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Inquiry in Science Education: International Perspectives

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ABSTRACT: This paper set emerged from an international symposium that aimed to shed light on issues associated with the enactment of inquiry both as means (i.e., inquiry as an instructional approach) and as ends (i.e., inquiry as a learning outcome) in precollege science classrooms. The symposium contributors were charged with providing perspectives from

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their countries on the following major themes: (a) philosophical and practical conceptions of inquiry in the science curriculum; (b) images of the enactment of inquiry in the curriculum, curricular materials, classroom instruction, and assessment practices; and (c) factors and conditions, internal and external to the educational setting, which facilitate or impede inquiry-based science education. Another major theme that emerged from the symposium was related to the very conceptions of inquiry teaching. The individual contributions and synthesizing commentaries demonstrate that despite their situatedness and diversity, many themes and issues cut across the represented locales, and serve to show the significance and potential fruitfulness of any discourse regarding inquiry in science education that this paper set might, and we hope will, trigger in the near future. *Sci Ed* **88:**397–419, 2004; Published online in Wiley InterScience (www.interscience.wiley.com). DOI 10.1002/sce.10118

INTRODUCTION (*FOUAD ABD-EL-KHALICK*)

"Inquiry" has been a perennial and central term in the rhetoric of past and present science education reforms in the United States. During the second half of the twentieth century, "good science teaching and learning" has come to be distinctly and increasingly associated with the term inquiry (Anderson, 2002). Presently, "inquiry teaching" serves as the benchmark for sounding dissatisfaction with current, and advancing images that are commensurate with, envisioned and espoused practices in precollege science teaching. Current science education reform documents in the United States [i.e., American Association for the Advancement of Science (AAAS), 1990; National Research Council (NRC), 1996] present generalized conceptions of inquiry teaching and learning that are claimed to reflect current scholarship on nature of science (NOS) and in education. An undercurrent theme in these conceptions is advancing and distinguishing between inquiry as means and ends. "Inquiry as means" (or inquiry *in* science) refers to inquiry as an instructional approach intended to help students develop understandings of science content (i.e., content serves as an end or instructional outcome). "Inquiry as ends" (or inquiry *about* science) refers to inquiry as an instructional outcome: Students learn to do inquiry in the context of science content and develop epistemological understandings about NOS and the development of scientific knowledge, as well as relevant inquiry skills (e.g., identifying problems, generating research questions, designing and conducting investigations, and formulating, communicating, and defending hypotheses, models, and explanations).

While reform documents do not operationally define inquiry teaching and learning, some documents, such as the *National Science Education Standards* (NSES) (NRC, 1996), present lively vignettes of how an inquiry approach to teaching and learning would be enacted in precollege science classrooms (Anderson, 2002). Such vignettes put aside, however, the only kind of (inquiry) teaching that *happens* is the kind that is enacted in actual classrooms. Irrespective of how inquiry has been conceptualized during the past 50 years or so, and conceptions of inquiry have changed during this period, research has consistently indicated that what is enacted in classrooms is mostly incommensurate with visions of inquiry put forth in reform documents, past (e.g., Rutherford, 1964; Welch et al., 1981) and present (e.g., Anderson, 2002; NRC, 1996).

The history of science education reforms in the United States has taught us that when envisioned conceptions of inquiry meet the reality of schools and classroom teaching, and the associated social, political, economic, and cultural spheres, these more philosophical conceptions are often transformed into incommensurate (practical) curricula and then translated into incongruent enactments or classroom practices. This incongruency has long been recognized and researched and was often explained in terms of barriers that impeded the enactment of inquiry in classrooms and schools. These barriers ranged from the localized to those that cut across contexts (at least, in North America), from the technical to the political, and from factors associated with science teachers to those related to the culture of school science (e.g., Anderson, 1996, 2002; Welch et al., 1981). This line of research underlies the more systemic approaches to science education reform evident in more recent efforts (e.g., NRC, 1996). What is encouraging about such research is that, in some cases, addressing the identified barriers resulted in improved inquiry instruction in science classrooms (e.g., Duschl & Gitomer, 1997; Krajcik et al., 1994).

The ubiquitousness of inquiry, nonetheless, extends far beyond the locale of the United States. Indeed, the notion of "inquiry in science education" is one of the few overarching themes that cut across precollege science curricula in countries around the globe [e.g., Millar & Osborne, 1998; Ministry of Education (ME), 1999; National Center for Educational Research and Development (NCERD), 1997; Tomorrow 98, 1992]. One would imagine that, like the case of the United States briefly described above, such an international focus would bring along a host of similar and/or markedly different issues (e.g., barriers) associated with the enactment of inquiry in the unique contexts of countries around the world. An inquiry into these issues would benefit discussions about, and research into, inquiry-based teaching and learning in the science education community writ large. Motivated by this focus, the primary author led an interpretive inquiry, undertaken in the context of a symposium conducted at an international science education meeting (Abd-El-Khalick et al., 2001), which originally aimed to shed light on issues associated with the enactment of inquiry both as means and as ends in precollege science education from the perspectives of several members of the international science education community. It should be noted that, in *retrospect*, the focus of the symposium entailed the significant (and probably unwarranted) assumption that core conceptions or visions of inquiry in precollege science education were, more or less, shared among the various participant countries.

To achieve the above aim, the primary author charged the symposium participants, representing six countries across three continents, with providing perspectives from their countries in response to the following questions: (a) How is inquiry philosophically conceived and practically defined in your national or state curriculum (if any)? (b) Is inquiry enacted in the curriculum, curricular materials, science teaching, and assessment practices? If yes, how and to what extent? and (c) What factors and conditions, internal and external to the educational setting, facilitate or impede inquiry-based science education in your country or state? It was hoped that addressing these questions would allow making informed inferences about issues associated with the enactment of inquiry in precollege science classrooms in participants' countries. Richard Duschl was invited to serve as a discussant for the symposium and charged with identifying and discussing themes that cut across participants' contributions. During the symposium, however, other important themes emerged that were related to another major domain, namely, the very conceptualization of inquiry teaching and learning: The meaning of inquiry, its relationship with NOS and scientific literacy, and the multiple agendas that inquiry teaching is charged with achieving in science education. Participants agreed to share their ideas and contributions with the science education community. Commentaries by Richard Duschl and the primary author, which were written after the symposium, were added to participants' contributions to constitute this paper set, which was transformed during postsymposium writings and revisions into an inquiry into "inquiry in science education."

The paper is organized as follows: This introduction is followed by six brief contributions that represent individual participants' (revised) responses to the charge of the symposium. These contributions can also be thought of as data points for this interpretive inquiry. The reader will note that the contributors chose different units of analysis, if you will, to address the aforementioned questions. These units ranged from broad overviews of the state-of-affairs in a certain nation (e.g., Norman Lederman) to a case study of a particular curricular project within a country (e.g., Rachel Mamlok & Avi Hofstein). This variety serves to show how conceptions of inquiry and its enactment in classrooms are highly contextualized and intertwined with agents' (e.g., researchers, educators) unique relevant experiences. Each contribution, nonetheless, presents insights into the major theme of the paper set and, as they go from one contribution to the next, readers are invited to draw their own conclusions regarding the overt and implied themes and issues in these contributions. It should be noted that the primary author edited the contributions to provide some degree of coherence, but made every effort to maintain the unique character of each contribution and the voice of the contributor. A commentary by Richard Duschl follows the individual contributions and focuses, by and large, on emergent themes related to conceptions of inquiry teaching. The commentary situates these conceptions in a larger framework, and puts forth some worthwhile future directions. Next, some closing remarks by the primary author raise further issues and questions about inquiry in science education. Among other things, the individual contributions, commentary, and closing remarks (a) demonstrate that despite their situatedness and diversity, many themes and issues cut across the represented locales, and (b) highlight the significance and potential fruitfulness of any discourse that this paper set might, and we hope will, trigger in the near future.

SCIENTIFIC INQUIRY IN THE LEBANESE SCIENCE CURRICULUM (*SAOUMA BOUJAOUDE*)

In 1994, the Council of Ministers adopted the National Educational Plan, which was translated 3 years later into a new national curriculum (NCERD, 1994, 1997). Similar to many countries around the world, the goal of helping precollege students achieve scientific literacy is central to the new Lebanese science curriculum. This goal, coupled with specific inquiry-related objectives in the various science content areas, may be interpreted as a charge to help Lebanese students develop an understanding of, and ability to engage in, scientific inquiry, among other educational outcomes.

Conceptions of Scientific Inquiry

For the first time in its history, Lebanon now had a detailed science curriculum with explanatory introductions, general and specific objectives, and instructional activities, which made it amenable to analysis. BouJaoude (2002) developed and used an analytical framework to assess whether and to what extent inquiry was addressed in the new curriculum. The framework comprised four aspects: The knowledge of science, the investigative nature of science, science as a way of thinking, and interaction of science, technology, and society. Results indicated that 12% of the general objectives had to do with the investigative nature of science, which is taken here to refer to scientific inquiry. Moreover, this latter component had received increasing attention at all levels of the new curriculum. It is evident that the curriculum developers had attempted to address scientific inquiry, which seems to be an improvement over the previous curriculum in terms of the increasing emphasis on specific objectives and activities that encourage inquiry.

The above analysis, however, indicated that the new science curriculum lacked a coherent and well thought-out framework regarding inquiry. Rather, a few general ideas about science process skills, experiments, and a universal "Scientific Method" were scattered in the introductions and objectives for each educational level. For example, one general objective of the new NCERD (1997) curriculum is to "develop learners' intellectual and practical scientific skills" (p. 458). At the lower elementary level this objective seems to translate into the expectation that teachers would help students "carry out guided simple experiments and practice problem solving" (p. 465). However, despite the lack of additional objectives that set out to progressively develop students' inquiry understandings and skills, upper elementary students are expected to "carry out experiments and explain their results, plan experiments and control the variables, state expectations of what will happen in an experiment or in nature and compare them with the actual results" (p. 467). At the intermediate and secondary levels, there is a reversion to emphasizing decontextualized basic and integrated science process skills (e.g., observing, representing and analyzing data, drawing conclusions) in the rigid framework of (a noncritical adoption of) "The Scientific Method."

Factors Facilitating and Impeding the Enactment of Inquiry in Lebanese Classrooms

The emphasis given to inquiry in the new curricular documents (e.g., NCERD, 1994, 1997) is rather encouraging. Nonetheless, the significant question remains: Is inquiry being implemented in Lebanese precollege science classrooms? It is premature to generalize about the extent to which the new curriculum is being enacted as envisaged by its developers because of the lack of systematic empirical research on the topic. However, anecdotal evidence, and our first-hand observations of, and experiences with, science instruction in Lebanon prior to, and during the first few years following the introduction of the new curriculum, suggest that science instruction is still traditional in nature: Instruction is largely limited to a didactic chalk-and-talk approach coupled with occasional verification-type laboratory experiences.

It seems that the curricular emphasis on inquiry, while necessary, is not sufficient for the fruitful implementation of inquiry approaches to the teaching and learning of science in Lebanon. To start with, the absence of a clearly formulated philosophy of the nature of scientific inquiry may confuse Lebanese science teachers. For example, are teachers expected to teach science as inquiry or science through inquiry or both? It is partially clear that the curriculum encourages teaching science through inquiry. But what about science as inquiry? The assumption that teaching science through inquiry will lead students to understand science as inquiry may not be tenable, and in consequence, students may be losing out if one of the approaches is emphasized to the neglect of the other. Another potential problem is that the scope of the definition of inquiry presented (or inferred) from the curriculum is very limited. Such a definition seems to restrict inquiry to a collection of discrete science process skills implemented sequentially through (the mythical) "Scientific Method." What is more, the curriculum seems to highlight the hands-on component of inquiry or "doing science" to the neglect of the minds-on component. Here also, focusing on one aspect and not the other may be problematic for a meaningful enactment of inquiry in precollege science classrooms.

Finally, it should be noted that in addition to the curriculum, other components, including teaching, the quality of textbooks, and assessment practices, are important factors that need to be considered if students' experiences with scientific inquiry are to be fruitful and fulfilling. For instance, high stakes assessment is an important feature of the Lebanese educational system. To date, these assessments are not aligned with the emphasis given to inquiry in the new curricular documents (Osman, 1995). Thus, teachers lack the incentive to change their teaching, and writers and publishers the motive to emphasize inquiry in their textbooks, thus thwarting the attempts to reform the Lebanese science curriculum and rendering it more inquiry-oriented.

SCIENTIFIC INQUIRY AND SCIENCE EDUCATION REFORM IN THE UNITED STATES (*NORMAN G. LEDERMAN*)

Standards-based curricula and instruction appear to be necessary if science teaching and learning are to progress in a unified direction during the 21st century. Although flexibility and independence are important for school districts and states, there is value in the development and implementation of coherent themes, such as scientific literacy and inquiry, that serve as guiding frameworks for all to achieve. Indeed, such frameworks do not prevent individual school districts from fashioning curricula that address site-specific needs and interests. It is for this reason that the AAAS (1990) and NRC (1996) are adamant that neither reform document is a national curriculum. The question follows: To what extent do conceptions of inquiry in these documents provide a coherent guiding framework for reform-minded teachers, districts, and states?

Conceptions of Scientific Inquiry in the Reform Documents

There have been several reform efforts in the history of science education in the United States, but current reforms (i.e., AAAS, 1990; NRC, 1996) distinguish themselves from previous efforts in significant ways. One central difference is represented in placing extensive emphasis on scientific inquiry and NOS as cognitive outcomes. That is, students are not merely expected to master a set of inquiry-related skills but also to develop understandings *about* inquiry. For example, in addition to being able to devise valid research designs, students are expected to realize that investigations can take many forms and that the notion of a universal and procedural "Scientific Method" is an inaccurate representation of the scientific enterprise.

To my mind, a stress on understandings *about* inquiry is clearly more consistent with the goal of scientific literacy than the more perennial stress on *doing* inquiry. Indeed, do we expect citizens to execute a scientific investigation every time a decision on a science-related personal or social issue is needed: Of course not. Rather, our citizens are expected to know enough *about* science content, inquiry, and NOS to be able to understand scientific claims and make informed decisions. This goal of the reforms seems to have been forgotten in the push for all students to do independent inquiries. Certainly doing inquiry provides students with an important experiential base, but we are educating the overwhelming majority of our students to become critical consumers of science and participants in a scientifically laden culture. The AAAS (1990) document seems to have placed due emphasis on understandings *about* scientific inquiry. The NRC (1996) document, however, appears to place an equal emphasis on *doing* and knowing *about* inquiry, thus, in a sense, diluting the emphasis on the latter component.

The Enactment of Conceptions of Inquiry in Science Curricula

Many states have emulated the reform documents in the development of their science learning standards, but misconceptions about what these documents intended are widespread. Although many states have clearly followed up on the importance of students performing scientific inquiry, it is not uncommon for state documents and related professional development activities to omit attention to understandings *about* inquiry and NOS. To cite just one example, Oregon is guilty of these omissions in its attention to scientific inquiry (see Oregon Department of Education, 2001). This omission is not only evident in Oregon's science standards and teaching standard, but also equally prevalent in associated assessment practices. The scoring rubrics for student work samples on inquiry in Oregon focus exclusively on students' science process skills (e.g., formulating research questions, developing and implementing research designs, and analyzing data). It is, perhaps, understandable for states and districts to disregard (purposefully or inadvertently) the unique aspects of the current reforms. After all, understandings *about* inquiry and NOS are not common to most science curricula, and their assessment is equally unfamiliar. While understandable, this omission is unfortunate because these understandings are central to achieving scientific literacy as defined in current reform documents.

Scientific Inquiry and the Reforms: Prospects and Hurdles

The current reform efforts appear to have already impacted how science is taught in the United States. Most would agree that more attention to scientific inquiry is evident in both instruction and students' activities. My biggest fear for the future, however, is that science teaching will continue to focus on the performance of inquiry skills to the exclusion of understandings about inquiry and NOS, let alone foundational disciplinary subject matter. Without attending to this shortcoming, current efforts are not likely to accomplish the goal of scientific literacy any more so than the reforms of the 1960s. Those efforts only modestly developed students' abilities to perform certain rather regimented sets of science process skills. Students became highly skilled in making observations, but they knew little about the ontological status of the conclusions they made or the "knowledge" they produced. Students then did not (and probably will not in the future) develop the knowledge and skills to make informed decisions regarding everyday science-related personal and societal issues.

What is more, another problem is likely to hamper the actualization of well-intended efforts in those states, districts, and schools, which interpreted the reform documents accurately and realized the importance of students' understandings *about* inquiry and NOS. This problem is related to widespread misconceptions about *how* to help students achieve the desired outcomes. In particular, it is often believed that students will develop understandings about scientific inquiry and NOS simply by doing science. Having students experience authentic inquiry is absolutely necessary, but not sufficient. There is extensive research, extending over 30 years, which indicates that students do not come to understand either inquiry or NOS as a consequence of having experienced scientific inquiry or inquiry-oriented classroom climates (e.g., Durkee, 1974; Tamir, 1972; Trent, 1965). Unfortunately, the approach for teaching *about* inquiry and NOS implied in the NRC (1996) document is not consistent with such research and commits the same mistake of assuming that students learn *about* inquiry and NOS implicitly.

Student knowledge about inquiry and NOS does not occur by accident. Students do not develop such understandings simply through experiencing inquiry any more so than we would expect them to develop understandings of photosynthesis simply by watching plants grow. Teachers need to *explicitly* address the reform-based goals related to knowledge *about* inquiry and NOS within instruction about "traditional" science content and process skills. This end is best accomplished by having students perform scientific investigations followed by reflection on these activities and the nature of the knowledge produced. "Explicit" in this context does not refer to *direct* instruction. Indeed, allowing students to come to the desired understandings on their own with the aid of carefully crafted experiences and reflective questions is a much more effective approach. For several years now, we have consistently provided empirical evidence (e.g., Abd-El-Khalick, Bell, & Lederman, 1998; Akerson, Abd-El-Khalick, & Lederman, 2000; Khishfe & Abd-El-Khalick, 2002) for the success of an explicit reflective approach in improving both students' and teachers' conceptions of scientific inquiry and NOS.

If we are to achieve the scientific literacy goals as specified in the reform documents, extensive professional development efforts relative to inquiry and NOS are necessary. These efforts should not, and cannot, assume that teachers already possess knowledge about inquiry and NOS, let alone teach these to their students. Most science teachers have never directly experienced authentic scientific inquiry during their education in the sciences or within teacher education programs (Hahn & Gilmer, 2000). A critical component of professional development in this regard, at least intuitively, should include direct experiences with science as it is practiced in active research laboratories. However, research supporting the value of such experiences is yet to be available. Teachers need to be well versed in scientific inquiry as a teaching approach, a set of process skills, and a content area. In addition, teachers need to develop those pedagogical skills necessary to effectively teach about inquiry and NOS, that is, pedagogical content knowledge for inquiry and NOS. Finally, teachers *must* value knowledge *about* inquiry and NOS as important, if not more so, as "traditional" subject matter. Having the knowledge and the ability to teach scientific inquiry and NOS is of little use if science teachers do not value the importance of these instructional outcomes. Such importance is not intuitively obvious to teachers and students. How to enhance teachers' valuing of these curriculum emphases should occupy a prominent position in future research efforts.

INQUIRY TEACHING IN ISRAEL: THE CASE OF HIGH SCHOOL CHEMISTRY LABORATORIES (*RACHEL MAMLOK-NAAMAN AND AVI HOFSTEIN*)

Conceptions of Scientific Inquiry

Inquiry-type laboratories, we believe, provide an exemplar for the enactment of inquiry in Israeli precollege science classrooms through providing a context for students to experience authentic scientific inquiry. Many science educators believe that, when properly developed, inquiry laboratories have the potential to enhance students' constructive learning, conceptual understanding, and understandings of NOS (Hofstein & Lunetta, 1982, 2004). These laboratories involve conceiving problems, formulating hypotheses, designing experiments, gathering and analyzing data, and drawing conclusions about scientific problems or natural phenomena, and are especially effective if conducted in the context of, and integrated with, the development of scientific concepts and processes (Hofstein & Walberg, 1995). The successful implementation of our vision for inquiry laboratories, however, has been a challenging undertaking. Below, we discuss our experiences with such implementation in the case of high school chemistry. While specific to this latter context, we believe that our discussion sheds light on the broader picture concerning the enactment of inquiry-type laboratories in Israeli science classrooms.

Enactment of Inquiry in Curricular Materials, Teaching, and Assessment Practices

Inquiry laboratories were implemented in the context of the high school chemistry curriculum as part of comprehensive science education reform efforts in Israel (Tomorrow 98,

1992) that aimed to help all students achieve scientific literacy. *Chemistry: A Challenge* (Ben-Zvi & Silberstein, 1985) serves as the chemistry curriculum in Israeli high schools. The introduction of inquiry laboratories into this curriculum started in 1997 and involved several stages: the development of experiments, the design of tools to assess student achievement of the desired outcomes, long-term and intensive professional development experiences for chemistry teachers, and the implementation of these activities in a number of high school classrooms.

During the past 5 years, a series of about 100 experiments were designed to help students develop conceptual understandings of (a) chemical concepts that were integral to the chemistry curriculum, such as the properties of substances and compounds, acids and bases, oxidation–reduction reactions, and bonding and energy, and (b) the process of building and justifying scientific claims. The experiments were designed to be carried out by small student groups and ranged from well-defined "close-ended" to ill-defined "open-ended" investigations. Thus, at times students were only involved in partial inquiry, if you will, while at other times they engaged in the full process of asking a question, hypothesizing, planning an experiment, collecting, recording, and interpreting data, and arriving at a valid conclusion.

These inquiry laboratories were designed to avoid the well-documented pitfalls that have long hampered the actualization of the role envisioned for laboratories in science education. Among these pitfalls is the absence of sustained professional development activities that enable teachers to actualize the inherent advantages of inquiry laboratories (Krajcik, Mamlok, & Hug, 2001) and a persistent lack of valid and usable tools to assess progress toward, and achievement of, desired laboratory outcomes coupled with a lack of teachers' experience with such tools (Lazarowitz & Tamir, 1994). Thus, our participant teachers were involved in long-term and intensive professional development activities. They were also engaged in designing relevant assessment tools, identifying assessment criteria, and using the tools in different contexts with the intent of improving their validity and utility. Next, the laboratories were implemented in several high schools. Following the initial trial years, we devoted our time to the dissemination of the program and the evaluation of its impact on teachers' instructional and assessment practices, and students' performance and perceptions of the laboratory-learning environment.

Inquiry-Type Laboratories: Benefits and Burdens

Our research indicates that participant teachers perceived their intensive professional development activities as vital for the successful implementation of inquiry laboratories in their classrooms. Teachers indicated that these activities reduced their anxiety and increased their confidence to use a student-centered teaching approach, which required them to reconceptualize their role in the classroom from disseminators of knowledge to facilitators of learning. Students felt they were more involved in the learning process and indicated that they had generally favorable attitudes regarding their laboratory experiences. Some noted that these experiences provided them with opportunities to develop independent thinking, make sense of chemical concepts, and enjoy a group learning environment (Hofstein, Levi Nahum, & Shore, 2001).

The above successes, nonetheless, required enormous efforts and resources. To start with, considerable human and monetary resources went into the development of experiments, design of assessment tools, and professional development of teachers. Also, teachers received continuous support and guidance from the development and research teams. These efforts continue to date. Our experiences with implementing the chemistry program in 40 schools, though promising, provide a glimpse into the difficulties associated with the large-scale implementation of such an instructional approach across Israel and various science content areas. No doubt, such implementation would require the prolonged commitment and concerted efforts of all parties involved, including curriculum developers, researchers, teacher education programs, school administrators, science teachers, and students. Such efforts also require the financial and administrative support of the Ministry of Education.

INQUIRY LEARNING: A VENEZUELAN PERSPECTIVE (*MANSOOR NIAZ*)

Inquiry, Constructivism, and NOS

An important charge for science education is that students are not only expected to learn science content but also acquire scientific attitudes and grasp the intricacies of scientific inquiry. Indeed, Rutherford (1964), an early proponent of inquiry learning, emphatically argued that

> When it comes to the teaching of science it is perfectly clear where we, as science teachers, science educators, or scientists, stand; we are unalterably opposed to the rote memorization of the mere facts and minutiae of science. By contrast, we stand foursquare for the teaching of the scientific method, critical thinking, the scientific attitude, the problem-solving approach, the discovery method, and, of special interest here, the inquiry method. (p. 80)

Discussions of inquiry cannot, at least presently, be divorced from discussions of constructivism, which necessarily bring along issues related to NOS. The close relationship between NOS and constructivism has been recognized by Matthews (2000): "Constructivism is at its core, as it was with Piaget, an epistemological doctrine; and it is standardly coupled with commitments to certain postpositivist, postmodernist, antirealist, and instrumentalist views about the nature of science" (p. 165). Moreover, inquiry and constructivist teaching approaches seem to share many educational objectives, such as emphasizing student construction of concepts and the relationship between student acquisition of concepts and the concepts' development in the history of science.

Presently there is considerable debate among philosophers of science regarding NOS (Cartwright, 1983; Giere, 1999; Koertge, 2000; Kuhn, 1970; Lakatos, 1970; van Fraassen, 2000). Nevertheless, a review of recent literature in science education shows that it is possible to achieve a consensus view of NOS based on a number of aspects including that (cf. Abd-El-Khalick & Lederman, 2000) (a) scientific knowledge is tentative, (b) there is no universal scientific method, (c) theories do not become laws with the accumulation of supporting evidence, (d) scientific activities are theory-laden, (e) scientific knowledge relies on observation, rational arguments, creativity, and skepticism, and (f) scientific ideas are affected by their social and historical milieu. It is noteworthy that these consensus aspects do *not* explicitly confront controversial issues, such as the nature of reality or the ontological status of scientific concepts.

Under such a consensus framework for NOS, it *seems* possible to strike an accord between conceptions of inquiry, NOS, and constructivism. Nonetheless, as one might imagine, if controversial issues are brought into the mix, such an accord is likely to dissolve. This was the case in Venezuela, where the majority of curriculum designers and educators subscribed to radical conceptions of constructivism (cf. Morin, 1995; von Glasersfeld, 1989; Wertsch, 1985). The appeal of radical constructivist ideas grew to the extent that in 1998 the central Ministry of Education (ME) considered the incorporation of these ideas in curriculum projects. However, the move to adopt radical constructivism and associated philosophies and research methodologies (e.g., postmodernism, transdisciplinary theory, action research) as major themes in Venezuelan formal education was blocked following heated debates in educational and political circles (Esté, 2000; Gurfinkel, 1999). The debates gained special significance as they came to focus on fundamental issues, such as what counts as "scientific," when the scientific status of radical constructivism was scrutinized. Regardless of the outcome, these debates clearly showed that Venezuelan educators did not share a framework for NOS, scientific inquiry, or the implications of constructivist ideas for school curricula. Thus, one is entitled to ask about conceptions of scientific inquiry that are enacted in the Venezuelan science curriculum.

Inquiry in the Venezuelan Secondary School Science Curriculum

The most current Venezuelan "Programa de Articulación" for secondary education does not present clearly articulated conceptions of scientific inquiry. Rather, the ME (1990) document presents a list of goals for science education that conflates different aspects of inquiry, science process skills, and some discrete aspects of NOS. The ME argues that science education should emphasize the following aspects: (a) processes of science, such as observation, and data collection, representation, and interpretation, (b) methodological strategies that permit students to make decisions and stimulate creativity, (c) a dynamic vision of scientific activity in which knowledge is conceived as "temporary truths" and useful, (d) problem-solving with the objective of establishing a close relationship between work, production, science, and society, (e) laboratory and fieldwork based on simple investigations performed individually or in groups, and (f) quantification that stresses the analysis of data and formulae and deemphasizes the repetitive solving of numerical problems (pp. 10 and 11). Additionally, the curriculum provides a framework (Pedagogical Projects for the Classroom) for incorporating various aspects of inquiry by including activities based on local problems (e.g., environmental issues).

Enactment of Inquiry in Curricular Materials

The lack of a clear framework for inquiry and NOS in the science curriculum resulted in conveying contradictory messages to teachers in curricular materials. The topic of atomic structure is an illustrative case. The "Programa de Articulación" (ME, 1990) clearly states that the objectives of the unit on atomic structure are to study, among others, the contributions of Dalton, Thomson, Millikan, Rutherford, and Bohr (p. 38). This is a welcomed emphasis: Recent research in science education indicates that the historical study of atomic structure serves as a useful context for helping students investigate and internalize some consensus views about NOS, such as the tentative nature of scientific theories, and develop fundamental understandings about the nature of inquiry (Niaz, 1998, 2000). Interestingly, in the section on methodological suggestions for teachers, the ME document states that "it is not necessary . . . to focus on a historical development of the atomic models, as it would take more time to cover the unit" (p. 39). The potential of this unit to contribute to students' understandings *about* the scientific endeavor is thus minimized, probably because of the lack of a clearly articulated vision of the relationship between NOS, inquiry, and constructing understandings of scientific concepts in the science curriculum. In the absence of such an articulated and informed vision, it appears that the inclusion of some aspects of inquiry learning and NOS in the Venezuelan secondary education curriculum will not ensure its implementation in the classroom.

INQUIRY IN SCIENCE EDUCATION: AN AUSTRALIAN PERSPECTIVE (*DAVID F. TREAGUST*)

Philosophical Conceptions and Practical Definitions of Inquiry

The major goal of science education in Australia is improving the scientific literacy of students. In the early 1990s, the Australian Education Council put forth a set of national profiles and statements that served as a common framework for curriculum development in eight learning areas, including science, in terms of content, concepts, and processes. Some states adopted these profiles while other states made significant changes to them (Goodrun, Hackling, & Rennie, 2000). In Western Australia, the Education Department began a 2-year trial of the national profiles and, building on work carried out during and after this trial, produced the Western Australian K-12 Curriculum Framework (Curriculum Council, 1998) for eight learning areas including science. According to the Curriculum Council (1998)

> Science has many methods of investigation, but all are based on the notion that some form of evidence is the basis for defensible conclusions. Because scientific explanations are open to scrutiny, much scientific knowledge is tentative and is continually refined in the light of new evidence. The quest to construct coherent, tested, public and useful scientific knowledge requires people in their scientific undertakings to be creative and open to new ideas, to be intellectually honest, to evaluate arguments with skepticism, and to conduct their work in ways which are ethical, fair and respectful of others. (p. 218)

It should be noted that nowhere in the Curriculum Council (1998) document is the word "inquiry" used. Rather, the emphasis is on *investigating* whereby "students investigate to answer the questions about the natural and technological world using reflection and analysis to prepare a plan; to collect, process and interpret data; to communicate conclusions; and to evaluate their plan, procedures and findings" (p. 220).

Enactment of Inquiry in the Curriculum, Curricular Materials, and Classroom Instruction

Goodrun, Hackling, and Rennie (2000) paint an ideal picture of science teaching and learning involving nine themes, one of which is inquiry: "Students investigate, construct and test ideas and explanations about the natural world" (p. vii). Their research shows that science teaching and learning in Australia is centered on inquiry, though the term "investigation" is overtly used rather than the term "inquiry" in science education documents. This notion of investigating is included within the Working Scientifically strand of the Curriculum Framework, which comprises five outcomes: investigating, communicating scientifically, science in daily life, acting responsibly, and science in society. In planning curricula, learning experiences should link these outcomes with the development of conceptual scientific understandings and the process outcomes in other learning areas. According to Goodrun, Hackling, and Rennie (2000), working scientifically involves more than

> The processes of science . . . that stress learning skills such as observations, inference and designing a controlled experiment . . . Inquiry means that students combine these scientific processes with scientific knowledge as they reason and think critically about evidence and explanations to develop their understanding in science and ability to communicate scientific arguments. (pp. 145–146)

According to the Curriculum Council (1998), students plan investigations using a variety of processes that may involve "exploring ideas and materials; reflecting on their knowledge and experience; reviewing background information; thinking laterally; discussing ideas; clarifying purposes; identifying variables; making predictions . . . that lead to research questions or hypotheses; and inventing feasible, valid and accurate strategies for investigation" (p. 222). So the essential elements of inquiry are described without actually using the term "inquiry."

Surveys of science learning activities (Goodrun, Hackling, & Rennie, 2000) showed that 44% and 31% of primary school respondents "do experiments the way the teacher tells us" in every and most lessons respectively. Alternatively, in responding to the item "My science teacher lets us do our own experiment," only 10% and 16% noted this occurs in every or most lessons. Similarly, 59% of secondary students reported that teachers never let them choose their own topics and 47% noted that they investigate their own ideas once a term or less. However, 67% of these secondary students reported that group work and discussions are common, occurring at least once a week.

The above data do not allow direct inferences as to how much of these science lessons involve inquiry teaching and learning. It is likely that many laboratory investigations are more of the guided discovery than of the open inquiry type—hence the teacher directedness commented on by students. My observations in many secondary science classrooms and informal discussions with many science teachers in Western Australia would support this contention. The best examples of open inquiries are not part of the formal curriculum but rather offered through scientific competitions (similar to science fairs) organized by science teacher associations in conjunction with Australian and international business enterprises.

Factors and Conditions Facilitating or Impeding Inquiry-Based Science Education

Australian secondary schools are generally well equipped with laboratories (a federal government initiative) and have a school/staffing structure that employs a certain number of laboratory technicians per science department. These technicians are well qualified, sometimes to the baccalaureate level, and usually ensure that science teachers are able to conduct laboratory work, even at a sophisticated level, as needed. Hence there is no reason why a teacher cannot conduct laboratory work. This is not an impediment to inquiry teaching. In most secondary schools, all science lessons are conducted in laboratories, so that laboratory-based science is an integral aspect of science teaching and learning. Exceptions to this situation occur in small country schools that cannot accommodate laboratory technicians or only have a small number of laboratories. Another limitation on laboratory work is the external examination at the end of Year 12; the successful outcome of which is a prerequisite to university studies in most Australian states and territories. In these classes, laboratory work is less likely to be of an open-inquiry nature. By comparison, Australian primary schools do not generally have a specialized science laboratory though some schools have special activity rooms that can be used for science. Primary teachers have initial teacher education in science but unfortunately not all primary teachers have the confidence to teach science in an effective, inquiry-based manner.

INQUIRY IN THE SCIENCE CURRICULUM: THE CASE OF TAIWAN (*HSIAO-LIN TUAN*)

Conceptions of Inquiry in the Taiwanese Science Curriculum

Historically, Taiwan has been influenced by both Eastern and Western cultures. The former, a culture of Taoism, is characterized by the use of holistic and mystical approaches to contemplate the principle of all creatures. The latter culture entails using reductionistic, analytical, and mechanistic approaches to "interrogate" nature. Taiwanese people prefer conforming to nature and searching for harmony between humans and nature, rather than taking control of nature. Thus, for the Taiwanese, philosophy of science *is* Taoism and "inquiry" refers to people's experiences with nature rather than their proactive exploration of nature.

At the beginning of the nineteenth century, Western science was being actively imported into China. The Chinese came to realize the crucial role that science could play in furthering national interests and influence. Gradually, scientific inquiry came to be perceived as using rigorous, systematic, and objective methods to arrive at the "truth." This conception of scientific inquiry has been influential in the Taiwanese science curriculum. During the past 30 years, very few Taiwanese science educators have seriously discussed or questioned the definition and philosophical underpinnings of inquiry in the science curriculum. As such, during this period, inquiry has been equated with traditional laboratory work in which students conducted prescribed experiments to reinforce their knowledge of specific scientific concepts.

It was not until 1999 that the Ministry of Education (ME) developed new curriculum standards in which conceptions of scientific inquiry were expanded to emulate those put forth in the *NSES* (NRC, 1996). The new standards emphasized that all students in grades 1–9 should develop inquiry and research abilities, including applying "scientific methods, such as observing, collecting information, comparing, categorizing, integrating, summarizing, judging, and inferring to construct science concepts . . . [and] independent thinking and problem solving abilities" (ME, 1999, p. 14). It is our hope that the implementation of the new curriculum would bring along profound changes, such as replacing the old Taiwanese curriculum exclusive emphasis on confirmation and structured inquiry activities with an emphasis on guided and open-ended inquiry activities (cf. Tafoya, Sunal, & Knecht, 1980). So far, however, change has been restricted to a shift in the context in which "inquiry" activities are conducted, namely, from rigorous laboratory settings to less structured settings, such as everyday life problems.

Inquiry Components in Extant Curricular Materials and Assessment Practices

During the past few years, the ME permitted private book publishers to author precollege textbooks. In return, the Ministry's curriculum standards were to be adopted as "golden principles" by all Taiwanese publishers when developing curricular materials. The extent to which inquiry was addressed in the resultant textbooks for the different grade levels, however, varied widely. For instance, elementary school science textbooks are activity-oriented and emphasize science concepts and process skills (e.g., classifying, observing, inferring). Junior high school textbooks provide structured inquiry experiences that build on students' interests and curiosity. Typically, each chapter comprises two sections: The first is centered on an experimental science activity that students conduct and discuss, and the second presents science content information related to both the activity and the topic at hand. In senior high school, science textbooks and laboratory manuals are separate, with manuals prescribing traditional experiments intended to reinforce what students learn in regular science sessions. Thus, as one moves from elementary to secondary grades, conceptions of scientific inquiry, at least as presented in science textbooks, seem to gradually shift from more current views (various information gathering and testing methods) to more traditional views (traditional experimental methods).

Most of the elementary and secondary school science assessments are of the paper-and-pencil type and gauge student linguistic and logical thinking abilities rather than performance skills. Even in laboratory situations, students are assessed using reports rather than performance activities. Few teachers actually assess student inquiry skills. Students' performance on inquiry related skills are sporadically assessed during science fairs and related extracurricular activities.

Factors and Conditions Influencing Inquiry-Based Science Education

The implementation of the new Taiwanese curriculum started in September 2001. As noted above, the curriculum standards emphasize scientific inquiry and all children are expected to develop inquiry skills *if* these standards are translated into actual classroom practices. But whether teachers are willing and able to implement an inquiry-based curriculum will greatly influence the outcomes of the new curriculum. In addition to implementing the new curriculum, the ME will change the current examination system by substituting competency-based tests for traditional content-based exit examinations. It is hoped that such a change would help achieve the new curricular goals and relieve students from the burdens of traditional testing. However, school teachers are coming under increasing pressure from students, parents, and school administrators to teach both types of tests. Thus, instead of dropping content emphasized in the old curriculum, most science teachers end up teaching the content outlined in both old and new curricula to make sure that their students pass the competency-based examination and achieve high scores in the content-based tests.

The above-mentioned pressures render instructional time an impediment to inquiry-oriented teaching. Science teachers believe that it is their duty to cover all the science content outlined in textbooks to help students achieve high scores on exit examinations, and complain that this goal is not tenable given the time available to them. They argue that, compared to lecturing, teaching science concepts through inquiry would take too much instructional time. Additionally, teachers' "efficiency" beliefs serve as another impediment to inquiry teaching. Taiwan is an island with a high population density and few natural resources. Therefore, Taiwanese teachers hold strong beliefs regarding the importance of "teaching efficiency," which seems to be gauged in terms of time spent in teaching and student achievement. The "additional" time needed to engage in inquiry is perceived as less efficient when compared with lecturing about science concepts. Thus, examination-related anxieties, accountability pressures, lack of instructional time, and efficiency beliefs directly influence the way teachers approach science teaching in Taiwanese classrooms. By addressing these impediments, we hope that more inquiry teaching would occur and that students would come to develop the desired inquiry skills.

INTERNATIONAL PERSPECTIVES ON INQUIRY IN SCIENCE EDUCATION: A COMMENTARY (*RICHARD A. DUSCHL*)

The six papers that constitute this paper set, while reinforcing the widely held position that inquiry is a major theme in science curricula policy documents among nations, also reveal the variety of meanings associated with the term *inquiry*. Looking across the papers, there does indeed seem to be a tension between the philosophical and practical conceptions of inquiry in the curricula addressed by the contributors. Consider the range of terms and phrases the contributors use to characterize the role of inquiry in science education. These include scientific processes; scientific method; experimental approach; problem solving; conceiving problems, formulating hypotheses, designing experiments, gathering and analyzing data, and drawing conclusions; deriving conceptual understandings; examining the limitations of scientific explanations; methodological strategies; knowledge as "temporary truths;"

practical work; finding and exploring questions; independent thinking; creative inventing abilities; and hands-on activities.

Several dichotomies can be seen in this range of descriptors and in the rhetoric contained in the six contributions. These include (a) learning science versus learning about science; (b) science as a search for truth versus science as a problem-solving activity; (c) raising and answering questions versus posing and revising explanations and/or models; (d) science as a cognitive activity versus science as a social activity; (e) demonstrating what we know (concepts) versus investigating how we know and why we believe it; (f) hypothetico-deductive science (causal experimental science) versus model-based science; and (g) science as a process of justifying and testing knowledge claims versus science as a process of discovering and generating knowledge claims. These dichotomies embody some of the classic philosophical problems attached to contemporary conceptualizations of NOS, and tensions that have defined our field of scholarship during the second half of the twentieth century. This set of descriptors also focuses our attention on the need to distinguish within our curricula what it is we wish to be the goals of science education (e.g., content, process, NOS) and how an inquiry approach to science education can (or cannot) help achieve these goals. Mansoor Niaz introduces his paper with a quote from James Rutherford (1964), which sets the early agenda that science education is more than fact memorization. But this quote also outlines the multiple agenda problem as Rutherford states, “We stand foursquare for the teaching of scientific method, critical thinking, the scientific attitude, the problem-solving approach, the discovery method, and of special interest here, the inquiry method” (p. 80). One consequence of this diversity, as Saouma BouJaoude correctly points out, is the omission of a clearly formulated philosophy about the nature of scientific inquiry to be emphasized in classrooms. Another related consequence raised by Norman Lederman is the implication that such an omission has on teachers’ professional development. His position, which I am inclined to agree with, is that professional development activities need to address teachers’ knowledge of both scientific inquiry and NOS. The central question though is how. Attention needs to be given to this critically important domain. NOS, I believe, cannot be taught directly, rather it is learned, like language, by being part of a culture.

The shift that occurred this century from science education curricula that focused on “science for future scientists” to curricula that strive to embrace a “science for all” approach has confused the enterprise if for no other reason than that we are faced with too many options and goals for teaching science. We now see, for example from English speaking nations, some well-conceived and thought-out policy statements (e.g., AAAS, 1990; Goodrun, Hackling, & Rennie, 2000; Millar & Osborne, 1998) that attempt to organize precollege science curricula such that both goals (preparing future scientists and educating pupils to be scientifically literate) can be achieved. We have to ask some hard questions though. In particular, can inquiry approaches to science education serve either of these dual functions? Can these approaches adequately address the multiple agenda or the terms, phrases, and dichotomies presented above? Can inquiry approaches promote the learning of concepts, processes, attitudes, and thinking, and NOS as well? Can teacher professional development activities develop teachers’ knowledge of inquiry and NOS?

Advocating the teaching of science through inquiry, of course, is not a new idea. John Dewey placed inquiry at the center of his educational philosophy: For him, learning was best approached by engaging student communities in the doing. Approximately 50 years later Joseph Schwab advocated an approach to the teaching of science that was grounded in the idea of science education being an “inquiry into inquiry.” Schwab’s epistemological approach was also a reaction to the then, and some would claim still, dominant behavioral psychological grip on educational theory and practice. As we consider the place of inquiry in science education today, we would do well to heed the seminal messages from Dewey and Schwab. Respectively, concept development and learning are socially situated, and inquiry as a way of knowing and learning science derives fundamentally from the dialectical exchange between the observational acts of obtaining data and the guiding conceptions that frame the selection and analyses of the data.

I would claim that there have been two traditional and dominant approaches to science education that have essentially remained unchanged at the level of the classroom in spite of advances in our understanding of learning and learning environments. The first is the content-process (CP) approach. The second is the discovery-inquiry (DI) approach. Each of these two approaches transcends decades of scholarship and development in cognate fields relevant to the framing and understanding of learning in general and learning science in particular. Specifically, intellectual advances in cognitive and social psychology have given rise to new views about the design of learning environments. Where once it was conceivable to separate the development of curriculum from the design of instructional and assessment strategies, new research-based views of effective learning environments couple curriculum, instruction, and assessment into an interlocking framework (cf. Bransford, Brown, & Cocking, 1999; Pellegrino, Baxter, & Glaser, 1999). Similarly, new and important perspectives about the growth and development of scientific knowledge are emerging from the science studies disciplines (cf. Duschl & Hamilton, 1998). Of particular importance for the present discussion is the confluence of cognitive and social psychology with philosophy, and epistemology specifically, to explain, on rational and objective terms, the situated character of scientific investigations and research.

What these new psychological/philosophical models of NOS suggest is a third alternative to the CP and DI approaches, namely what I would like to refer to as an evidence-explanation (EE) approach. The hallmark of the newer problem-posing (Kortland, 1996), project-based (Duschl & Gitomer, 1997; Krajcik, Czerniak, & Berger, 1998), and technology-supported (di Sessa, 2000; Linn & Hsi, 2000; White & Frederickson, 1998) science programs is a commitment to have students track through inquiries and investigations beginning with authentic relevant questions and problems involving "fuzzy" data sets and building to the development, revision, and redevelopment of scientific models and explanations. Reflection, analysis, and evaluation are crucially important in these approaches, a position recognized in David Treagust's overview.

In these new EE curriculum approaches, lessons are linked together to produce coherent instructional sequences. Learning tasks are differentiated, students are assigned to work individually and in groups, and formative assessment strategies are frequently integrated into lessons to address the multidimensional dynamics of science learning. Engagement in inquiry would seem to require the development of at least three, if not more, interconnected knowledge bases. According to Krajcik, Czerniak, and Berger (1998), the three types of knowledge to be developed in project-based science are (a) content: knowing the central concepts and principles in a domain; (b) inquiry and problem solving: knowing how to problem-solve, design, and carry out investigations and employ metacognitive strategies; and (c) epistemic: knowing the "rules of the game," what counts as evidence, and when to collect more evidence to support/refute a position.

In our work (Duschl, Ellenbogen, & Erduran, 1999) we see the need to coordinate inquiry learning around three goals: conceptual, social, and epistemic. Conceptual and epistemic goals are consistent with Krajcik et al.'s first and third types of knowledge (Krajcik, Czerniak, & Berger, 1998). The other is a commitment to develop the social goal of communication and representation of scientific ideas and knowledge claims. Thus, in addition to guidelines set by psychology and philosophy, we also see emerging sets of pedagogical principles for effective science learning and teaching. The implication for science education researchers, policymakers, and instructional designers is the need to look across the three Ps (psychology, philosophy, and pedagogy) for the design of inquiry science approaches that support both student learning and reasoning and teachers' assessments of student learning and reasoning.

The present set of papers did not include representation from the European continent. Thus, an important perspective to an important discussion is missing. Emerging among the European community of science education researchers is a new to some but nonetheless alternative perspective called "didactics." Spanish (Jimenez Aleixandre, Pereiro Munoz, & Aznar Cuadrado, 2000), Dutch (Lijnse, 1995), and French (Tiberghien, 2000) scholars are engaged in defining and refining didactical approaches to science education. There is much I find common with American ideas on curriculum theory but the distinctiveness of the approach is, like curriculum theory, a multiprincipled approach to the design of curriculum and instruction. Future discussions of the nature and role of inquiry in science education need to embrace these important voices and community of scholars.

The incorporation of inquiry into science classrooms and teacher professional development programs is, I would argue, fundamentally a curriculum or didactics problem. We need new approaches to the design of instructional materials that bring together rather than separate out curriculum, instruction, and assessment. We need new models of curriculum, instruction, and assessment as well that attend in a coherent manner to the problems of teaching about NOS. We need, as di Sessa (2000) has suggested, to begin developing a theory of activity that will serve to guide us in the development of design principles that can shape science teaching and learning. In turn, we may then begin to work toward the charge Fouad Abd-El-Khalick set out for our contributors, which is to initiate and encourage sustained discourse among the international science education community regarding the highly valued and yet unattained goal of enacting inquiry in precollege science curricula both as a means (i.e., inquiry as an instructional approach) and as ends (i.e., inquiry as a learning outcome).

CLOSING REMARKS (*FOUAD ABD-EL-KHALICK*)

It is fairly accurate to say, I believe, that concepts or images that are too exclusive or restrictive have little value for educational settings, which are highly situated and contextual. Indeed, restrictive images of the enactment of inquiry in precollege science education would not even start to deal with the associated complexities raised by contributors to this paper set. These complexities range from the more philosophical, such as the interaction of Western philosophies of science with the Eastern philosophy of Taoism and its implications for perceptions of inquiry in Taiwan, to the practical, such as the availability of technical laboratory personnel in secondary schools in Western Australia. Between these two extremes lie a host of other issues including conceptions of "teaching efficiency" among Taiwanese teachers dictated by sociodemographic perceptions or realties, debates over the nature of knowledge and learning in Venezuela, and teacher struggles with the instructional implications of including inquiry as a teaching approach for the first time in the new Lebanese science curriculum.

However, it is also accurate to say that concepts that are too inclusive have an equally minimal value for educational settings. That is, if any and all images of instructional activities in precollege science classrooms would fit under a losely articulated rubric of "inquiry in science education," then the construct would lose its power as an overarching theme for imagining, developing, coupling, and enacting curricular goals, pedagogical tools, and assessment practices that would allow the actualization of current reforms vision in science education. We have seen in the above pages images of inquiry that range from fairly straightforward (unproblematic or unproblematized) and somewhat structured laboratory-activities-with-a-twist, all the way to ill-structured approaches for generating evidence-based answers to ill-defined questions. This range of images brings to light two issues. The first is the crucial question posed by Richard Duschl regarding the multiple agenda for science education and the fact that inquiry teaching and learning seem to be charged with achieving a goodly number of the items on this extensive agenda all at the same time. The second issue relates to the purposeful and applied nature of our field of scholarship. Education is a largely intentional enterprise and osmotic notions of engaging students in authentic scientific inquiry (whatever that might mean) with the hope that they will achieve a multiplicity of learning outcomes seem unlikely. For instance, it is tempting to imagine that one and the same “inquiry” instructional episode could be used to help sixth graders develop understandings of some science concept, and at the same time help them acquire integrated inquiry skills and learn something about NOS. However, I believe that many veteran and reform-minded science teachers would argue that that would be a rather difficult undertaking.

Thus, instead of thinking of a generalized image of inquiry in science education and assuming it will allow achieving multiple goals, it might be more useful to think of several images that are intimately linked with small clusters of valuable instructional outcomes. What is needed is a sort of a multidimensional heuristic that defines a space of outcomes, which would facilitate discourse and streamline communication about images of inquiry between players within any educational setting (e.g., policymakers, curriculum theorists and developers, administrators, teachers, teacher educators, and students), such that the likelihood of impacting actual classroom practices related to inquiry is substantially increased. Even though I do not claim that articulating such a heuristic is an easy undertaking, it is not very difficult to imagine one possible configuration for it. One dimension could include the types of knowledge and understandings that Duschl refers to, that is, conceptual, problem solving, social, and epistemic. Another dimension could include a range of inquiry-related activities, such as, problem-posing; designing investigations; collecting or accessing data; generating, testing, and refining models and explanations; communicating and negotiating assertions; reflecting; and extending questions and solutions. A third dimension could include a range of (the necessarily reductionistic but nonetheless crucial) skills, such as mathematical, linguistic, manipulative, and cognitive and metacognitive skills, needed to meaningfully engage in inquiry at one level or another. A fourth dimension could comprise a range of spheres, including personal, social, cultural, and ethical, with which any of the aforementioned outcomes could interface. When navigating through this four-dimensional space, one could think of the elements on each dimension either as possible outcomes of, or as prerequisites for meaningful engagement in, inquiry-based science education. The former would help conceive and place more emphasis on inquiry as means (inquiry as teaching approach), while the latter thinking would help gauge the level at which students could engage in inquiry and help emphasize inquiry as ends (inquiry as an instructional outcome).

Working with such a heuristic might have a decisive advantage in helping us wade through advocated images of scientific inquiry in classrooms, and ask questions that would help advance our understanding of the enactment of inquiry in precollege science education. Once a set of outcomes is located within this four-dimensional space, specific questions from psychology, philosophy, and pedagogy (Duschl’s three Ps) could be asked to gauge either the nature and “authenticity” (if you will) of an inquiry episode or its potential for achieving the target set of outcomes. These questions could be related to the specific age group and educational context at hand. It should be noted that the above is just a crude attempt to imagine a heuristic that would facilitate thinking about, and inquiries into, inquiry in science education.

However, one might question the validity of the above-mentioned heuristic and meaningfulness of the associated "images" of inquiry given that most discourse regarding inquiry in science education seems to center around engaging students in "authentic" scientific inquiry. Indeed, a good number of science educators who engage such discourse assume that we know what "authentic" scientific inquiry actually is. Nonetheless, scholarship in philosophy, history, and sociology of science, as well as science studies, seem to collectively indicate that while there might be a fairly general set of aspects characterizing scientific inquiries, there is a host of "ways" in which such inquiries are conducted. Moreover, the differences between these ways are not trivial. Indeed, as a result of such scholarship, the scientific endeavor is looking more like a mosaic of disciplines with a host of ontological, epistemological, and methodological commitments, than a unified and homogeneous entity. As such, we need not be leery of advancing various images of inquiry in precollege science classrooms as long as these images help achieve specific educational outcomes, and are consistent with philosophical, historical, and sociological scholarship into science, and also with psychological and pedagogical scholarship into teaching and learning.

The same point regarding the discourse of engaging students in authentic inquiry brings me to my final comment on "inquiry in science education," namely the assumption that precollege students are actually capable of engaging in "authentic" scientific inquiry (whatever that might be). This is a fairly significant assumption. We need to stop and ask ourselves whether students actually have the motivation, knowledge, and skills needed to engage in such inquiry. We sometimes seem to forget that the sort of educational practices we are working to force out from precollege science classrooms are still a significant part of the educational practices in the academy. Indeed, practices related to committing large bodies of specialized information to memory, conducting prescribed laboratory exercises, and repetitive algorithmic problem solving were not invented in the precollege school culture. Rather, at least in the United States, these practices were handed down from major universities to high school science programs in the 1920s and 1930s because these universities claimed that high schools were not adequately preparing students to pursue university studies. Irrespective of our philosophical or pedagogical takes on these practices, they are still a large part of disciplinary "scientific education" (Kuhn, 1970). As a result of these practices, college students who end up, for a variety of motivations, pursuing scientific careers and thus engage in authentic scientific inquiry, have usually amassed an extensive and specialized knowledge base, and mastered a set of articulated manipulative, cognitive, and metacognitive skills. Is it then safe to assume that such knowledge and skills are not relevant to doing authentic science? Probably not. And thus, is it reasonable to assume that precollege students have the knowledge, skills, and motivation, to engage in the *same* kind of activities? Should the sort of science-based inquiry activities undertaken in precollege settings be of a different genre commensurate with students' ages and backgrounds, and specific curricular priorities? Can the one and same precollege science education curriculum achieve goals associated with pursuing scientific education and achieving scientific literacy for informed citizenry? Answers to these questions are not very difficult if tackled at a general level. However, they might prove to be much more difficult if specific implications for precollege science curriculum and instruction and for our thinking about inquiry are *seriously* pursued.

It should be noted that these closing remarks represent one other perspective and pose another set of questions to be added to ones raised by contributors to this paper set. What this paper set and commentary surely show is that much more discourse regarding inquiry in science education is in order. Also, there still are other significant perspectives that need to be brought into the mix before we can start framing such discourse or claiming it to be representative of views from the international science education community. We do hope, though, that this paper set would help initiate discourse among as many varied countries and perspectives as possible.

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