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A Sociological Standpoint to Authentic Scientific Practices and its Role in School Science Teaching

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ABSTRACT

In this paper we place an emphasis on authentic science practices grounded by anthropological and sociological lenses of science and discuss their implications for science teaching. We highlight the problem of typical science teaching as teaching merely about the "normal science" and ignoring the sociological characteristics of scientific practice. After briefly reviewing the sociological and anthropological perspectives of science, we propose including the social characteristics of science and the notion of communities of practice in designing science learning environments and considering them as essential components of the nature of science teaching practices. Next, we discuss the characteristics of authentic scientific practices as reported in recent studies and examine how researchers operationalized authentic science practices in their educational studies. Finally we suggest some implications for practice in augmenting students' and teachers' awareness about authentic science practices using the anthropological and sociological lenses.

KEYWORDS: Authentic science, scientific inquiry, scientific literacy, anthropology of science, sociology of science, the nature of science

Otantik Bilimsel Uygulamalara Sosyolojik bir Bakis ve Okullardaki Fen Ögretimi

ÖZET

Bu çalışma kapsamında, bilimin antropolojik ve sosyolojik açıları ile temellendirilen 'otantik bilim uygulamalarını' vurgulamakta ve fen eğitimi için önerilerinden bahsetmekteyiz. Geleneksel fen eğitiminin sadece 'olağan bilim' olarak öğretilmesinin problemli olduğunu belirterek 'bilimsel uygulamaların' sosyolojik özelliklerini yansıtmadan öğretildigine dikkat çekmekteyiz. Bilimin antropolojik ve sosyolojik özelliklerini kısaca tartıştıktan sonra fen öğrenme ortamlarını tasarlamada ve bilimin doğasının ilkelerini öğretmede bilimin sosyal esaslarını ve 'uygulama toplulukları' kavramını içermesi gerektiğini önermekteyiz. Daha sonra, yakın zamanda yapılan çalışmalarda 'otantik bilim uygulamalarının' özelliklerini ele almaktayız ve araştırmacıların bu çalışmalarda 'otantik bilim uygulamalarını' nasıl kullanılabilir hale getirdiklerini tetkik etmekteyiz. Son olarak ise bilimin antropolojik ve sosyolojik açılarını kullanarak 'otantik bilim uygulamaları' hakkında öğrencilerin ve öğretmenlerin farkındalıklarını artırmak için önerilerde bulunmaktayız.

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ANAHTAR KELİMELER: Otantik bilim, bilimsel araştırma, bilimsel okuryazarlık, bilim antropolojisi, bilim sosyolojisi, bilimin doğası

INTRODUCTION

A central goal of science education is to cultivate scientific literacy for *all* (AAAS, 1990, 1993; NRC, 1996). To achieve this goal, school science classrooms have been organized around scientific inquiry tasks including, but not limited to, problem generation, formulating research questions, designing scientific investigations, collecting and analyzing data, developing arguments, writing reports, and peer review. According to the *National Science Education Standards* (*NSES*) scientific inquiry is defined as "the diverse ways in which scientists study the natural world and propose explanations based on the evidence derived from their work. Scientific inquiry also refers to the activities through which students develop knowledge and understanding of scientific ideas, as well as an understanding of how scientists study the natural world" (NRC, 1996, p.23). The Benchmarks for Science Literacy (AAAS, 1993) suggests that students are encouraged to engage in authentic scientific investigations to be cognizant about the nature of scientific inquiry and develop a thorough understanding of science and its endeavor. It is apparent that the recent reform movements and national and international documents advocate teaching about not only scientific knowledge and methods of scientific inquiry but also about the characteristics of science and its endeavor.

PROBLEM

In his groundbreaking essay, *The Structure of Scientific Revolutions*, Thomas Kuhn (1970) clearly illustrated how scientific knowledge has evolved over time. Nowadays, Kuhn’s assertion that science is socially constructed has been agreed upon by most of the scholars. Most science educators view scientific knowledge is socially constructed and it is subject to change and tentative in nature. Sometimes because of the newly acquired empirical evidence and/or the discovery of more advance measurement tools, and sometimes because of the newly emerged theories and models or stronger scientific explanations, previously accepted scientific theories and/or models are replaced by the newly emerged ones. Scientific paradigm shifts occur when the older theories and explanations are no longer used by the majority of the scientists in explaining the subject of the field. Until this revolutionary science takes place, the scientific practices evolving around the norms of currently accepted paradigm are called the “normal science” (Kuhn, 1970). In normal science the dominant paradigm is not questioned. It is during the revolutionary science that the dominant paradigm is questioned and as needed it is replaced by a new paradigm (or an older one).

Kuhn (1970) pointed out that school science is primarily designed to teach about the normal science and the textbooks in general and any authoritarian text in particular (including the teacher, supplemental texts, curriculum materials, laboratory procedure, etc.) perpetrate the normal science. Because the knowledge represented in textbooks or in any predesigned science-learning environment context is the end product of science, students and teachers do not learn and teach about the presuppositions, contradictions, controversies, and speculations in scientific progress (Niaz, 2010).

What students and teachers think about science and its endeavor, and how they believe that scientific knowledge is generated, validated, and communicated are still popular topics of investigation partly because our current understanding of science is quite different from the modernist, logical positivist view of science, that has dominated the field until the late 20^{th} century. Most recently, researchers have begun to question whether teaching merely about the "normal science" is the only path to achieve scientific literacy and whether citizens being informed about only the "normal science" will be able to develop mostly desired understandings of science or not. The nature of the communication and the characteristics of the events during a scientific paradigm shift are often not addressed in a typical school science classroom or in a typical science learning environment.

For the last couple decades, science educators have investigated individuals' views about the Nature of Science (NOS) as a critical component of scientific literacy. They studied teachers and students' understandings of science--and how they think that scientific knowledge is generated, validated, and communicated. Abd-el Khalick et al. (1998) and Lederman et al. (2002) proposed and operationalized some characteristics of the NOS. These characteristics include beliefs that scientific knowledge is tentative, empirically based, subjective, and parsimonious; it includes human creativity and imagination; and it is socially and culturally constructed. Many studies pertaining to the NOS views have been derived from the philosophical and historical perspectives of science (e.g., Abd-el Khalick et al., 1998; Lederman, 1992).

Teaching the tenets of the NOS in K-16 levels has been an important goal of science education programs around the world and has taken a place in science education reform documents (AAAS, 1990, 1993; NRC, 1996) as well as in international movements (see, McComas & Olson, 1998). To examine and further understand individuals' views about the NOS, researchers (e.g. Lederman et al., 2002; Aikenhead & Ryan, 1992) developed instruments--including questionnaires and surveys--and documented bibliographies (Bell et al., 2001)--listing the NOS studies found in the literature that may guide interested researchers explore individuals' understanding about the NOS tenets.

In efforts to help improve individuals' understanding of science and support the cultivation of scientific literacy, some researchers have attempted to teach the tenets of the NOS using the historical aspects of scientific knowledge (e.g., Abd-el Khalick, 1999; Abd-el Khalick & Lederman, 2000; Irwin, 2002; Lin & Chen, 2002; Seker & Welsh, 2006; Kaya, 2007). Some preferred to teach the NOS tenets through implicit NOS activities. Some designed and implemented explicit and reflective NOS activities (e.g., Akerson et al. 2000; Khishfe & Abd-El-Khalick, 2002). Some others used socio-scientific issues (e.g., Zeidler et al., 2002; Sadler et al., 2006). All these effort were intended to promote scientific literacy. Many studies in the literature with few experimental ones reported some positive gains in teachers and students' understanding of science and its endeavor.

Teaching through the historical aspects of scientific knowledge can have the potential to show the progress of scientific knowledge over time. Historical artifacts and scientific discoveries, scientists' biographies and life stories, and the details of the scientific presuppositions, contradictions, controversies, and speculations in scientific progress can be discussed in science classroom. Lakatosian perspective on scientific progress can be conveyed with the appropriate use of the historical aspects of science. However these perspectives can only provide a snapshot of historical artifacts and scientific accomplishments. They do not illustrate the social characteristics of how scientific knowledge is generated within the communities of scientists.

We argue that there are some other important, yet mostly ignored, characteristics of scientific endeavor that students and teachers do not have direct opportunities to observe and comprehend no matter they do scientific investigations that are inquiry based, including historical artifacts and discoveries, involving explicit and reflective NOS teaching strategies, or including socio-scientific issues. When we view science as a social entity and the scientific practice as a mutually agreed upon practice among the practitioners, it brings up additional characteristics that are needed to be included in the NOS tenets list that any social entity may have. These include, but not limited to, the characteristics of a community of practice, feelings of ownership and commitment to the work being completed, and the uncertainty of the outcome. In this paper we pose the following questions: "How important it is for teachers and students to be aware of the 'role of commitment' in science?"; "How important it is to be cognizant about the "uncertainty" of the investigation that is being undertaken?"; "How important it is to realize that the teamwork, or the group of students working together, has the same characteristics with any one of the other social communities has?" We refer to the sociological and anthropological lenses of science as we seek answers to these questions.

THEORETICAL FRAMEWORK

Science philosophers have studied the logic of scientific inquiry and how one can make rational arguments in scientific logic. Science historians have been interested in the historical artifacts concerning the evolution of scientific knowledge and how the scientific theories and knowledge were generated over time. Science sociologists have primarily been interested in exploring the norms, characteristics, and the roles of the social organizations in scientific practice.

Using the tools of the humanities and the social sciences, sociology of science studies sciences, technologies, and their relations with the society. Merton school (Merton, 1973) initiated studying the institutional characteristics of the scientific practice and created a framework of concepts and tools for the sociology of science. Merton, however, left the content of scientific inquiry out of the sociological account (Knorr-Cetina, 1991). In 1970ths and 80ths, social constructivist ideas took more emphasis than the institutional approaches of scientific practice and the Sociology of Scientific Knowledge (SSK) has emerged as a school of taught. SSK specifically concerns with how scientific knowledge is generated within the communities of scientists and it does not leave the content of scientific inquiry out of the sociological account.

Scientific communities and science laboratories became a unit of analysis under the auspices of the SSK. In order to further explore the norms and characteristics of scientific practice, laboratory studies have emerged. Laboratory studies explore the characteristics of the knowledge generation process in science communities (Knorr-Cetina; 1995). Laboratory studies view the physical "laboratory" as itself a salient agency of scientific development. This is because laboratory is a means for changing the symmetrical relationships between social order and natural order as well as human actors and non-human actors (Knorr-Cetina, 1995; Pickering, 1995). Laboratory studies explore the role of scientists' social interactions and negotiation in constructing scientific facts (Latour & Woolgar, 1979; Traweek, 1988).

Sociologists and anthropologists began to conduct participant observations in laboratories to better understand about the scientific practice (Latour & Woolgar, 1986; Traweek, 1988). Their observations and interpretations as to how science is practiced have provided valuable insights to science educators.

Latour and Woolgar (1986), in the *Laboratory Life: The construction of scientific facts*, have involved in the research laboratory at the Salk Institute. Latour and Woolgar were concerned with "the work in which the daily activities of working scientists lead to the construction of scientific facts" (p.40). To represent a culture of scientists in a neuro-endocrinology laboratory, Latour and Woolgar answered to several questions, such as, "What are scientists doing?," "What are they talking about?," "How are they constructing scientific knowledge?," etc. Latour and Woolgar studied how scientists integrated the formal and the informal writings in constructing scientific knowledge and demonstrated how scientists used the creativity and imagination as the essential building blocks of their practices and their construction of scientific knowledge. Latour and Woolgar noted that scientists work in competitive environments and they are constantly challenged by their colleagues to test the credibility of their scientific claims. Persuasion was the way to resolve others' challenging arguments and/or claims. Latour and Woolgar stated that "the result of the construction of a fact is that it appears unconstructed by anyone; the result of the rhetorical persuasion in the agnostic field is that participants are convinced that they have not been convinced" (p.240).

In her essay titled "*Beamtimes and Lifetimes-The World of High Energy Physicists,*" Traweek (1988) reports about her observations conducted at the Stanford Linear Accelerator Center (SLAC). Traweek studied the characteristics of the particle physicists' community, how it emerged and evolved, how its novice participants become experts and how knowledge is generated within the norms of the community. She pointed out the role of the physicist network as a way for the novices to connect with the other particle physics community members. Graduate students, for example, were informed to be aware of the physicists' network. The network was essential for the novice researchers to shape their careers in particle physics. Traweek reported that "talk" is an important notion in how physics community members evaluated their peers and each other's work, and persuaded colleagues to support their work. Hence, "talk" is both evaluative and persuasive in particle physics laboratory as well as a means for membership in that culture. Traweek drew some attention to the machines and the detectors utilized in the laboratory and noted that the machines and the detectors are vital to the physics community. She defines a detector as "the target plus the recording device and the computing system that analyzes the records" (p.48). According to Traweek, physicists used these detectors to carry out their investigations, yet without these detectors, the physics community would not exist.

The characteristics of science derived from the history and the philosophy of science perspectives have been integrated in the NOS instructional efforts. Sociological and anthropological lenses of science propose additional characteristics of scientific enterprise that should be integrated in the NOS teaching practices. Sociological characteristics of science can potentially enrich the discourse of students' scientific activities and the context of their interaction during their investigations. Not giving attention to sociological characteristics though greatly reduces the authenticity of the students' scientific investigations. In order to make our point more clear, in the following section we discuss the term authenticity and the authentic scientific activities more details to show how the sociological characteristics of science are critical. We also report how science educations conceptualized and operationalized authenticity in their research studies.

AUTHENTICITY and RELATED STUDIES

Although authentic science or authenticity has received attention in the literature, the meaning of authenticity varies greatly from one study to another. The dictionary definition of an 'authentic' activity refers to an action that is completed in the same way as its original action (Webster, 2002). 'Authenticity' refers to the quality of or condition of being authentic (Webster, 2002). Apart from its dictionary meaning, the meaning of authenticity is described distinctively in authentic science studies.

For instance, Brown et al. (1989) viewed “authentic activities as the ordinary practices of the culture where the meaning and purpose of activities are socially constructed through negotiations among present and past members” (p.34). In his essay titled *Authentic School Science,* Roth (1995) defined ‘authentic’ activities within the notion of ‘community of practice’ (Wenger, 1998). Roth viewed authentic activities similar to the activities scientists do in a community of practice. According to Roth, authentic science practices have ill-defined problems driven with the notion of uncertainty. Similarly, Barab and Hay (2001) defined authenticity ‘as the quality of having correspondence to the world of scientists’ (p.74) and referred to the ‘community of practice’ (Wenger, 1998) in their description.

Schwartz and Crawford (2004) described authenticity as ‘it pertains to the practice of scientific inquiry, conducted by scientists, within the community of science’ (p.337). Authentic science is also attributed to the complex activity that scientists do (Chinn & Malhotra, 2002). Yalvac, Carlsen, and Bauchspies (2006) proposed the context of an authentic scientific inquiry for school science similar to what scientists do in their social organizations, such as, how scientists communicate, negotiate and generate their knowledge claims. Furthermore, Thompson and Parrott (2003) defined ‘authentic science’ as “an activity that is complex, require elaborate procedures, expensive equipment, specialized knowledge and advanced data analysis” (p.1).

Hodson’s categorization of science learning into three elements is insightful to explaining ‘authenticity’ (Hodson, 1998). For the efforts to achieve scientific literacy for *all*, Hodson (1998) argued that there are three elements of science education: (i) learning science; (ii) learning about science; and (iii) doing science. According to Hodson, learning science refers to “acquiring and developing conceptual and theoretical knowledge”; learning about science is “developing an understanding of the nature and methods of science, an appreciation of its history and development, and an awareness of the complex interactions among science, technology, society and environment”; and doing science is attributed to “engaging in and developing expertise in scientific inquiry and problem solving” (p.5). How Hodson defines ‘doing science’ is aligned with the notion of ‘authentic’ scientific activities.

In his learning science design efforts, Edelson (1998) drew attention to three elements of authentic scientific inquiry to be able to adapt science practice to the classroom: (a) attitudes, (b) tools and techniques, and (c) social interaction. In order to better understand scientific practice-- authentic science--, students should be encouraged to develop a commitment to the pursuit of unanswered questions as how scientists develop. Scientific tools and techniques enable scientists to come up with their questions, formulate their investigations, and support them in communicating and collaborating within their communities of science. Edelson mentioned that science is not just hypothesizing, making claims, and doing experiments; instead, science concerns with the interactions among the scientists that provide them with the opportunities that they share their questions, findings, and conclusions with other scientists.

Reeves et al. (2002) emphasized ten facets for an authentic scientific practice task: (1) have real-world relevance; (2) are ill-defined, requiring students to define the tasks and sub-tasks needed to complete the activity; (3) comprise complex tasks to be investigated by students over a sustained period of time; (4) provide the opportunity for students to examine the task from different perspectives, using a variety of resources; (5) provide the opportunity to collaborate; (6) provide the opportunity to reflect; (7) can be integrated and applied across different subject areas and lead beyond domain-specific outcomes; (8) are seamlessly integrated with assessment; (9) create polished products valuable in their own right rather than as preparation for something else; and (10) allow competing solutions and diversity of outcome (p.564).

Researchers proposed different models to engage students in authentic science activities. Barab & Hay (2001) suggested 'simulation model' and 'participation model' to establish authentic science learning environments. In simulation model, students are encouraged to do scientific practices as scientists—the real world practitioners-- do, but within a designed classroom environment similar to a community of practice. In participation model, students are engaged in doing science at the elbow of scientists in laboratory settings. The latter constitutes an authentic learning environment for students to directly engage in science practices with the help of real world practitioners that are the scientists.

Buxton (2006b) proposed three models for authenticity: (a) canonical, (b) youth centered and (c) contextual. Buxton discussed the characteristics of each model separately. Studies under canonical perspectives point out the consistency with scientific practices in a community of scientists. Youth centered studies refer to scientific inquiry tasks that are relevant to students' lives in which students are scaffolded by their teachers. Contextual perspective is an amalgamation of canonical and youth-centered perspective.

Cunningham et al. (2001) discussed the design characteristics of an Environmental Inquiry Project initiated at Cornell University. Their framework involved sociology of scientific knowledge, social construction of technology, and the notion of community of practice along with the situated learning theory. Environmental Inquiry Project was designed to promote authentic scientific inquiry tasks by creating a community of practice where students conducted open-ended inquiry projects. Students were given a bioassay protocol to follow, but they were free to choose the organisms and the toxic chemicals of their interests. Students worked in groups and they collaborated within and across the group members. An online peer review system was used to share students' questions, research design, investigation protocols, findings and conclusions. Sharing their research findings with other students and presenting them to their peers allowed students to construct their understanding of the nature of science. Those understandings included social characteristics of science and its endeavor.

Carlsen (2001) was concerned with environmental science for science education through an NSF funded project called "Environmental Inquiry: Learning Science as Science is Practiced." In this project, students were encouraged to conduct open-ended scientific investigations that the answers of their investigations were not known by their teachers or written in their textbooks. As a part of the environmental project, peer review took place to help students communicate with one another and negotiate their knowledge claims.

Lee & Songer (2003) designed *Kids as Global Scientists* curriculum for middle school students who were engaged in authentic science tasks, such as collecting local weather data, comparing the local data with the data collected in geographically different locations, interpreting weather maps and images, and forecasting real world weather situations. For example, in the forecasting task, students were expected to develop an understanding of real world weather situations through which content knowledge was transformed, scientific thinking skills were emphasized, and meteorologists' forecasting practices were utilized by the students.

In Griffing's study (2003), teachers and graduate students participated in a summer workshop to initiate an authentic scientific investigation by asking good questions that are not answered yet. Using information technologies and scaffolding of a scientists, study participants designed and evaluated their activities. Participants used image databases, spreadsheets, and image processing software to access and analyze the cell biology imaging data. In addition, analogies were used to scaffold the participants to better help them understand cell biology images. Griffing's study participants experienced an authentic scientific investigation context using information technology approaches.

Scallon (2006) conducted a study to explore the impact of a guided inquiry versus an authentic scientific investigation on students' conceptual understandings, their understandings of scientific investigation, and their practical reasoning skills. According to their research interests, student participants engaged in scientific inquiry activities. Participants were eight grade students from six classes in a rural school. The study lasted nine-weeks. Findings showed that guided inquiry group gained more conceptual understanding than the authentic scientific group gained. The authentic scientific investigation group gained significantly better understandings of scientific investigation and improved their practical reasoning skills than the guided inquiry project group.

DISCUSSION and IMPLICATIONS

The position that scientists' typical practices in the laboratory settings and within their communities can be translated for K-12 science classrooms puts a strong emphasis on authentic science practices in science teaching. For the efforts to engage students in authentic school-science practices, anthropological and sociological lenses of science have provided valuable insights. Even though the definition of the term authentic, or authenticity, has varied in the recent studies, researchers agreed upon the significance of teaching through scientific inquiry at K-16 levels. The characteristics of the scientific inquiry student should complete is, however, not well-defined. There is an ongoing discussion about the essential characteristics of scientific inquiry teaching methods.

In this paper our interpretation of authentic scientific inquiry is that students are given the opportunities to conduct open-ended inquiry tasks within the notion of the communities of practice (Wegner, 1998). So instead of following the curriculum initiated content knowledge, students' authentic inquiry tasks should evolve over the student defined content for an authentic scientific inquiry experience. In their authentic (scientific) inquiry, students should generate their own research questions that are meaningful to them or to their communities, identify ways of resolving the questions they have generated, conduct empirical investigations, and construct their knowledge claims. Resolving and constructing students' knowledge claims should involve the appropriate steps of convincing peers in light of their investigation findings, study results, and/or claims; negotiating and discussing their claims collaboratively and socially. It is apparent that the end product of their investigation as knowledge claims should not be the main final objective of their inquiry tasks, indeed students' formulation of their inquiry tasks and the steps they follow should be the means for assessment and evaluation. This assessment process resembles the peer review and the reward system of scientific communities.

In adopting the real science practices in science teaching, Edelson (1998) criticized that traditional science teachers have not been prepared to appropriately urging their students to engage in uncertain science, helping them use the tools and techniques (instead of rote-memorization or comprehension of them), and encouraging social interactions and negotiations among them. Edelson pointed out the role of technology as a scaffolding tool that can allow students to engage in authentic science practices. Effective use of technology can support and sustain effective communication and collaborative activities among the members of the community students and teachers form together.

Authentic science practices have been criticized as too demanding to be implemented in school science. They are viewed as complex activities because they require 'expensive equipment, elaborative procedures, advanced theoretical knowledge, highly specialized expertise and advanced techniques for data analysis and modeling' (Dunbar, 1995; Galison, 1997; Giere, 1988, as cited in

Chinn & Malhotra, 2002, p.177; Thompson & Parrott, 2003, p.1). However if one views the authentic inquiry tasks students will engage in are not necessarily investigating the same topics that practicing scientists investigate (e.g., studies in particle physics or in medicine), then most of the demanding features of authentic scientific practices will no longer be a concern or a limitation. Teachers can create authentic learning environment that does not require expensive and advanced equipments and techniques (Roth, 1995), if we do not limit our imagination with the curriculum dictated content or its taxonomy.

Adapting authentic science practices in science classroom asks for three principles. One is that pre-service and in-service science teachers should be familiar with the features of authentic science practices grounded in anthropological and sociological lenses of science. Two is that students should be given the opportunity to formulate their own open-ended inquiry context that is not limited with the science curriculum or its taxonomy. Third is that accountability should not be on teaching student the content knowledge presented in the textbooks, or dictated by the curriculum; instead, the curriculum in general and teachers in particular should promote the formulation of communities of practice and implementation of authentic scientific practices in school science.

As for pre-service science teachers, we suggest that science teacher programs should inform pre-service teachers about the concept of communities of practices (Wenger, 1998) in science methods courses where the social theory of learning is taught and discussed. Student teachers can be engaged in authentic science practices in the laboratory settings where they will work at the elbows of scientists so that they will understand how scientists work in their social environment, in other words, how scientists generate their research question and how their social collaboration and negotiation shape their scientific work in establishing knowledge claims. Getting involved in authentic science practices with scientists can help teachers understand that doing science is engaging in and developing expertise in scientific inquiry and problem solving, and that learning science either from science textbook or from science teachers is not real world science.

As for experienced science teachers, professional development practices can cover the characteristics of authentic science practices and formulation of communities of practice. Teachers should be provided with the opportunities that allow them to work with scientists so that they will personally and socially experience what ‘doing science’ is. It is essential to note here that school-university partnership is critical to implement and exemplify authentic science practices to K-12 teachers and student. Although many school science programs and national stake tests push science teachers to devote their time and efforts towards the standardized tests or other nationwide exams, professional development workshops can convey the characteristics of learning science, learning about science, and doing science.

As for students regardless of age, sex, and grade level, they should be given the opportunities to participate in authentic learning environments where they will engage in real scientific practice because they have been repeatedly told that scientific concepts can be learned through reading science textbooks or listening to their science teachers, which in turn led them to formulate naïve understandings of science and its enterprise. The concepts of uncertainty, commitment, mutual engagement, shared repertoire, and collaboration in scientific practice should be exposed to every citizen so that the people will not view science as a body of knowledge explaining the physical phenomenon, but a social human activity that is parsimonious and social. This is contradictory to learning "science" from textbook materials or from their teachers that perpetrates the 'normal science'. Recent science education standards and documents promote the idea that science students should be directed toward doing science activities (NRC, 1996; AAAS, 1993). School-university or school-research center partnerships where student and teachers can engage in doing science activities at the elbow of scientists are potentially powerful to cultivate informed understanding of the nature of science for *all*.

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