiment? (unpack the answer)

2a. Why do scientists do experiments?
If **TO TEST IDEAS** then:

2b. How does the test tell the scientist something about the idea?

3. How does a scientist decide what experiment to do?

IV. Results

1. What happens when a scientist is testing his/her ideas, and gets a different result from the one he/she expected? (unpack the answer)

19 Osborne et al. Delphi study about "What Ideas-about-Science should be taught at school? (2003).

Unlike the content of science, for which there is well-established consensus, there would appear to be much less unanimity within the academic community about which "ideas-about-science" are essential elements that should be included in the contemporary school science curriculum. Hence this study sought to determine empirically the extent of any consensus using a three stage Delphi questionnaire with 23 participants drawn from the communities of leading and acknowledged international experts of science educators; scientists; historians, philosophers, and sociologists of science; experts engaged in work to improve the public understanding of science; and expert science teachers. The outcomes of the research was a set of 9 themes encapsulating key ideas about the nature of science for which there was consensus and which there was consensus and which were considered to be an essential component of school science curriculum.

The 30 themes about nature of science grouped under 3 major categories: The Nature of Scientific Knowledge, the Institutions and Social Practices of Science, and the Methods of Science.

a. Nature of Scientific Knowledge

1. Science and Certainty
2. Historical Development of Scientific Knowledge
3. Cumulative and Revisionary Nature of Scientific Knowledge
4. Empirical Base of Scientific Knowledge
5. Status of Scientific Knowledge
6. Common Conceptions of Science and Risk
7. The Language of Science
8. Science as Human, Collaborative Activity
9. Reporting Scientific Findings
9. Scientific Knowledge and Values
10. Distinction between Science and Technology

b. Methods of Science

11. Scientific Methods and Critical Testing
12. Analysis and Interpretation of Data
13. Hypothesis and Prediction
14. Diversity of Scientific Thinking
15. Creativity
16. Science and Questioning
17. Observation and Measurement
18. Specific Methods of Science
19. Science and Technology
20. Cause and Correlation
21. Role of ICT
22. No General Ideas Independent of Science Content

c. Institutions and Social Practices in Science

23. Moral and Ethical Dimensions in Development of Scientific Knowledge
24. Cooperation and Collaboration in Development of Scientific Knowledge
25. Developments in Scientific Knowledge are Subject to Peer Review
26. Contextual Nature of Science
27. Constraints on Development of Scientific Knowledge
28. Range of Fields in Which Scientific Knowledge is Developed
29. Accountability and Regulation of Scientific Practices

Finally, the 9 consensual themes about nature of science aspects emerged from the Osborne study are:

1. Scientific Methods and Critical Testing
2. Creativity
3. Historical Development of Scientific Knowledge
4. Science and Questioning
5. Diversity of Scientific Thinking
6. Analysis and Interpretation of Data
7. Science and Certainty
8. Hypothesis and Prediction
9. Cooperation and Collaboration

20. The nature of science aspects in the English-speaking countries.

Table 1 represents the consensual nature of science aspects in the anglo-saxons countries. I relied on the mentioned studies below in order to develop my teaching setting. The main aspects to insert in the appraoch were: science as human activity, science and questioning, the tentative nature of science, empirically-based (based on and/or derived from observations of the natural world, necessarily involves human inference, imagination, and creativity.

The present study used a framework drawing on the following areas: characteristics of scientists, history of science and students' epistemology of science.

McComas & Olson	Osborne et al	Lederman et al
Scientific knowledge is tentative	Science and certainty	Scientific knowledge is tentative (subject to change)
Science relies on empirical evidence	Analysis and interpretation of data	Empirically-based (based on and/or derived from observations of the natural world)
Scientists require replicability and truthful reporting	Scientific method and critical testing	
Science is an attempt to explain phenomena	Hypothesis and prediction	Subjective (theory-laden)
Scientists are creative	Creativity/Science and questioning	Creativity (involves the invention of explanations)/ imagination
Science is part of social tradition	Cooperation and collaboration in the development of scientific knowledge	
Science has played an important role in technology	Science and technology	Socially and culturally embedded
Scientific ideas have been affected by their social and historical milieu	Historical development of scientific knowledge	
	Diversity of scientific thinking	
Changes in science occur gradually		
		Distinction between observations and inferences
		The functions of, and relationships between scientific theories and laws.
		Scientific knowledge necessarily involves human inference
New knowledge must be reported clearly and openly		
Science has global implications		

Table 1: represents the comparison of themes emerging from the Delphi Study with those from McComas and Olson's (1998) study of national standards and Lederman study (1998).