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Reforming Science Teaching: What Research says about Inquiry*

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Inquiry has a decades-long and persistent history as the central word used to characterize good science teaching and learning. Even at a time when a new word, constructivism, had entered the general educational lexicon as the descriptor of good education, the authors of the *National Science Education Standards (NSES)* chose to stay with inquiry and totally ignore the new word. But in spite of its seemingly ubiquitous use, many questions surround inquiry. What does it mean to teach science as, through, or with inquiry? Is the emphasis on science as inquiry, learning as inquiry, teaching as inquiry or all of the above? Is it an approach to science education that can be realized in the classroom or is it an idealized approach that is more theoretical than practical? Is it something that the "average" teacher can do, or is it only possible in the hands and minds of the exceptional teacher? What are the goals of its use? Does it result in greater or better learning? How does one prepare a teacher to utilize this type of science education? What barriers must be overcome to initiate such science education in the schools? What dilemmas do teachers face as they move to this form of science education? The list of questions goes on. They are of particular importance to people committed to the *NSES* and wanting to see these standards put into greater practice. Reformers from all categories—teachers, teacher educators, administrators, policy makers and members of the general public want to know what answers research has for such questions. Given the central role of teacher education in the process of educational reform, however, these questions are of particular interest to science teacher educators.

Researchers' pursuit of answers has resulted in an extensive literature. Defining the arena broadly, the number of studies is in the hundreds and probably more. This body of research literature is worth exploring, but it will be necessary to limit and focus.

Since the *NSES* is at the center of current discussions of U.S. science education improvement, it is well to begin with that document and consider its use of inquiry. This beginning point, of course, does not imply that the NSES document is without problems or that is fully grounded in the latest research. It is well to remember that it is a political document, based on an attempt to find consensus among the various educational, scientific and public constituencies in the realm of science education. As a result of its wide usage, the language of the document is useful for our communication. Consideration subsequently can be given to how far research goes in answering the questions at hand.

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The Use of Inquiry in the NSES

A careful reading shows that among several usages of inquiry in the *NSES*, are three main ones. Each one is fairly distinct from the other two, even though each has various nuances.

Scientific Inquiry

"Scientific inquiry refers to the diverse ways in which scientists study the natural world and propose explanations based on the evidence derived from their work" (p. 23). Throughout the *NSES*, this form of inquiry is treated as being grounded in certain abilities and understandings. This definition of inquiry reflects an understanding of how science proceeds and is independent of educational processes.

Inquiry Learning.

When used in this manner in the *NSES*, inquiry refers to a learning process in which students are engaged. It is said to be an **active** learning process—"something that students do, not something that is done to them"(p. 2). The writers of the *NSES* clearly see some relationship between this form of inquiry and scientific inquiry, i.e., it is implied that inquiry learning should reflect the nature of scientific inquiry. The descriptions of inquiry learning include a lot of language implying that it occurs in a formal educational context. It is said, for example, that it "encompasses a range of activities" (p. 33), and has multiple stages including "oral and written discourse"(p. 36). In addition to building a rationale for inquiry learning that is tied to scientific inquiry as in the NSES, it is important to attend to understandings of it that grow out of studies of human learning. Some would argue, for example, that all learning is inquiry learning, i.e., it is an active mental process that demands the active participation of the learner. The argument is essentially the same as the argument of those who say that all learning is "constructivist"—another well-used term in many circles. For the purposes of our discussion, it may be well to simply acknowledge that inquiry is at the heart of learning before moving on to discuss a definition of inquiry as it pertains to teaching.

Inquiry Teaching

Within the *NSES*, inquiry is used in a variety of ways with respect to teaching. Since "inquiry is central to science learning" (p. 2), as noted above, it is expected to be prominent in science teaching. Its importance, however, "does not imply that all teachers should pursue a single approach to teaching science"(p. 2). On the other hand, the *NSES* states that, "Inquiry into authentic questions generated from student experiences is the central strategy for teaching science"(p. 31). In addition to this broad, rather process-oriented, definition of inquiry teaching, the *NSES* talks about inquiry as a learning activity (p. 13). It "refers to the activities of students in which they develop knowledge and understandings of scientific ideas, as well as an understanding of how scientists study the natural world"(p. 23). The *NSES* acknowledges that all inquiry is not fully deserving of the name by distinguishing between a "full inquiry" and a "partial inquiry"(p. 143). Inquiries also are used as a means of assessment in such a manner that, "Any boundary between assessment and teaching is lost. . ." (p. 202).

In the teaching context, inquiry seems to be used in a variety of ways without careful distinction as to the differences. It is seen both as a characteristic of a desired form of teaching and as a certain kind of activity. In either case, there is no precise operational definition and, even though the *NSES* has some specific teaching examples, the reader is left to create his or her own images of what constitutes this form of teaching.

Reviewing the Literature

In terms of what the research literature says about educational reform, it appears that this third usage of the word inquiry, i.e., inquiry teaching, is the one of central concern. It is the one that means so many different things to different people, the one that is difficult for many people to visualize in actual practice and the one that is so difficult for many teachers to put into successful practice. But even if one chooses inquiry teaching as the focal point for educational reform efforts, scientific inquiry may be at the center of the content being taught and the learning sought, by its very nature, may be inquiry in character.

What is Inquiry Teaching?

Since the *NSES* contains no precise operational definition of inquiry teaching—though it does contain some specific teaching examples—many and varied images of inquiry teaching can be expected among its readers. The research literature on inquiry, tends to lack precise definitions, as illustrated in a large-scale meta-analysis of the science education literature done nearly 20 years ago (Anderson, 1983). The inquiry label was used with respect to various NSF-supported curriculum projects in the component of the meta-analysis that addressed 105 empirical studies of "inquiry-oriented" curriculum projects (Shymansky, Kyle & Alport, 1983). Another portion of the meta-analysis project addressed studies on specific teaching techniques (Wise & Okey, 1983) including ones identified as "inquiry-discovery," a category of techniques said to be "more student-centered and less step-by-step teacher directed learning." Yet another one of the meta-analyses (Lott, 1983) focused on studies of inquiry teaching in which there was a comparison of so-called inductive and deductive teaching approaches. The label was used again in the meta-analysis of science teacher education studies (Druva & Anderson, 1983).

In one sense the same situation persists today, in that inquiry teaching is defined differently by different researchers, or the researcher may choose to use a different term for an approach that others apparently would identify with the inquiry label. On the other hand, many of these same researchers go to considerable lengths to describe and define specifically what it is they are studying. In their studies of "project-based" science instruction (Blumenfeld, Krajcik, Marx, & Soloway, 1994; Krajcik, Blumenfeld, Marx, & Soloway, 1994; Ladewski, Krajcik, & Harvey, 1994; Marx, Blumenfeld, Krajcik, Blunk, Crawford, Kelly, & Meyer,1994), for example, the researchers are quite explicit about the nature of the instruction they are studying. Similarly, in Project SEPIA (Duschl & Gitomer, 1997) the researchers are quite explicit about both teaching approaches and the culture of the classroom.

The dilemma this situation poses for the person attempting to synthesize what the research has to say about inquiry teaching is that making generalizations about it becomes difficult because of varied conceptions of inquiry teaching. This broad category includes such a wide variety of approaches that the label is relatively non-specific and vague. Explicit descriptions of teaching practice help, but when various researchers are studying somewhat dissimilar teaching approaches, the generalization process still poses difficulties.

An example of a descriptive framework used to categorize two different orientations (i.e., ones similar to the inquiry and non-inquiry orientations) is one developed to describe classrooms in a variety of U.S. settings where many of the teachers were identified as teaching in accordance with the approaches of the new national standards in science and mathematics (Anderson, 1996). The labels of traditional and reform pedagogy were expressed in operational terms in the rubric provided in table 1.

Some form of operational definition such as the above probably is necessary, though not sufficient, for persons wishing to communicate with teachers about the meaning of inquiry teaching.

Does Inquiry Teaching Produce Positive Results?

Educators often wonder what research tells us about the outcomes of inquiry teaching; this curiosity often is accompanied by the expectation that if such research has been done, the results will be rather clear cut. While much research has been done, the results are not as definitive as some would hope.

In general, research shows that inquiry teaching produces positive results. It can work. In drawing such conclusions from the empirical research, however, one must be specific about what the criterion measures are and what the basis is for judging success. While research says inquiry teaching can produce positive results, it does not, by itself, tell teachers exactly how to do it.

The previously cited meta-analyses of inquiry teaching in science show positive but relatively modest gains from using inquiry teaching. In the studies of inquiry-oriented curriculum programs (Shymansky, Kyle & Alport, 1983) substantial effect sizes in favor of the inquiry-oriented materials were found on various quantitative measures, including cognitive achievement, process skills and attitude to science, although some question must be raised as to whether inquiry was the distinguishing characteristic of these curricula since there was essentially no correlation between positive results and expert ratings of the degree of inquiry in the materials. Wise and Okey (1983) found an average effect size of 0.4 standard deviations in favor of inquiry-discovery teaching for cognitive outcomes. While Lott (1983) found only small differences between inductive and deductive approaches, the differences were in favor of the inductive approach. Other meta-analyses conducted independently at approximately the same period of time such as those by Weinstein, Boulanger and Walberg (1982) and Bredderman (1982) produced results similar to those cited above.

Table 1.
Traditional—Reform Pedagogy Continuum

Predominance of Old Orientation	Predominance of New Orientation
Teacher Role:	
As dispenser of knowledge	As coach and facilitator
Transmits information	Helps students process info.
Communicates with individuals	Communicates with groups
Directs student actions	Coaches student actions
Explains conceptual relationships	Facilitates student thinking
Teachers knowledge is static	Models the learning process
Directed use of textbook, etc.	Flexible use of materials
Student Role:	
As passive receiver	As self-directed learner
Records teacher's information	Processes information
Memorizes information	Interprets, explains, hypoth.
Follows teacher directions	Designs own activities
Defers to teacher as authority	Shares authority for answers
Student Work:	
Teacher-prescribed activities	Student-directed learning
Completes worksheets	Directs own learning
All students complete same tasks	Tasks vary among students
Teacher directs tasks	Design and direct own tasks
Absence of items on right	Emphasizes reasoning, reading and writing for meaning, solving problems, building from existing cognitive structures, and explaining complex problems

More recent reviewers, such as Haury (1993), draw similar conclusions from the research on inquiry-related teaching with respect to such outcomes as scientific literacy, science processes, vocabulary knowledge, conceptual understanding, critical thinking and attitudes toward science. A more nuanced review from Flick (1995), however, attends to the research on explicit instruction as well as to the research on inquiry-oriented instruction. He notes the major gains in student achievement on selected kinds of instructional objectives from explicit teaching, but goes on to point out that "[T]he high levels of teacher supervision implied by explicit teaching models may not foster the kinds of thinking required for instruction with complex and more ill-structured tasks" (p. 17).

In the final analysis, any exploration of what the research says about the effectiveness of inquiry teaching leads to a discussion of one's objectives for science education. If one accepts the full sweep of objectives in the *NSES*, including conceptual understanding of science principles, comprehension of the nature of scientific inquiry, and a grasp of applications of science knowledge to societal and personal issues, there is a pattern to what the research tells us that includes many indicators of the effectiveness of Inquiry teaching.

This point, however, is not the end of the discussion because all teachers, parents, and policy-makers are not convinced that these objectives are as important as more specific knowledge of vocabulary and facts. This point gets further attention below in the section dealing with the dilemmas teacher face in adopting an inquiry approach to science teaching.

Finally, it should be noted that research in this area continues. With respect to the question of effectiveness of inquiry teaching, studies have appeared that are directed to special student populations, such as a study by Scruggs & Mastropieri (1993), which found significantly higher learning for an inquiry-oriented approach with students with learning disabilities. Studies continue in other countries as well. For example, a study in university level biochemistry in Turkey (Huveyda, NEED., 1994) found higher achievement for students using an inquiry approach than those in a traditional approach, while another university level study in Ireland (Heywood & Heywood, 1992) found similar results on pupil tests for students in discovery and expository approaches, but greater student motivation with discovery approaches. A pattern of general, but not unequivocal, support for inquiry teaching continues to come from the research.

As research in this area has matured, it has tended to move away from the question of whether or not inquiry teaching is effective, and has become focused more on understanding the dynamics of such teaching and how it can be brought about. The studies on "project-based" science instruction (Blumenfeld, et al., 1994; Krajcik, et al., 1994, Ladewski, et al., 1994, Marx, et al., 1994), for example, and the work on Project SEPIA (Duschl & Gitomer, 1997) have this greater level of sophistication. Similarly, the case studies of schools successful in initiating reforms consistent with the national science and mathematics standards (Anderson, 1996) and case studies such those of Roth and Bowen (1995) give us understanding of what is involved in inquiry teaching. Such research directs us to additional questions worthy of consideration.

Is Widespread Inquiry Teaching Possible?

Aside from the question of its effectiveness, there is the question of whether or not it is possible to place an inquiry approach to teaching into practice in schools on a widespread basis. In general, research indicates that inquiry teaching is possible for many teachers to initiate, although the research is not clear on just how difficult it is do to so, what percentage of teachers are able to be successful at it, or how many are likely to choose to teach in this manner.

One of the earlier reports of school practice that speaks to these issues was the case study research Stake and Easley (1978) reported two decades ago. The case studies examined classroom practice in schools across the country. Teachers often were using the curriculum materials developed with NSF support that had been intended to foster inquiry teaching. Generally speaking, however, the materials were not being used in a manner consistent with this philosophy. Inquiry was not widespread. Of the many classrooms visited in eleven school districts across the country, only three classes were identified where this type of approach was in use. Two major reasons were cited in the case studies for this dearth of inquiry teaching, whether defined by the NSF-sponsored curriculum programs or by other means. First, there was a widespread philosophic persuasion in favor of a textbook approach. The textbook was viewed as an authority, and furthermore, teachers were persuaded that learning from a textbook was a discipline students needed to master. A second reason was the frustration and difficult problems encountered in implementing inquiry teaching as intended.

While research has not been reported which would indicate that typical school practice has changed significantly in this respect, there is research indicating that under the right circumstances inquiry teaching is possible. Researchers have through an extensive search process located schools where "reformed" teaching was typical of a school's science or mathematics department (Anderson, 1996). In other instances, investigators have set about establishing the conditions under which a form of inquiry teaching would emerge. The previously mentioned "project-based" science instruction (Blumenfeld, et al., 1994; Krajcik, et al., 1994, Ladewski, et al., 1994, Marx, et al., 1994), and Project SEPIA (Duschl & Gitomer, 1997) are examples. The more interesting result of this research of the 1990's, however, probably is not simply that it is possible to foster inquiry teaching, but that doing so is difficult. It is important to understand the difficulties encountered in doing so.

What Barriers and Dilemmas are Connected with Inquiry Teaching?

It is common to talk about barriers or obstacles that must be overcome for teachers to acquire an inquiry approach to teaching. In fact, they have been discussed in the literature for a long time; an important example is Welch, Klopfer, Aikenhead, & Robinson (1981). An additional helpful word, however, is dilemmas. The former words imply something external to the teacher, but much of the difficulty is internal to the teacher, including beliefs and values related to students, teaching, and the purposes of education. Teachers considering new approaches to education face many dilemmas, many of which have their origins in their beliefs and values. It is not unusual to think of learning to teach through inquiry as a matter of learning new teaching skills. It is that, but it is also much more. Teachers encounter both barriers and dilemmas.

Research gives us a picture of many of these barriers and dilemmas. In a cross-site analysis of a set of case studies of schools that had successfully initiated new approaches to science and mathematics instruction, such barriers and dilemmas were clustered in three dimensions, the technical dimension, the political dimension and the cultural dimension (Anderson, 1996). The technical dimension included limited ability to teach constructively, prior commitments (e.g. to a textbook), the challenges of assessment, difficulties of group work, the challenges of new teacher roles, the challenges of new student roles, and inadequate inservice education. The political dimension included limited inservice education (i.e., not sustained for a sufficient number of years), parental resistance, unresolved conflicts among teachers, lack of resources, and differing judgments about justice and fairness. The cultural dimension—possibly the most important because beliefs and values are so central to it—included the textbook issue again, views of assessment and the "preparation ethic," i.e., an overriding commitment to "coverage" because of a perceived need to prepare students for the next level of schooling.

What this research tells us is that the task of preparing teachers for inquiry teaching is much bigger than the technical matters. Even though teachers need to learn how to teach constructively, acquire new assessment competencies, learn new teaching roles, learn how to put students in new roles and foster new forms of student work, the task of preparing teachers for inquiry teaching includes much more. The political and cultural dimensions are important as well. The task must be addressed in the political and cultural context of the schools in which teachers work. The matter must be addressed systemically (and not just in the political sense of that term) and in depth in all of these dimensions, i.e., at a level that includes central attention to beliefs and values.

Other recent science education research, such as the previously mentioned studies of "project-based" science instruction, has addressed the matter of dilemmas as well. Ladewski, et al. (1994) provide a case study which gives a full description of the dilemmas experienced by one teacher. Blumenfeld, et al. (1994) note that teachers may be deeply involved in a new approach to teaching for a long time before they begin to recognize and discuss dilemmas which pose difficulties and are rooted in their beliefs and values. Even though difficult, teachers were able to resolve such dilemmas over time with suitable interventions, such as collaboration with peers and reflection on personal practices (Marx, et al., 1994).

The connection between teachers' beliefs and values on the one hand and their classroom practices is apparent in other research. For example, Maor and Taylor (1995) found that a teachers' epistemology was an important mediating influence on how students used a computer as a tool for science inquiry. Hodson (1993) explored the relationship between both teachers' and students' views of the nature of science and curriculum experiences and concluded that a simple linear model of the interrelationships was inadequate; it required a more complex model.

While inquiry teaching was identified earlier as the most profitable focal point of this review, it probably is now clear to the reader that inquiry teaching cannot be addressed totally independently of scientific inquiry and inquiry learning. They are interrelated. Teachers' understanding of science as inquiry and learning as inquiry are fundamental to the task at hand.

How can Teachers be Helped in Using Inquiry Teaching?

Although teachers' beliefs, values and understandings regarding the nature of science, the teacher's role in the classroom, students' role in learning, and the nature of student work have all been established as important in the process of teachers acquiring a new approach to teaching, addressing them directly may not constitute the optimum approach.

Research indicates that teachers focus on what works in terms of student involvement or classroom management, rather than on melding theory and practice (Blumenfeld, et al., 1994.) Teachers' understanding takes "the form of practical, not theoretical or propositional, knowledge" (Marx, et al., 1994, p. 517). Teachers anchor their understanding in classroom events and base it on stories and narratives more than on theories and propositional knowledge (Krajcik, et al., 1994). Teachers' view of teaching is "dominated by tasks and activities rather than conceptual structures and scientific reasoning" (Duschl & Gitomer, 1997, p. 65).

In other words, theory, beliefs, values and understandings are of critical importance in the process of teachers acquiring an inquiry approach to teaching, **but** one should not expect to address them in isolation from a practical context or expect that they will be addressed directly as mental constructs. It is a good example of the old shibboleth that the shortest distance between two points is not a straight line.

If a straight line is not the appropriate path, which of the many circuitous routes is the one of choice? Research identifies some key activities that one would expect to find along this path. The "real world" classroom context has already been identified. Inservice education, for example, must not only address practical matters, it should attend to practical activities that teachers are actually using in their own classes.

Another key facet is identified by the word, collaboration(Blumenfeld, et al., 1994; Krajcik, et al., 1994, Anderson, 1996). New understandings develop and new classroom practices emerge in the context of teachers' collaboration with peers and experts. Collaboration is integral not only to the technical dimension of reform endeavors, but to the cultural dimension.

> *Collaborative working relationships among teachers provide a very important context for the re-assessment of educational values and beliefs. In this context—where the focus is the actual work of each teachers' own students—one's values and beliefs are encountered at every turn. It is a powerful influence. The reforming teachers in our cases did not do their work in isolation; they worked together with fellow teachers in their team or department. Crucial reform work takes place in this context. (Anderson, 1996, p. 68)*

Collaboration is a powerful stimulus for the reflection which is fundamental to changing beliefs, values and understandings.

The process of helping teachers develop an inquiry approach to teaching generally is much more involved than portrayed here thus far. An effective systemic effort almost certainly will have many facets to it and will attend to matters spread across the three dimensions—technical, political and cultural—mentioned earlier (Anderson, 1996).

Summary

A succinct summary of the key elements of what research says about reforming science teaching to yield the desired inquiry orientation must include attention to both means and ends. Teachers seeking an inquiry orientation should focus on the nature of student work, the students' role and their own role. Teachers and others in positions of leadership should focus on creating a climate of collaboration among teachers and providing a context within which teachers can reflect on their values and beliefs. The facets of the needed systemic process are many and must stay in place over a long period of time.

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