The influence of constructivism on nature of Science as an area of research and as a classroom subject

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Abstract

This paper is an general article about the influence of constructivism on nature of science Constructivism has influenced research on the teaching and learning of nature of science, as well as actual teaching of the nature of science ideas. In the area of research, a constructivist learning theory perspective has influenced researchers to shift from using quantitative research techniques to using qualitative research methods in investigating the nature of science in the science classrooms. In the area of promoting the teaching of the nature of science, a constructivist learning theory perspective has influenced science educators to shift from merely emphasizing the teaching of the history of science in science classrooms to sequencing in instruction in

science lessons and promotion of better teacher preparation programs in the universities.

Introduction

Science curricula vary widely among countries, states, school districts, and individual schools. The most vivid differences are concerned with the particular science topics or concepts to be included. Such differences in course and curricular content are unavoidable, as each course must present only a small sample of the scientific generalizations and principles drawn from a consistently and rapidly expanding discipline (Lederman, 1992). There is no consensus among science educators concerning the specific content to be included in contemporary science courses or even the methods and strategies of instruction to be used. However, there appears to be strong agreement on at least one of the objectives of science instruction. The development of an "adequate understanding of the nature of science" or an understanding of "science as a way of knowing" continues to be convincingly advocated as a desired outcome of science instruction (American Association for the Advancement of Science (AAAS), 1989, Lederman, 1992). Although the "nature of science" has been defined in numerous ways, it most commonly refers to the values and assumptions inherent to the development of scientific knowledge (Lederman & Zeidler, 1987). This characterization nevertheless remain fairly general, and philosophers of science, historians of science, sociologists of science, and science educators are quick to disagree on a specific definition for the nature of science (NOS). Such disagreement, however, should not be surprising given the multifaceted and complex nature of the human endeavor we call science. Moreover, similar to scientific knowledge, conceptions of NOS are tentative and dynamic: These conceptions have changed throughout the development of science and systematic thinking about its nature and workings did too (Abd-El-Khalick & Lederman, 1998). However, at the end, there is an agreement (even through not complete) about nature of science among science educators that scientific knowledge is tentative (subject to change), empirically based (based on and/or derived from observations of the natural world), subjective (theory-laden), partly the product of human inference, imagination, and creativity (involves the invention of explanation), and socially and culturally embedded. Also two additional important aspects are the distinction between observations and inferences, and the functions of and relationships between scientific theories and laws (Lederman, Abd-El-Khalick, Akerson, 2000).

The aim of this paper is to look at how one particular learning perspective has influenced the research on NOS and the way the nature of science is taught by reviewing some relevant NOS studies. Many researchers taking different research perspectives have done research in the nature of science. This paper examines how a constructivist learning theory perspective has influenced research on the nature of science, as well as the teaching and learning of the nature of science. In doing so, this paper divides into three parts. The first part looks at the historical development of the nature of science and discusses the current status of research on the teaching and learning of NOS, as well as the teaching and learning of NOS in pre-college classrooms. Second part discusses how constructivism has influenced research on the teaching and learning of nature of science by examining how research in the area of NOS was conducted prior to the use of constructivism as a learning theory perspective. In the third part, the paper examines the influence of constructivism on teaching and learning of nature of science ideas in classrooms by first examining how NOS was promoted prior to the use of constructivism, and then compare this with how they were promoted using a constructivist perspective.

The nature of Science as a content area

The longevity of the nature of science objective in science education is attested to by the National Society for the Study of Education (1960) and Hurd (1960) who claim the existence of the objective of teaching the nature of science in the American schools as early as 1920. Actually, one can trace the advocacy for students' understandings of nature of science to the reports of the Central Association of Science and Mathematics Teachers (1907) in which a strong argument was presented for increased emphasis on the scientific method and the processes of science. Concerns for the development of adequate understandings on the nature of science "have worn many hats" through the years (Lederman, 1992). In the early 1900s the nature of science objective was expressed in terms of increased emphasis on the scientific method "so as to better train students' mental faculties" (Hurd, 1960); in the 1960s the objective was linked to the advocated emphasis on scientific process and inquiry (Welch, 1979); and most recently it has been included as a critical component of scientific literacy (American Association for the Advancement of Science, 1989;

National Science Teachers Association, 1982). Clearly, science educators and scientists have been extremely persistent in their advocacy for improved student understanding of the nature of science. Indeed, Kimball (1968) has referred to this objective as one of the most commonly stated objectives for science education and Saunders (1955) went so far as to describe it as the most important purpose of science teaching.

Research related to the nature of science can be conveniently divided into four related, but distinct, lines of research: (a) assessment of student conceptions of the nature of science; (b) development, use, and assessment of curricula designed to “improve” student conceptions of the nature of science; (c) assessment of, and attempts to improve, teachers' conceptions of the nature of science; and (d) identification of the relationship among teachers' conceptions, classroom practice, and students' conceptions (Lederman, 1992).

Although the belief in the importance of students' understandings of the nature of science has persisted through the twentieth century as mentioned above, assessments of students' conceptions did not start until 1954 (Wilson, 1954). Initial assessments of students' conceptions indicated that students did not possess adequate understandings of NOS and led to the conclusion that science teachers must not be attempting to teach nature of science. A second line of research focusing around curriculum development and assessment was initiated by Cooley and Klopfer (1963). The results of this movement were ambiguous. That is, the same curriculum was effective for one teacher with a particular group of students, but not for another teacher with different group of students. The appropriate conclusion was that the individual science teacher must make a difference. Predictably, a subsequent line of research focused on the assessment of teachers' conceptions. Disturbingly, there was no attempt to focus on the behaviors and other classroom variables related to individual teachers. The assessment of teachers' conceptions of the nature of science indicated that they did not possess the desired level of understanding (Lederman, 1992). Because teachers cannot be expected to purposefully teach what they do not understand, many researchers focused their attention on the development and assessment of techniques designed to improve teachers' understandings of NOS (Lederman, 1992). Unfortunately, the results of such attempts were ambiguous and the specific variables contributing to improved conceptions of NOS remained unknown.

The above mentioned lines of research were informed by two basic implicit assumptions: a teacher's understanding of the nature of science is related to his/her students' conceptions and a teacher's instructional behaviors and decisions are significantly influenced by his/her conceptions of nature of science (Lederman, 1992). Recognition of these assumptions and the results of general research on teaching contributed to a refocusing of researchers' attentions on the testing of these assumptions and attempts to derive those classroom variables related to changes in students' conceptions (Brickhouse, 1990). Interestingly, Trent (1965) had made such recommendations 30 years earlier. As a consequence of this more recent research, it appears that the most important variables that influence students' beliefs about the nature of science are those specific instructional behaviors, activities, and decisions implemented within the context of a lesson. It appears that continued stress on higher-level thinking skills, problem solving, inquiry-oriented instruction, and frequent higher-level questioning within a supportive risk free environment are at least related to desired changes in students' conceptions (Lederman, 1992). There appears to be a clear recognition that each line of research is a piece of a much larger puzzle (Lederman, 1992). There appears to be an overt recognition that teachers can not teach what they do not understand, and that simply possessing the desired knowledge dose not ensure its effective communication to students (Mac Donald & Rogan, 1990). Additionally, science educators' interest in students' conceptions of the nature of science has been placed within the context of constructivist epistemology (Wheatley, 1991) and, within this view, is unavoidably related back to specific classroom activities and instructional approaches. In short, the current state in the area of research on the nature of science is a coherent effort, with researchers building upon and informing each other's work, as it is the case in constructivist learning perspective.

The recent growth of qualitative techniques in research on the nature of science, which are in accordance with constructivist learning theory perspective, has allowed researchers to avoid the problems created by limiting responses to an a priori set of categories or viewpoints (Lederman, 1992). As a consequence, resent research has allowed science educators to identify the wide variety and complexity of perceptions held by both teachers and students, as well as some of the classroom variables related to changes in students' conceptions. Although the results of recent qualitative investigations have not outwardly contradicted the results of prior quantitative approaches, which were using cognitive science learning theory perspective, they have provided more in depth and valid assessments of teachers' and students' conceptions and have afforded the researcher a more contextual view of instructional sequence and the factors which mediate one's conceptions (Lederman, 1992).

The influence of constructivism on the research of the nature of Science

During the period when cognitive science learning theory was popular, the early researchers on the nature of science were usually using quantitative techniques, mainly paper-and-pencil, in assessment of students' conceptions of the nature of science. Therefore, it is assumed that this learning theory might have greatly influenced the early research on the nature of science.

To highlight studies on nature of science during the time when cognitive science learning theory was popular, this paper discusses several studies. In 1961 Klopfer and Cooley developed the Test on Understanding Science (TOUS) which was to become the most widely used paper-and-pencil assessment test of students' conceptions of the nature of science. Using TOUS and a comprehensive review of several nationwide surveys, Klopfer and Cooley (1961) concluded that high school students' understandings of the scientific enterprise and of scientists were inadequate. In another comprehensive study, Mackay (1971) pre-and-post tested 1,203 Australian secondary students extending across grades 7-10, using TOUS instrument. He found that students lacked sufficient knowledge of (a) the role of creativity in science; (b) the function of scientific models; (c) the roles of theories and their relation to research; (d) the distinctions among hypotheses, laws, and theories; (e) the relationship between experimentation, models and theories, and absolute truth; (f) the fact that science is not solely concerned with the collection and classification of facts; (g) what constitutes a scientific explanation; and (h) the interrelationships among and the interdependence of the different branches of science.

To illustrate studies investigating the effects of a curriculum on students' conceptions using a cognitive learning theory, this paper discusses another study by Klopfer and Cooley (1963). In this study Klopfer developed the first curriculum designed to improve students' conceptions of NOS. The curriculum was called “History of Science Cases for High Schools” (HOSC). The rationale for the curriculum was that the use of materials derived from the history of science would help to convey important ideas about science and scientists. A sample of 108 geographically representative science classes, including biology, chemistry, and physics, with total number of 2,808 students enrolled in them, was used to assess the effectiveness of the HOSC curriculum measured by the TOUS instrument. After a five month treatment period, students receiving the HOSC curriculum exhibited significantly greater gains on the TOUS than the control groups. This result was consistent across disciplines. It was concluded that the HOSC instructional approach was an effective way to improve students' conceptions of the nature of science. The larger sample size used in this study gave it much credibility and it was followed by widespread curriculum development regarding the nature of science in science textbooks.

As illustrated by the above mentioned studies, researchers who conducted studies on the nature of science during the times when cognitive science learning theory was popular, focused on developing instruments which measure students' conceptions and the effectiveness of specially designed curriculum before and after administrating these tests.

By the late 1980s, researchers in science education were beginning to be influenced by the constructivist learning theory, which developed out of Jean Piaget's work. Whereas researchers using a cognitive science learning theory tended to use quantitative techniques in their studies to measure students' conceptions about the nature of science, researchers using a constructivist learning theory tended to use qualitative techniques and started to observe science classrooms to understand how students construct meaning about the nature of science during the lectures.

To illustrate research on the nature of science conducted from a constructivist learning theory perspective, this paper discusses two studies. In a study carried out by Zeidler and Lederman (1989), the researchers observed 18 high school biology teachers and 409 students in their classrooms. In this study, specific attention was focused on the nature of teacher-student interactions and the specific language used in the classroom. It was hypothesized that conceptions of the nature of science may be implicitly communicated to students by the language teachers use in presenting subject matter. In general, when teachers used “ordinary language” without qualification (e.g., discussing the structure of an atom without stressing that it is a model), students tended to adopt a realistic conception of science. This conception views scientific knowledge as true, real, existing independently of personal experience, and where some scientific objects (e.g., atoms, light, ions) have the same ontological status as ordinary objects (e.g., chair, table). Alternatively, when teachers were careful to use precise language with appropriate qualifications, students tended to adopt instrumentalist conception. The instrumentalist view emphasizes the practical utility of scientific explanations, the role of human imagination and creativity in the development of scientific knowledge, the tentative nature of science, and the utility of arbitrary constructs and models. In short, this view is more consistent with the currently accepted view of science.

In the second study Lederman and O'Malley (1990) has called into question prior approaches to assessing students' conceptions of the nature of science as well as previous recommendations for improving students' understandings of the nature of science. In their study the researchers asked a sample of 69 students spanning grades 9-12 to complete four open-ended questions intended to assess students' conceptions of the tentative and revisionary nature of science.The questionnaire was administered at the beginning of the school year and as a posttest at the end of the academic year. After students' pre-and posttest responses were categorized as exhibiting absolutist or tentative views, a stratified sample was selected for a follow-up videotaped interview. During the interview, students were asked to clarify their questionnaire responses and provide information concerning the sources of their beliefs and factors causing beliefs to change. Although responses on the questionnaires indicated that students possessed absolutist view of science, the interviews indicated that the students actually were quite clear in their beliefs that scientific knowledge is tentative. Additionally, students did not view laboratory activities or any other science activities as specifically related to their present views of science. The researchers concluded that the use of interviews to assess students' understandings of the nature of science are essential. In addition, they pointed out the troubles involved when researchers attempt to categorize students' written responses on paper-and-pencil tests. Given that the overwhelming majority of prior research on students' and teachers' conceptions of the nature of science did not involve interviews, the implications about the accuracy of over three decades of data were called into question by the researchers in this study.

As illustrated by these studies, researchers working from a constructivist learning theory perspective emphasized the importance of using qualitative techniques, such as classroom observations and interviews, for gathering data about the students' and teachers' understandings of NOS. These techniques are consistent with constructivist theory in the sense that they try to see the construction of meanings in their actual setting. Thus, a constructivist learning theory perspective appears to have caused researchers to shift their emphasis from quantitative research methods to qualitative research methods for researching the nature of science understandings in American classrooms.

Influence of constructivism on the teaching of the nature of Science

Just as a constructivist learning theory perspective influenced research conducted on the nature of science, this learning theory perspective also influenced how the nature of science understandings were promoted for teaching in pre-college science classrooms. Prior to the adoption of a constructivist learning theory by many science educators, cognitive science learning theory perspectives dominated learning and instruction in science classrooms.

Science educators promoting the teaching of the nature of science during the era dominated by cognitive science learning theory perspective encouraged science teachers to teach history of science and the general value of an historical approach to science in their classrooms for a better understanding of nature of science. Even before the emergence of the cognitive science learning theory perspective Jenkins (1989) traced the promotion of the teaching of the history of science back to 1850 in Great Britain, and Russell (1981) to the early 1940s in the United States. In the time when the cognitive science perspective became popular, the list of science educators from many countries who have recommended the study of the history of science in high school has become too long to be able to catalog (Solomon et al., 1992). The results of this substantial literature is a list of possible areas of benefits for science education; the most common are (a) a better learning of the concepts of science, (b) increased interest and motivation, (c) an introduction to the philosophy of science, (d) a better attitude of the public towards science, and (e) an understanding of the social relevance of science (Solomon et al., 1992).

To illustrate this point, this paper discusses findings by Duschl (1990) on teaching the nature of science. Duschl says, using a moon metaphor: “What is presently missing in our science curriculum are instructional units that teach about the other face of science – the how” (p. 41). In his article Duschl (1990) argues that science educators have focused upon teaching students "knowledge of science" and forgotten the "knowledge about science" (history of science). Without the latter, students are simply taught "final form science". They are, in effect, "being told where we are now, without being told how we got there". He sees three dangers in presenting such a one-sided view. Duschl (1990) warns that students may falsely conclude: (a) all scientific knowledge claims are considered equal in weight, (b) scientific knowledge claims do not interact with others, and (c) scientific theories do not change. It appears that by omitting the history of science, students cannot understand how the "collective mind of science" arrived at the knowledge it holds today.

It shows that the emphasis in articles promoting the teaching of the nature of science ideas, written by science educators using a cognitive science learning theory perspective, was to teach students the history of science in science lessons.

With the emergence of constructivist learning theory in the mid to late 1980s, science educators shifted their emphasis to helping students construct stronger and more generalized cognitive models of scientific ideas. Science educators also appeared to emphasize sequencing in instruction to help students for better construction of scientific models and improving teacher educational programs for better facilitating students in their constructivist classrooms. To illustrate these points, this paper discusses two articles on teaching the nature of science.

In an article Lawson (1999) argued that "sequencing instruction that focuses on scientific reasoning pattern first in observable context and then in non-observable context helps students better understand the nature of science and use scientific reasoning in and beyond the science classroom" (p. 401). To the question "How can we help students develop theoretical reasoning patterns and acquire an accurate understanding of the nature of science?" asked by Lawson, he himself answered with the following statement, "If intellectual development is truly stage-lake, then for "descriptive" students it would appear that we need to immerse them in "hypothetical" contexts and provide lots of opportunities for direct physical experience, for social interaction with others, and for equilibration. Once these students develop hypothetical reasoning patterns, we then need to repeat the process in theoretical contexts. In other words, teachers need to: 1) know where their students are in their intellectual development, 2) be aware of the intellectual demands that instructional tasks place on students reasoning abilities, 3) correctly match instructional contexts with students abilities, and 4) sequence contexts in a way that moves from description and classification, to casual hypothesis testing in familiar contexts, to casual hypothesis testing in not-so-familiar contexts, and then to theory testing (where theories are defined as general explanatory systems that postulate the existence of unseen entities and/or processes) (p. 407).

In another article McComas (2000) argued that "misconceptions about science are most likely due to the lack of philosophy of science content in teacher education programs and the failure of such programs to provide real science research experiences for pre-service teachers while another source of the problem may be the generally shallow treatment of the nature of science in the textbooks to which teachers might turn for guidance" (p. 53). The "myths of science" commonly included in science textbooks, in classroom discourse, and in the minds of adult Americans, which are incorrect representations of the nature of science, are described by McComas as follows:

- Hypothesis become theories that in turn becomes laws
- Scientific laws and other such ideas are absolute
- A hypothesis is an educated guess
- A general and universal scientific method exists
- Evidence accumulated carefully will result in sure knowledge
- Science and its methods provide absolute proof
- Science is procedural more than creative
- Science and its methods can answer all questions
- Scientists are particularly objective
- Experiments are the principal route to scientific knowledge
- Scientific conclusions are reviewed for accuracy
- Acceptance of new scientific knowledge is straightforward
- Science models represent reality
- Science and technology are identical
- Science is a solitary pursuit

McComas warns that "both students and those who teach science must focus on the nature of science itself rather than just its facts and principles, school science must give students an opportunity to experience science and its processes, free of the legends, misconceptions and idealizations inherent in the myths about the nature of the scientific enterprise" (p. 68).

These two articles illustrate the major difference between articles promoting the teaching of the nature of science from cognitive science learning theory perspective from that of a constructivist learning theory perspective. That difference is the shifting of the emphasis on the teaching of the history of science in science classrooms to sequencing in instruction in science lessons and promotion of better teacher preparation programs in the universities.

Conclusion and implications

It seems clear from examining both the research and the teaching literature that constructivism has influenced research on the teaching and learning of the nature of science, as well as actual teaching of the nature of science ideas. In the area of research, a constructivist learning theory perspective has influenced researchers to shift from using quantitative research techniques to using qualitative research methods in investigating the nature of science in the science classrooms. In the area of promoting the teaching of the nature of science, a constructivist learning theory perspective has influenced science educators to shift from merely emphasizing the teaching of the history of science in science classrooms to sequencing in instruction in science lessons and promotion of better teacher preparation programs in the universities. Implications for classroom teaching could be formation of cooperative learning groups and letting student in these groups to talk freely about issues of nature of science among themselves and share these ideas with the whole class, so that they can explore more in-depth their misconceptions. Another implication could be giving students in these groups homework where they will explore the life of a famous scientist and act his life in front of the class or present it as a slide show.

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